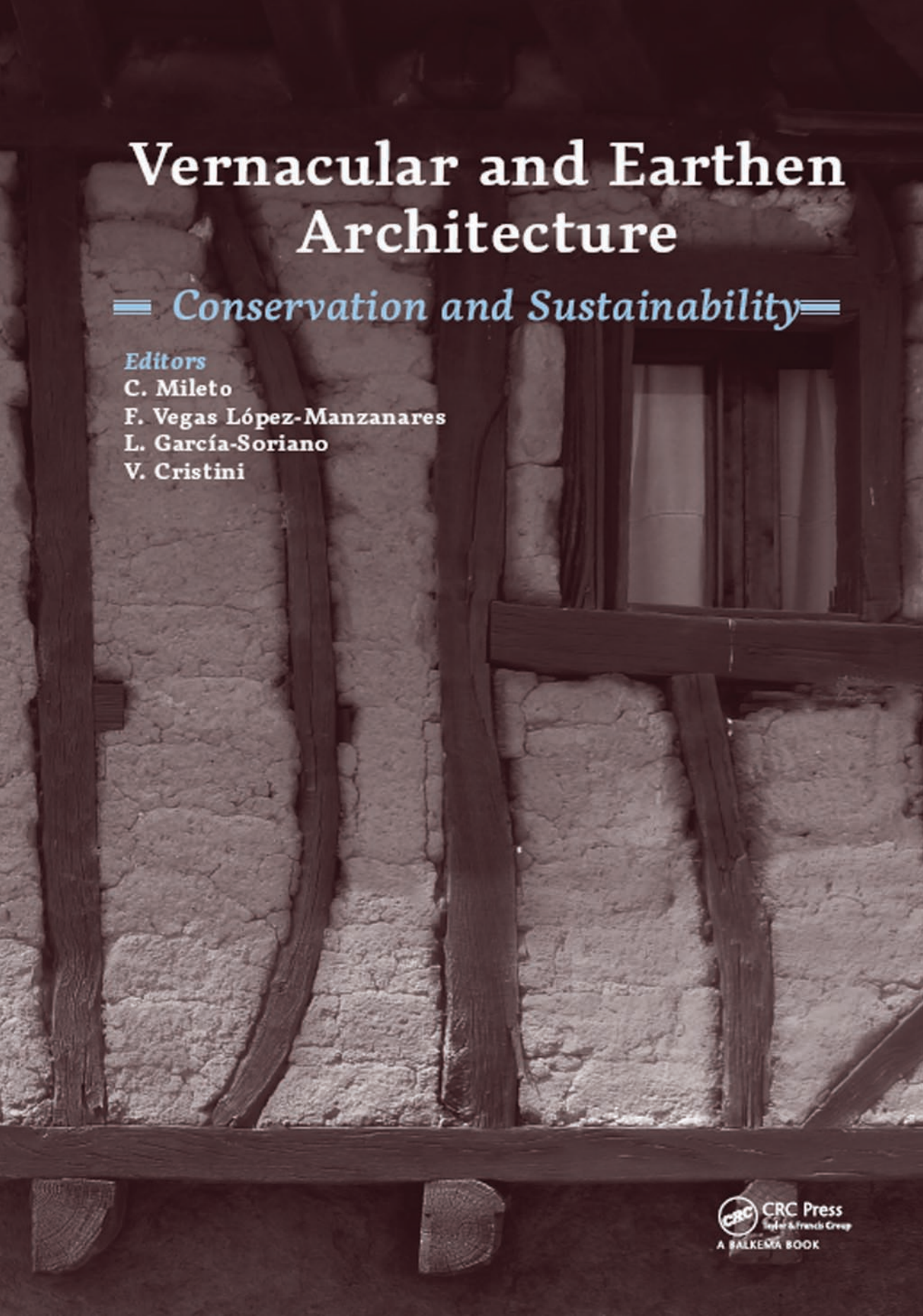


Vernacular and Earthen Architecture

Conservation and Sustainability

Editors
C. Mileto
F. Vegas López-Manzanares
L. García-Soriano
V. Cristini

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VERNACULAR AND EARTHEN ARCHITECTURE: CONSERVATION AND SUSTAINABILITY



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Vernacular and Earthen Architecture: Conservation and Sustainability

Editors

C. Mileto, F. Vegas López-Manzanares,
L. García-Soriano & V. Cristini
Universitat Politècnica de València, Spain

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Preface

SOStierra2017 (International Conference on Vernacular Earthen Architecture, Conservation and Sustainability) was born of the need to debate and highlight the recent studies, problems, and difficulties linked to vernacular earthen architecture and its conservation. In addition, and on a broader scale, it deals with the vernacular architecture which includes earthen architecture and the possibilities that vernacular heritage opens up for a more sustainable future. The SOStierra2017 conference, held on 14, 15 and 16 September 2017 at the Higher Technical School of Architecture of Universitat Politècnica de València, as part of the project "SOStierra: La restauración y rehabilitación de arquitectura tradicional de tierra en la Península Ibérica. Líneas guía y herramientas para una intervención sostenible" (Restoration and rehabilitation of traditional earthen architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention) (Ref.: BIA2014-55924-R) funded by the Spanish Ministry of Economy and Competitiveness.

The wide range of topics discussed at this conference has been organized into six main blocks. 1-Vernacular earthen architecture (study and cataloging of vernacular earthen architecture; vernacular construction techniques that employ earth; sustainability mechanisms in vernacular earthen architecture); 2-Rehabilitation of vernacular earthen architecture (case studies of vernacular earthen architecture rehabilitations; techniques and materials employed in the rehabilitation of vernacular earthen architecture; studies and sustainability mechanisms in vernacular earthen architecture rehabilitations); 3-Contemporary earthen architecture (case studies of contemporary earthen architecture; techniques and materials used in the construction of contemporary earthen architecture; contemporary earthen architecture and sustainability); 4-Restoration of monumental earthen architecture (study and cataloging of monumental rammed earth architecture in the Iberian Peninsula; study and cataloging of monumental earthen architecture; techniques and materials employed in the restoration of monumental earthen architecture); 5-Lessons from vernacular heritage for a sustainable contemporary architecture (study and cataloging of vernacular architecture; sustainability mechanisms in vernacular architecture; conservation and restoration of vernacular architecture; application of sustainability lessons from vernacular heritage to contemporary architecture); 6-Structural analysis of vernacular architecture (non-destructive testing, inspection and structural monitoring; structural repair and strengthening techniques; analytical and numerical approaches; seismic behavior and retrofitting).

Given the wide scope of these topics, all six have been grouped under the common umbrella of the SOStierra2017 conference, although two of them, Restoration of monumental earthen architecture and Lessons from vernacular heritage for a sustainable contemporary architecture, were covered in two independent events connected with the SOStierra2017 conference: ResTAPIA 2017—3rd Conference on Rammed Earth Conservation (the first was held in 2012 and the second in 2014, both at Universitat Politècnica de València), and VerSus 2017—3rd Conference on Lessons from Vernacular Heritage for Sustainable Architecture (the first was held at ESG-Escola Superior Gallaecia in Cerveira—Portugal in 2013, and the second at Universitat Politècnica de València in 2014).

The Scientific Committee for SOStierra2017 | REStapia2017 | Versus 2017 was made up of 68 internationally recognized researchers from 26 different countries and all five continents. All the contributions to the conference, both the abstracts and the final texts, have been subjected to a strict peer-review evaluation system by the members of the scientific committee. The 133 contributions by 286 authors from 35 countries published in this book, "Vernacular and Earthen Architecture: Conservation and Sustainability", have been chosen following a strict selection process from almost 250 submissions received. As well as the papers, the book includes guest contributions from two renowned authors in the field of earthen architecture: "Markers of Earthen Construction Modern Revival" by Hubert Guillaud (CRAterre-ENSAG, ISCEAH, France) and "The Geography of Earth Building" by Miles Lewis (University of Melbourne, ICOMOS-CIAV, Australia). These are major contributions not only to the knowledge of vernacular architecture and earthen architecture, but also to its conservation, restoration, and to lessons to be learnt from this for future architecture.

The International Conference SOS-TIERRA 2017 was held under the aegis of: ICOMOS-CIAV (International Scientific Committee for Vernacular Architecture); ICOMOS-ISCARSAH (International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage); ICOMOS-ISCEAH (International Scientific Committee on Earthen Architectural Heritage); ICOMOS Spain; CHAIR UNESCO UNITWIN—Earthen Architecture, Building Cultures & Sustainable Development; PROTERRA (Red Iberoamericana de Arquitectura y Construcción con Tierra). Additional institutional support was received from: IPCE—Instituto del Patrimonio Cultural de España of the Spanish Ministry of Education, Culture and Sport; IVE (Institut Valencià de l'Edificació); INTBAU-Spain (International Network for Traditional Building, Architecture & Urbanism—Spain); IEB (Instituto Español de Baubiologie); EcoHabitar (Magazine EcoHabitar: Bioconstrucción—Bioarquitectura—Biología del Hábitat).

The organization, publication, and implementation of the conference have been made possible by the funding received from the Spanish Ministry of Economy and Competitiveness (through the research project "Restoration and rehabilitation of traditional earthen architecture in the Iberian Peninsula: Guidelines and tools for a sustainable intervention", Ref.: BIA2014-55924-R); Escuela Técnica Superior de Arquitectura and the Instituto de Restauración del Patrimonio (IRP) at Universitat Politècnica de València; financial collaboration of institutions including Diputación de Valencia; Máster en Conservación del Patrimonio Arquitectónico of the Universitat Politècnica de València; Máster en Técnicas Tradicionales of the Universitat Politècnica de València; companies like ARESPA—Spanish Association of Historic Heritage Restoration Companies, Catedra Cerámica-ASCER—Spanish Ceramic Tile Manufacturers' Association; Vallmaria—Construction company; E.I. Artola—Construction company, Argumentum—Publishers.

Finally, we would like to thank all the authors who have contributed to the quality, scope, diversity, and wealth of these publications. We would also like to express our gratitude to all the members of the Scientific Committee for their work throughout the long review process for abstracts and papers. And above all, we wish to thank the Organizing Committee for the complex organization of the entire conference, the style and language reviewers for their corrections, and all the collaborators for their invaluable work in management and organization throughout the entire process.

Camilla Mileto, Fernando Vegas,
Lidia García-Soriano & Valentina Cristini
June 2017

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Markers of earthen construction modern revival

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ABSTRACT: This article evokes the main historical sequences that accompanied the modern revival of earthen construction, mainly in Europe, and its influences on other regions of the world (USA, Australia, North Africa). The modern history of earthen construction has been the subject of many research studies and publications and the focus of cultural events (exhibitions, festivals), scientific events (symposiums, conferences, congresses), and specialized educational programs, most often through regional approaches. And so, the global history of the modernity of earth construction remains to be written. To contribute to the construction of this puzzle, the article provides a useful bibliography for researchers wishing to further develop this research topic.

1 INTRODUCTION

Historically, the resurgence of earthen construction appears to be closely related to troubled times: periods of social revolution or cultural crisis (Renaissance, the Enlightenment, the Counterculture of the 1960s), political turning points (the French Revolution, the colonization of new territories in the USA, European colonization in Africa), reconstruction periods after destructive conflicts (World Wars I and II), periods of social crisis (difficult access to housing for many), economic crisis (reduced access to industrial resources) and environmental crisis (energy crisis, depletion of non renewable resources, destruction of ecosystems, climate change). Under such circumstances, most often, earth construction draws its « ideological » legitimacy from a corpus of authors going back to Antiquity (Herodotus, Vitruvius, Varron, Columelle, Caton, Palladius) and in reference to the legacy of vernacular architectural cultures whose recognized constructive intelligence and human value may inspire the design of alternative housing models.

2 THE RENAISSANCE OF MODERNITY

2.1 *From the renaissance to the enlightenment*

After the Renaissance, which saw the edition of the *De Re Aedificatoria* (1443–1452) by Leon Battista Alberti, valorizing the economy and the qualities of traditional processes linked to earth construction in the implementation of rural buildings, several authors will follow. In France, Charles Estienne publishes *La Nouvelle maison rustique ou l'économie générale des biens de la campagne* in 1554, an enterprise pursued by his son-in-law Jean Liébault, amounting to eighty editions with several publishers and restored in 1702 by the agronomist Louis Liger up until the late 18th century. During the French Pre and Post-Revolutionary periods, many authors published works promoting rammed earth construction (Delorme 1745, Goiffon 1772, Rozier 1786, Cointeraux 1790–91, Rondelet 1812). They do not fail to highlight the durability of rammed earth buildings as well as their incombustibility, but also their thermal properties, economic advantages as well as their technical accessibility for self-construction. Translations of Cointeraux's two first *Cahiers d'Ecole d'Architecture Rurale* (1790–1791) have a considerable impact on the renewal of rammed earth construction at that time (Holland 1797, Del Rosso 1793, Seidelin 1796, Gilly 1798, Seebass 1803, Conrad 1840, L'vov 1801 who founded a school specialized in earthen architecture in Tiukhili, near Moscow (1797–1803) based on the model established by Cointeraux in Paris). Translations of the works of Cointeraux inspired a new generation of authors in Europe and the USA (Johnson 1806, Nicholson 1807, Rees 1810–17, Papworth 1818, Faust 1839, Wimpf 1810 and more recently William-Ellis in 1919).

2.2 *The industrial era and the advent of concrete*

Following the synthesis of cement carried out by French engineer Louis Vicat in 1817, the creation of Portland cement by Joseph Aspdin in England in 1824 and the appearance of reinforced concrete from the late 19th Century (through an agreement between cement manufacturers and the *Comité des Forges* in France), the industrialized countries of

the North gradually abandon the use of traditional materials (earth, stone, wood) opting for modern materials instead (cement, steel and reinforced concrete). The use of local materials will then be reserved for rural buildings, which will also gradually integrate industrial materials.

2.3 *Colonial influences*

The major influences of Orientalism in painting (*le voyage au Maroc* by Eugène Delacroix and his famous watercolor notebooks, the paintings of the Atlas by Jacques Majorelle in Morocco), colonial exhibitions including that of Vincennes in 1931, feature exotic architectures and pavilions that present a false vision of the earthen architectures of the colonies of Africa. At the end of the 19th century, the work of Africanist anthropologist and adventurer Leo Frobenius (1897) and the development, during the first half of the 20th century, of studies on traditional immovable heritage in the colonized territories, contribute to revive an interest for vernacular earth building cultures. This is also the case in Morocco, with several research studies made on the kasbahs, the ksour and the collective granaries (Montagne 1930, Terrasse 1938, Jacques-Meunié 1951, 1962).

2.4 *From the interwar period to the 1960s*

In Italy and in France, between the two World Wars and until the 1950s, geographers undertake studies on rural architectures that define the great typologies of farm buildings and their annexes. The works of Albert Demangeon, published in the Annales de Géographie Armand Colin founded by Pierre Vidal de la Blache remain a reference. Some of these works highlight earthen architecture in a specific way, as it is clearly prevalent in some of the studied territories. An example of this is found in the works of Italian geographer Osvaldo Baldacci (1958) who refers to a civilization of « crudo » (raw earth) in Italy in his book *L'ambiente geografico de la casa di terra in Italia* (Vol. LXV, p. 13–43). This trend will spread to other European and more distant countries and will continue until the early 1990s, through a great number of publications (in France: Bardou and Arzoumanian 1978, CRAterre 1979, Houben and Guillaud, 1984, 1989, Bardagot 1991. In Germany: Niemeyer, 1946, Miller 1947, Fauth 1948, Pollack and Richter 1952. In England: Brunskill 1971, 1974, 1978, Mc Cann 1983). In Australia: Middleton 1953, Lewis 1977, Schneider 1987). In France, the *Corpus de l'architecture rurale française*, focusing on each of the regions composing the French territory, starts off during World War II in 1942, under the direction of Georges-Henri Rivière, and will be concluded in the early 1980s. The Corpus is a compilation of no less than 1759 monographs of rural dwellings made by architects who were threatened, at the time, to be forced to register for Compulsory Work Service (*Service du Travail Obligatoire* - STO) in Germany. The varied works of this collection mention rammed earth (pisé) construction (Dauphiné and Lyonnais regions), raw earth brick construction (Midi toulousain and Pyrenean regions) as well as timber framing and wattle and daub construction (Alsace, Normandy, Landes regions).

3 THE END OF THE 20TH CENTURY

3.1 *Rebuilding after World War II*

With post World War II reconstruction, several European countries are considering earth for residential construction as a viable option, but mainly in rural settings. A literature aimed at training specialized earth construction technicians is produced in Germany and England. Training centers are implemented and hundreds of artisans are trained. DIN standards for earth construction are first published in Germany in 1944 and serve as a reference for German manufacturers until they are withdrawn, in 1970. In France, experiments carried out by the Ministry of Reconstruction and Urban Planning (MRU), in their research center in Ivry, validate the possibility of rebuilding in rammed earth. In Picardy the two Bosquel farms are implemented, under the direction of architects Jean Bossu and Paul Dufournet. There will be no follow-up to this prototype project.

3.2 *Revival attempts in the south*

The independence of colonized nations in the 1960s is accompanied by a political and ideological desire not to resort to obsolete building materials and techniques for the construction of modern housing structures, and to promote the development of industrial materials in response to strong economic and urban growth. In the 1960s, in Morocco, the United Nations (UN-Habitat, UNDP) make great investments to support government projects that promote the use of stabilized compressed earth bricks. Large-scale projects such as « BTS 62 » and « BTS 67 » aim at implementing thousands of affordable housing units in Marrakesh and in the outskirts of Casablanca. In Ouarzazate, French engineer Alain Masson and Belgian architect Jean Hensens experiment with dwelling structures in stabilized rammed earthen, covered with vaulted roofs with a full formwork design. Major operations to safeguard the Ksourian heritage are also carried out (Tissergate, Draa Valley).

3.3 *The influence of Hassan Fathy*

In Cairo, in 1969, *Gourna: a Tale of two villages* is published by Egyptian architect Hassan Fathy and recounts the construction of the village of *New Gourna* in Luxor, on the west bank of the Nile. In the decade that followed, Hassan Fathy, who deemed the rehabilitation of earth for building and namely the use of adobe bricks as « the » solution to improve rural construction, will become a reference for a new generation of architects contesting the industrial housing production systems. Arches, vaults and cupolas will become manifestos both in architectural and ideological terms, but also pedagogical models to re-learn to build with earth. This is particularly the case at the School of Architecture of Grenoble, France, through the teachings of architect Patrice Doat, who founded CRAterre in 1979.

3.4 *The double energy crisis of 1973 and 1979*

The most recent period, decisive in the revival of earthen architecture is undoubtedly the one directly impacted by the two energy crises of 1973 and 1979. This period offers the opportunity to strongly challenge the logic of a global system that leads to disaster and for communities to claim « the right to develop their own living environment » (ibid, CRAterre, 1979). In addition to the commitment of many personalities (René Dumont, Jacques-Yves Cousteau, Ivan Illich, Ignacy Sachs, Ernst Friedrich Schumacher, John F.C. Turner), appropriate, alternative technologies (« A.T. »), are supported by « the New American revolution » (Revel 1970), a concept initially put forth by Schumacher in his book *Small is beautiful* (1973). The *Whole Earth Catalog* (1968–73) by Steward Brand and *Shelter* (1975), disseminate new tools for more self-contained, less resource and energy consuming buildings, involving recovery and recycling systems. Earth construction is well perceived in this context. On the basis of new ecological arguments, the « passive solar » adobe architectures (Steve Baer, David Wright, Tony Predock) of New Mexico and California, will inspire a new generation of European architects in several countries. In France, in 1981, the exhibition *Des architectures de terre* by Jean Dethier, architect and urban planner, curator of architectural exhibitions at the Centre de Création Industrielle—Centre Georges Pompidou, relaunched an international debate on the North/South development gaps and on the difficult access to housing to the most fragile populations. The author of the exhibition then develops the idea of implementing a pilot operation to demonstrate the technical and economic viability of using earth materials in the context of a social housing project. The *Domaine de la terre* project, carried out between 1983 and 1985, resulted in the construction of 65 low-rent housing structures near Lyon, in the town of Villefontaine, through the use of unstabilized rammed earth, stabilized earth blocks and straw-earth. This project, accomplished under real conditions at the time, confirms the potential of a new earthen construction sector that could be developed.

3.5 *A worldwide global rebirthing*

Over the last thirty years, the revival of earthen architectures has been reinforced through scientific research as well as through the development of university and professional training programmes. France holds a position of leadership thanks to the work accomplished by CRAterre, which has created a ripple effect among a great number of educators, researchers and professionals from other European countries. The last decades have also seen the establishment of very active national and international networks (UNESCO Chair of Earthen Architecture, PROTERRA, ICOMOS-ISCEAH, Città della Terra Cruda, Dachverband Lehm e.V. and other informal networks in many countries). Conferences, symposia and seminars on earth architecture have multiplied and take place yearly, if not more often. We cannot keep track of all events taking place linked to the rebirth of earthen building and earthen architecture. The last World Congress, TERRA 2016, organized in Lyon, France, by CRAterre, brought together nearly 800 participants. World-class architects such as Renzo Piano, Norman Foster, Wang Shu, Herzog et De Meuron have worked with earth materials in their projects. The very recent *Terra Award,* first international prize on earthen architecture, organized by CRAterre under the aegis of the UNESCO Chair of Earthen Architecture and granted during the last TERRA World Congress, celebrated 357 projects sent from all over the world. 40 of them were preselected and 8 were finally graduated according different categories of projects. Undoubtedly, the path leading to a more sustainable global renewal of earthen construction and architecture seems clear, however…

4 REMAINING RESISTANCES

4.1 *A revival of the quest for identity*

In many countries, the question of the definition and publication of best practices for building and other norms and standards remains a crucial factor to ensure the development of earthen construction. Issues dealing with the precarious state of ancient earth buildings are also of great concern. Solutions which favor the use of industrial

materials and common building practices are most often incompatible and generating potential pathologies. Some restoration principles support maximum insulation (exterior or interior cladding, implying opposing arguments) and others are based on the thermal inertia naturally occurring on thick earth walls, offering an optimized thermal behavior (enhanced through the addition of internal insulation using organic or biosourced breathable materials). There is no consensus regarding the restoration of earth buildings and businesses are not trained or question their own practices.

4.2 *A new earth architecture exists, but…*

A new earth architecture « exists » but is still seeking its own identity. It does not show a semantic coherence in the expression of its architectural language, which is quite often contrary to the constructive intelligence of vernacular cultures and their regional specificities. In Northern countries, « stabilized » rammed earth is a preferred construction method (Australia, USA), often involving the use of cement, distorting the very face of earthen architectures by pledging allegiance to the hegemony of concrete. And so, the ecological and economic advantages offered by the material are thus questioned and challenged today. Moreover, the use of sophisticated formworks renders the building process more difficult. In Southern countries, adobe and cob are preferred by builders. These techniques are more easily appropriated, require little equipment and essentially call upon the physical energy of worker. A deeper analysis of building as a concept and an intelligence in vernacular cultures would make it possible to put earth construction on the track of regeneration, innovation, and transcending, in the Hegelian sense (*aufhebung*).

Today, this revival of earthen construction still relies on the articulation between tradition and innovation. It is recognized that contemporary earth architecture can be an extension of the vernacular heritage, under certain conditions. Building engineering would require improvement through the evolution of knowledge and know-how and a scientific characterization. Furthermore, experimentation through demonstrative pilot projects encourages research and the development of new techniques (cast earth, projected earth, lightened earth) and new ways of implementing earth materials.

The link between earth materials and ecological goals is an established fact. Earth materials do not require the consumption of high amounts of embodied energies and their « life cycle » is deemed « virtuous » as it does not generate negative externalities (pollution, overconsumption, waste). Earth materials can also, depending on the techniques applied, provide natural insulation (« lightened » earth) or inertia (thermal mass of thick pisé or cob walls).

Earthen architectures and their extensions ensure the perpetuation of local identities and particularities in an increasingly global, « cultural scarcity » generating world. Earthen architectural heritage is valued through a flourishing economy based on international cultural tourism. Earth architecture also appears as « subversive » in relation to the major lobbies of the building industry, industrial and financial interests and property speculation. In a way, it stands as a symbol of hope, only highlighted by the aesthetics of earth matter, both raw and beautiful (Wilson 2014). Its qualities are increasingly recognized.

5 CONCLUSION

The renewed vitality of earth architectures today is also sustained by a wider universal awareness of the dangers faced by the planet and the human race, and the general aspiration towards a social model proponent of « frugal innovation » (Prabhu and Radjou, 2015), a new « natural contract » (Serres, 1987) and a reconciliation with the environment. This renaissance seems to establish itself more reliably in the landscape of contemporary housing production, after more than thirty years of investment in research and training activities, and the achievement of architectural projects that bring back the confidence that ancient generation had about the use of earth as an easily accessible, easily applicable building material. Nevertheless, this revival alternates between the temptation to contribute to the development of a « juicy » market and the desire to participate in other logics of transaction, namely the exchange of « services », the sharing of knowledge, « participatory » self-construction projects, new social attitudes rehabilitating the « gift economy » principle (Mauss, 1925).

Consequently, earthen construction accompanies the emergence of an economy of exchange. A circular economy and short distribution channels are on the agenda.

There is also a possibility for earthen construction to be on the rebound through the identification of new « green » sectors involving « bio-based » (vegetable fibers such as straw, hemp and reed) and « geo-based » (earth, stone) materials by government authorities, refocusing on the local resources of territories for the more concrete application of sustainable development principles. The energy transition is another factor of validation of earth materials as a valuable resource for building in conjunction with other compatible

bio-based and geo-based materials improving the heat capacity of earthen structures. The hybridization resulting from the use of earth and such new materials offers wide possibilities for innovation.

Important obstacles remain to be overcome, such as the lack of structural calculation standards for earthen structures, the fact that the thermal qualities of earth materials are not taken into account (as in « light » insulation and in the mass inertia of thick earth walls). There is also the reluctancy manifested by insurance companies, the difficulties in quantifying the costs linked to building with earth and a lack of vocational training opportunities.

The connections between the modern revival of earthen construction and vernacular cultures are patent, but the need remains to « digest » the past so as to project the future (Weil, 1952); it is also true that said links do not suffice to explain the cyclical relaunch of earth construction as a recurring social phenomenon. We also evoked the connection between the resurgence of earthen construction and troubled times in history. Recent years validate the direct relationship between economic crises, energy crises and, more broadly, environmental crises, with the emergence of threats of increasing gravity that are a cause of concern. All resources must be mobilized to counter these threats and building with earth, at its humble level, can and must support this goal, within the broader framework of a global action plan but also at local scales.

NOTE

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The geography of earth building

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ABSTRACT: This paper describes a picture of early earthen architecture that is distorted by the disappearance of most of it, and by the archaeological misinterpretation of what remains. Moist sod construction is widespread, but there is now evidence also of dry sod construction. The first mud bricks were cut from a layer of mud spread on the ground, giving them a flat plate form which then dominated ancient Mesopotamia and the later Arab world. In wetter climates a brick or block shape developed, and in Anatolia the Kurds developed an ingenious compromise between the flat plate and the block shape. In Iran, where the timber shortage is most acute, there is a technique of building adobe arches on gypsum ribs. Rammed earth was a later North African invention and *lehmwickel,* or earth winding, was a widespread technique in Europe and in German–influenced areas elsewhere, but until recently usually mistaken for wattle and daub.

1 SOD OR TURF

Sod or turf is cut from moist grassy ground, and the blocks are held together by the grass roots. The blocks are usually thin and flat, and used to build very thick walls, or laid across timbers to create a roof. This form of construction probably became common in the Bronze Age as soon as metal blades suitable for cutting the material were available. How sods were extracted before that time—if they were—is a mystery.

There is enough surviving evidence to suggest that the use of sods or turves in building construction was widespread. Inevitably, the archaeological record is heavily biased towards those structures in which sods were combined with timber or stone, and have therefore left interpretable remains, but such buildings certainly came later, and they were probably always in the minority. The prototypical hut would have had walls of sod only, though it would of necessity had some sort of framing for the roof. Only very occasionally has useful evidence of this roofing survived, but one instance is that of supposedly Mesolithic sod huts in Sussex, with curved sod walls a metre high and willow or alder poles bent to form vaulted or conical roofs, which may have been covered with oiled skins or else with turves (Castleden 1987: 37). Some of the oldest examples of sod construction are not houses but prehistoric mounds or barrows, such as at Trelen in Cornwall (Owoc 2005: 2).

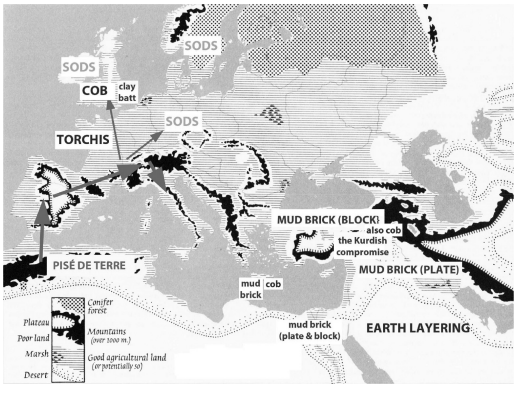


Figure 1. The distribution of earth construction (Miles Lewis).

Neolithic stone structures in the Orkneys, North-East of Scotland, appear to have been stone walled and roofed but with layers of sod over the top, although published reports are disappointingly vague. The oldest identifiable true (structural) sod construction in Ireland is possibly a rectangular sod-walled house built on Coney Island in Lough Neagthe not long after 2000 BC (Gailey 1984, 16).

Typically sods would be cut out of the ground with a spade. In Scotland, where peat was sometimes used in the same way as sods, a special peat-cutting spade was in use in the nineteenth century. It was reported in 1848 that peat being used as tiles on the estate of a Mr Wason at Corwar, having been 'cut out of the moss by an instrument for the purpose' (*Builder,* 14 October 1848: 495). The Wason family had connections with New Zealand, where such a tool has been reported, probably the same as the Scottish one (Allen 1991: 35).



Figure 2. Sod roofing on a stone structure, Skara Brae, Scotland (Miles Lewis).

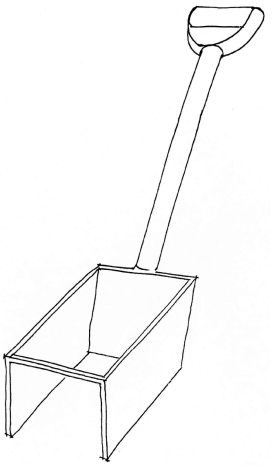


Figure 3. Peat-cutting tool used in New Zealand, probably the same as in Scotland (Miles Lewis after Allen 1991, p 35).

Elsewhere a strip of sod was turned up with a plough and then cut up into the required lengths. Some of the best-known sod constructions are those of the North American prairies where a specially developed 'grasshopper' plough was used to cut the sod (Turner 1975: 26).

But there is evidence of an earlier use of dried sods. At Fort Kearny on the Platte River, Nebraska, in 1848 Lieutenant D P Woodbury first had his troops preparing adobe bricks, but later had them to the cutting sods instead, in order to speed construction (Murphy 2011). Early photos show the sods to be similar to adobes in size, and indeed if dried they would in effect be adobe. In Australia there are examples which seem to be of this sort, for the proportions of the blocks are wrong and the wall too thin for moist sod construction.

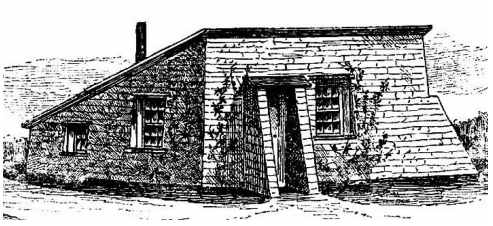


Figure 4. A sod house on the prairies (King 1886, p 102).



Figure 5. Ruined house near Dimboola, Australia, showing what appear to be dried sod blocks (Miles Lewis).

2 ADOBE

The first mud bricks appeared before the existence of carpentry and were hand-moulded, or were cut from a layer of mud spread on the ground, giving them a flat plate form. The subsequent development of the open timber mould, like a bottomless box, made possible a deeper block than that formed directly on the ground, though that was not necessarily what the maker chose to create. Indeed it is not always possible to tell from the remains whether an adobe has been cut on the ground or open moulded. The blocks used at Çatalhöyük, which are exceptionally large slabs, look as if they have been moulded, and so do those at Hili, on the Persian Gulf and at Harappa and Mohenjo-Daro in the Indus Valley. Meanwhile the plano-convex brick had emerged in the Middle East by the third millennium BC, for no very obvious reason, and the two forms were used in parallel for some time.

The flat plate form continued to dominate ancient Mesopotamia and the later Arab world. But in wetter climates a brick or block shape developed. One reason was perhaps the need to shelter the blocks while drying ('hacking' in modern brick terminology), for a deeper block occupies less floor area, and is stronger for stacking,

The two traditions meet in Turkey. In northern Anatolia the Urartu culture, and probably the Hittite culture before it, used the block shape, which has continued into modern times. In the South, where there is a sizeable Arab population, the flat plate form is still in use. The Kurds, alien to both traditions, have developed an ingenious compromise between the two. They use divided moulds to manufacture in equal numbers blocks and plates of uniform thickness. That is, the blocks are shallower than normal and the plates deeper.



Figure 6. A mock-up of plano-convex brick walling in the Archaeological Museum, Istanbul (Miles Lewis).

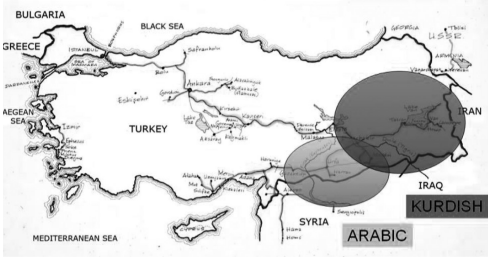


Figure 7. The Arabic and Kurdish subcultures in Turkey (Miles Lewis).

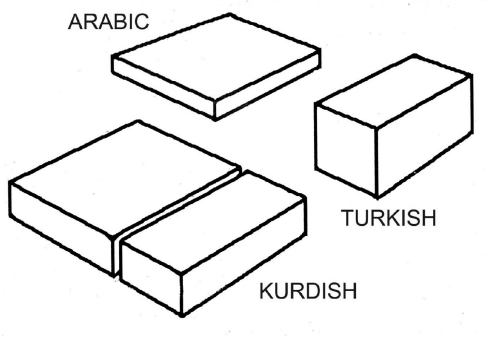


Figure 8. Adobe: The Kurdish compromise.

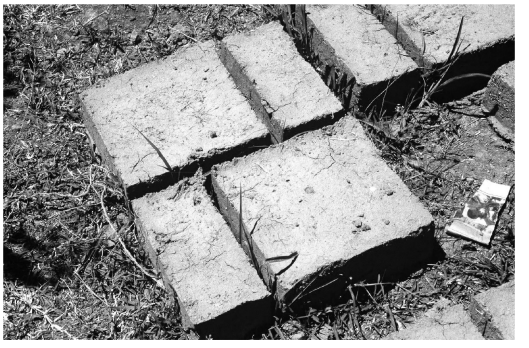


Figure 9. Kurdish mud bricks from a staggered mould, at Yalindamlar, Turkey (Miles Lewis).



Figure 10. Kurdish mud bricks laid in a wall at Yalindamlar, Turkey (Miles Lewis).



Figure 11. Brick bond described by Vitruvius, reconstructed by Reber: no date, p 44.

To make use of these two sizes in equal numbers they are laid in a wall in two rows with narrow blocks on one face and wide ones on the other. To ensure bonding these are alternated—that is, the wider bricks on the outside in one course and on the inside in the next. Interestingly, this bond had been described by the Roman writer Vitruvius.

3 THE GYPSUM ARCH

In Iran, where the timber shortage is most acute, there is a technique of building adobe arches on gypsum ribs. The ribs are cast on the ground over a layer of sand, in a channel formed by loose adobes on either side. They are of gypsum plaster

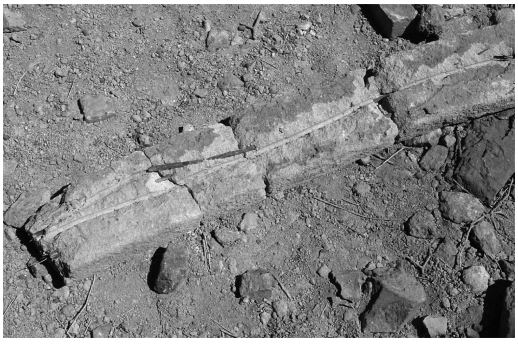


Figure 12. A gypsum rib, Anar Mehriz Caravanserai, Iran, Qajar period (Miles Lewis).

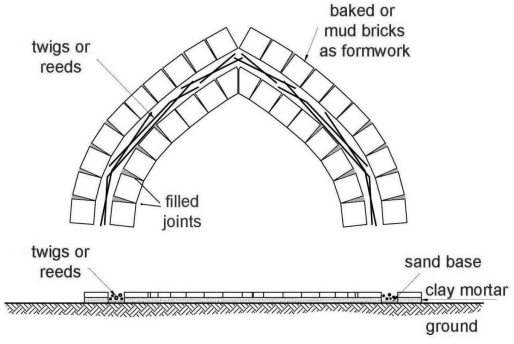


Figure 13. Casting gypsum ribs on the ground, after Mohammed Reza Bazldjou, personal communication.

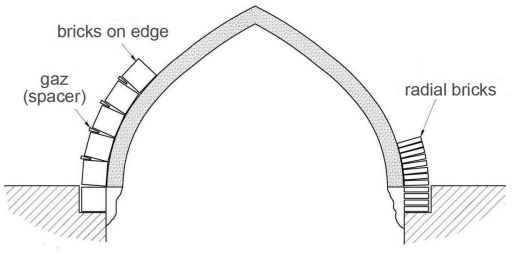


Figure 14. Construction of an arch using gypsum ribs as falsework, with brick on edge, left, or radial brick, right: after Mohammed Reza Bazldjou, personal communication.

reinforced with reeds or other vegetable material. These ribs are placed across the opening and the first of radial mud bricks constructed on them. Or if this is likely to be too heavy, a ring of brick on edge is placed first: on top of this the wall can be built out to the thickness required.

Gypsum ribs are also used in a variety of ways in in the construction of vaults and domes.

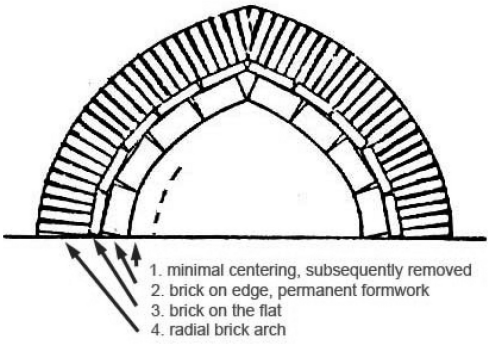


Figure 15. Construction of an arch using minimal formwork, after Michell 1978, 136.

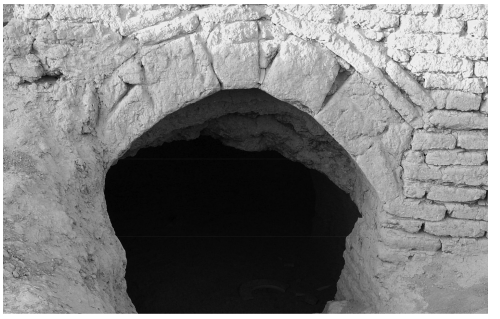


Figure 16. Mud brick arch with brick on edge, Meybod fortress, Iran (Miles Lewis).

4 RAMMED EARTH

Archaeologists have commonly the term *pisé* loosely to refer any sort of earth construction (Knapp 2013) but contrary to common belief rammed earth (*pisé de terre, tapia*) is not a very ancient construction. It depends upon formwork which requires sophisticated carpentry with sawn boards and usually metal fixings, and this was not practicable in very early times. There is no authenticated example in the ancient Near East, and it first appears in Phoenician North Africa (and independently in China). Given that they had not used it in their East Mediterranean homeland it is possible that the Phoenicians first learnt it from the Berbers.

Rammed earth passed from North Africa to Spain and France, possibly with Hannibal's army and although this has not been recognised, it seems to be the origin of the Roman development of concrete. Pliny refers to walls of earth and stones constructed in a framework of planks (*in formis*)', called 'formaceae', which were common in Africa, Spain and around Tarentum in southern Italy. He also refers to walls in Africa and Spain...

> that are called framed walls (*formaceos*), because they are made by packing in a frame enclosed between two boards one on each side, and are stuffed rather than built and do they not last for ages, undamaged by rain, wind and fire, and stronger than quarry-stone? (Pliny no date, 384-5)

Palladius (whose own estates were in Italy and Sardinia), says in *De Re Rustica* that all gardens should be enclosed, and that some people use mud enclosed 'in formis' to imitate brick walls, or mud stone where the materials are available (Papworth 1853-92, sv Formaceum). Varro also mentions fences of earth and gravel formed in a mould, which were to be seen not only in Spain, but in the area around Tarentum (Varro no date, i, xiv, 4). Only in the nineteenth century was it specifically suggested, by Robert Stuart, that the Romans had learnt the method from the Carthaginians (Stuart 1832, sv wall). The proposition was subsequently repeated by Richard Delbrueck as if it was his own original thought (Delbrueck 1907, 2, 384-5).

The rest of the story is well-known. Rammed earth became endemic in Spain, as *tapia,* from what is said to have been the North African word for a mud wall, *tabut,* and the Arabic *tabiya* for an earth wall (Arellano 2006, 16). It was used especially in Islamic fortifications (Gil-Crespo 2016), and in due course it was exported to Spanish colonies in the Americas (Weimer 1983). In the United States the name was corrupted to 'tabby'.

Rammed earth also became endemic in France as *pisé de terre*, especially in the Lyonnais, where it was rediscovered and revived by writers in the eighteenth century. The influence of these writers, especially François Cointeraux, brought the method to England, Germany, Italy, the United States, Australia, New Zealand, and even back to Spain (Baridon et al. 2016).

5 LEHMWICKEL

Lehmwickel, or earth-winding, is another victim of archaeological misinterpretation. Because it was effectively unknown in an international context prior to my own work (Lewis 1997, 2009), traces of it were never recognised, and were usually misinterpreted as wattle and daub.

In broad terms, a mixture of clay and straw is wound around the outside of a timber stake with pointed ends. Commonly the mixture is spread out like a mat and then wound up, but sometimes it is in strips or bands, and sometimes a sort of rope. Rows of these wrapped stakes are placed vertically, close together, within the panels of a timber (*fachwerk*) frame. Because they are then plastered over, their existence is often is often unknown to viewers. *lehmwickel* is also used in ceilings, where it is valuable as insulation, and here it is sometimes exposed to view.

Lehmwickel is most typically a German construction, and certainly one associated with German settlement in Hungary, North America and Australia. But it seems to be just as old a technique in northwestern France, where it commonly referred as *quenouilles* (also *grenouilles, baguettes*). Its origins are unclear, but it seems most likely that *lehmwickel* was originally associated with those Germanic tribes, including the Franks, who pressed in upon the declining Roman Empire—tribes which had been living in the forested areas of Europe, and now moved westwards *en masse.*

In Germany *lehmwickel* of the spiral rope type is illustrated in a textbook as late as 1911 (Bohm 1911, 152), and a version called *lehmwickelstakung,* seems to have been used or revived, or at least to have influenced other construction methods adopted, during the building materials shortages following the Great War.



Figure 17. La Ville-Cotterel, Montauban, France, 1729: detail of quenouilles [lehmwickel] in a ceiling (Miles Lewis).



Figure 18. Reconstructing lehmwickel at the Szentendre Museum Hungary, 1994 (Sabján Tibor).

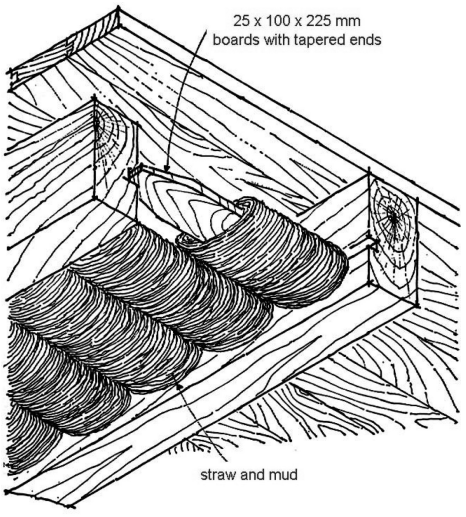


Figure 19. *Lehmwickel* or 'Dutch biscuits' as used at New Harmony [Harmonie], Indiana, USA: Blair 1964, 55.

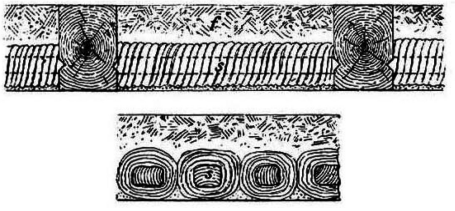


Figure 20. Rope style *lehmwickel.* Böhm 1911, 152 [reformatted].

6 CONCLUSION

These techniques have all evolved to meet the requirements of the climate, soil and other conditions of specific areas, and only after that have they become identified with specific races and cultures. Some of them have then been spread by those races to different and possibly unsuitable regions. But none of these techniques has been properly understood in terms of that mechanism. Historians have been more concerned with the technology involved, and to some extent with the history, but the geography which gave rise to them has been neglected.

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A sustainable repair process for heritage buildings in historic Jeddah

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ABSTRACT: Historic Jeddah, the gate way to the holy city of Makkah is a world heritage site located on the eastern shores of the Red Sea in Saudi Arabia. It was settled about 2500 years ago and gained prominence in the 7th century AD as it become the main seaport for pilgrims to Makkah and commerce and trade. It is characterized by distinctive architecture of buildings with internal and external sedimentary stone load bearing walls, staggered roof terraces and large decorative wooden *roshans* (bay windows). It personifies the architectural style of the red-sea basin that has influences from areas along the pilgrimage and trade routes. This paper discusses a traditional sustainable repair process (*ta'leeq*) used in historic Jeddah's heritage buildings for repair of sedimentary stone load bearing walls suffering from structural problems such as, cracking because of the extreme weathering conditions of high temperature and humidity.

1 INTRODUCTION

1.1 *Urban heritage in historic Jeddah*

The urban character of historic Jeddah resembles a typical medieval Arab Muslim city, encircled by perimeter walls as seen in Figure 1. These walls stood five meters high and two meters wide and had six fort-like watchtowers and gates (*babs*) constructed from limestone, lime mortar, wood planks and painted with lime wash. The map of historic Jeddah in Fig. 2 shows how the gates lead to the inner parts of historic Jeddah's four urban quarters of (*ha'rat al'mazloom*) and (*ha'rat al'sham*) to the north; and (*ha'rat al'yaman*) and (*ha'rat al'bahr*) to the south (Adas et al. 2008). Major pedestrian axis in the old city is the last-west corridor, called *souk Al'alawi*, which links old sea port to the west with *Bab Makkah* in the east (Fig. 2). Close-knit communities and social cohesion characterized life in these urban quarters and resulted from its spatial organization and hierarchical urban elements that included irregular lined streets to maintain

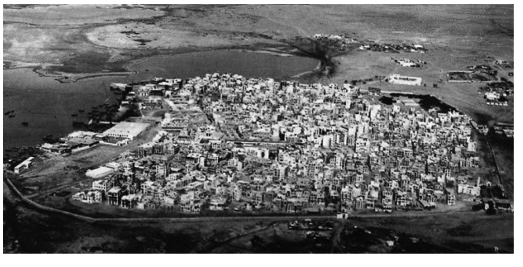


Figure 1. Historic Jeddah, 1947 (Adas et al. 2008).

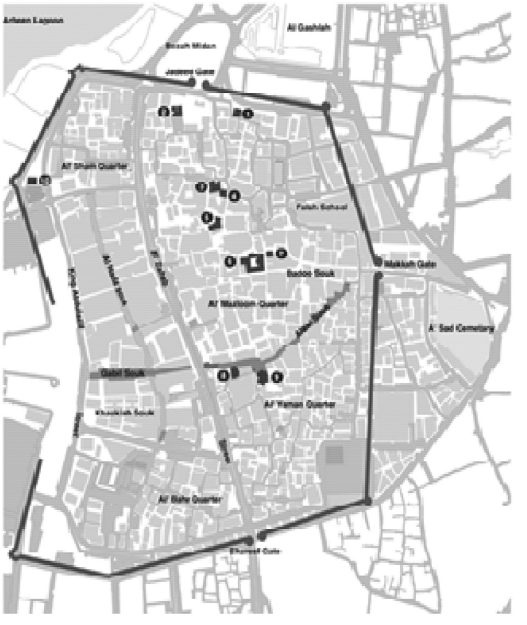


Figure 2. Historic Jeddah map with walls and gates (Adas et al. 2008).

privacy of entrances, narrow residential alleys and pathways oriented to take advantage of buildings' shade to provide access with thermal comfort, and properly scaled open spaces or *bara'hat* that provide places for social interaction.

A mix of residential and commercial activities are lined up along the major pathways and organized so that prominent buildings are located at urban junctions and open spaces. Public schools and religious buildings such as *alshafe*, *almimar*, and *alhanafi* historical mosques

1.2 *Architectural heritage in historic Jeddah*

The architecture and design of historic Jeddah's tower houses are simple yet striking. The historical houses represent a very rich heritage that is a living testimony for how local builders responded to changing social needs and other environmental conditions that existed during the time periods in which these houses were built. Historic Jeddah traditional tower houses' design is authentic, functional, and stylistically unique. How the buildings maximize cross ventilation to lessen humidity and improve thermal comfort contribute to the unique architectural style.

The heritage buildings are constructed from sedimentary limestone (*ha'jur mangabi or kashoor*), load bearing walls with small intermittent wooden beams (*taka'lille*), and wooden logs (*gun'dull*) ceilings that setback as building rises and go higher to create roof terraces, reaching a maximum height of five stories. A main arched wooden doorway beautifully engraved in floral and leaf patterns in the Islamic tradition. As seen in Fig. 3, dominant and impressive architectural feature in the facades of heritage tower house buildings in historic Jeddah is the intricately carved and decorated wooden elements called (*roshan*) single or (*rawa'sheen*) plural (Adas 2010). Primarily, the *roshan* covers the large openings to provide cross ventilation and multiple outer views from the inside through its operable horizontal louvers while maintaining the privacy of occupants. *rawa'sheen* project out of the exterior walls in similar fashion to bay window or orioles and are typically built of wooden components made of very hard dense wood, decorated with delicately carved wooden motifs and embellishments on their front and side surfaces. The size, level of ornamentation, and intricacy of the *rawa'sheen* reflect the social and economic status of the owner as evident in *Jamjoom* and *Nassif* tower houses with construction of very large and finely produced *rawa'sheen* dominate the main facades of these houses symbolizing Jeddah's rich history. In smaller houses, *rawa'sheen* are smaller and, in some cases, reduced to simple wooden windows with a screen over the middle to maintain



Figure 3. Sketch of a tower house in Jeddah. Source: (Adas et al, 2008).

privacy. The lime washed walls of the main facades of historical houses are adorned in some cases with very refined and unique geometrical patterns in the Islamic tradition. In Fig. 4, the floor plans of a typical tower house in historic Jeddah shows main entrance that usually lead to the entrance hallway (*dahlis*) and adjacent ground floor spaces used for sitting (*maga'ad*) that are usually situated in the front and keeping utility rooms toward the back. The main staircase climbs to various floors leading to a transitional space (*suffah*), which leads to main setting rooms to the front (*majlis*) and utilities such as kitchens (*mirak'kab*) and bathrooms (*bait'alma*) and storages (*makha'zin*) to the back. Lofty roof terraces (*khar'jah*) with adjacent rooms (*mabeet*) provide sleeping quarters during summers. Two-meter parapet walls enclose the terrace; wood screens allowing free flow of cool sea breeze adorn these parapet walls.

The architecture of traditional tower houses in historic Jeddah tells the saga of master builders who used local building materials, common sense, and artistic talent to create an architecture that is still inspiring today. The traditional tower houses

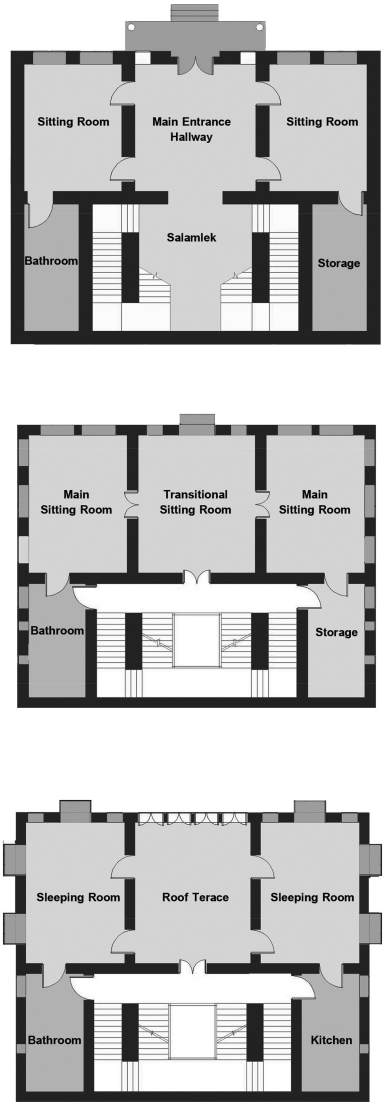


Figure 4. Floor plans for typical tower houses (Adas et al. 2008).

buildings capture the past splendor of historic Jeddah's architecture and its urban ambiance (SCTH 2014).

2 TRADITIONAL CONSTRUCTION TECHNIQUES

Heritage buildings in Jeddah were designed and constructed by the local master builder (*ma'alem*) and his team of workers, lime renderers, and

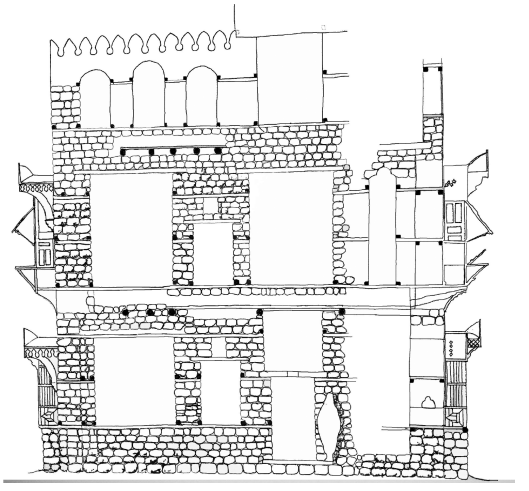


Figure 5. Section showing construction details for a heritage building in historic Jeddah (Adas et al. 2008).

roshan carpenters [2]. The section in Fig. 5 shows construction details for ceilings, floorings, walls that were built using manual methods and local construction materials including sedimentary coral stone blocks (*ha'jar managbi*), lime mortar (*moona or tee'in with noorah*) for bonding of stone blocks, intermittent small wooden beams (*taka'llile*) in interior and exterior load bearing walls for structural strengthen and ease of maintenance for sections of wall, and built-up ceiling structures that are composed of local tree logs (*gun'dull*) from mangrove trees (*shoura*) as ceiling beams and topped with a flooring layer made up from wooden planks, mat sheets made of palm leaves (*ha'seer*) with a hardened top rendered lime layer (*tobb'tab*).

In rehabilitation projects in historic Jeddah, restoration specialists should favor traditional building repair methods due to their inherent sustainability (Al-Aidroos 1989). This paper focuses on one such technique that is specialized in the structural repair of interior and external *managbi* stone load bearing walls in heritage buildings in historic Jeddah. The process is called (*ta'leeq*) from the Arabic verb (*al'laq*) meaning to suspend above or sustain above. This process is discussed in further details in the next sections.

3 LOAD BEARING WALL REPAIR PROCESS (*TA'LEEQ*)

As explained, load bearing walls construction in historic Jeddah's tower houses followed a very rigorous technique by the local master builder and his team. The *man'gabi* stone rough blocks



Figure 6. *Taka'llile* in facades of Historic Jeddah (authors).

are arranged in an interlocking manner in two courses with a middle filled with smaller stones (*na'gal*) and bonded with a mortar made from a mix of hydraulic lime and clean silt and soil. At a height of every five to six blocks or about one meter, round or rectangular wooden beams (*taka'llile*) with a cross sectional area of approximately 25–30 cm^2 are installed along the perimeter of the wall. In Fig. 6, these beams are very evident in the façade of tower houses in historic Jeddah. Fig. 8 shows these intermittent wooden beams (*taka'llile*). Splicing and nailing of these intermittent wooden beams are used to maintain continuity of *takalille* along both the internal and external side of the walls approximately every one meter of building height as shown in Fig. 7.

Based on the authors experience in preparation of restoration plans of four tower houses in historic Jeddah and supervision of the repair works of load bearing walls as seen in Fig. 9 and as mentioned in the wall repair section of the restoration manual of heritage buildings in historic Jeddah, which is based on traditional techniques developed by the local master builder, the repair process targets only the parts or sections of the walls that need maintenance and repair without disturbing the other parts of wall below the damaged part or above it.

This is so because the process of *ta'leeq* permits it by transferring the loads of the upper parts of



Figure 7. Repair of *taka'llile* and *gun'dull* (authors).



Figure 9. *Ta'leeq* of the exterior side of a wall (authors).

the wall to the floor and to walls in the lower levels (Adas 2005).

Structural problems in heritage buildings walls that necessitate wall repair arise over time because of uneven loading and subsequent cracking and movement of stone blocks inside these walls (Adas 2012). This is mainly caused by many factors such as rise of water table that lead to weakening of underground soil layers, loss of bonding characteristics for lime mortar which leads to cracking and stone blocks movement (Adas 2010). The *ta'leeq* process calls for several sequential steps. First the temporary shoring of the upper parts of the walls to ensure structural stability by installation of supports at angle beneath the *taka'llile* in the affected parts of the wall. These supports are generally sections of tree logs cut to size to rest on the floor



Figure 10. *Ta'leeq* of an interior wall (authors).

and secured in a certain manner so the *taka'llile* is not affected by the loading (Adas 2012). The local master mason must start the rebuilding process dealing with lower affected areas and moving upward along the height of the wall.

After finishing and securing the support of the *taka'llile*, the mason removes the affected stone blocks and old mortar from the upper part of the affected area and moves down until the lower edge of the affected area. Secondly, the area is wetted sufficiently and the wall is rebuilt using the same stone blocks and applying new lime mortar, and new layer of lime rendering. The process is repeated in damaged/and or the parts that suffered from movement of stone blocks or cracks. The picture in Fig. 9, shows the local master mason employing *tal'leeq* method by using strong wooden planks as specified by the *ta'leeq* method to shore and support the upper sections of the wall while performing repairs on the façade of a heritage building in historic Jeddah.

As shown in Fig. 10, the method is applied to an internal wall section while supporting the upper part of the wall by temporary support of *taka'llile*. This method saves time, effort, and material. It allows the reuse of the same stone blocks and minimize the need for extensive repair of the wall. The master mason identifies the parts of the walls that need repair and apply the method without any delay (Al-Aidaroos 2015).

4 CONCLUSIONS

Ta'leeq as the major repair method used by the local master masons in historic Jeddah ensures the continuity of heritage buildings in a very sustainable manner. The method has been used and its durability tested throughout the ages in the repair of load bearing walls in historic Jeddah's heritage buildings. The method is validated and robust and it is costs effective, minimally intrusive and sustainable.

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Santal mud dwellings: Materials, construction and space typology

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ABSTRACT: Santals mostly live in Northern parts of Bengal. Santal houses are distinct in the precision of mud construction and style of space formation. Most of the existing studies on Santals focus on the ethnographic, demographic, political and social issues. As such their vernacular construction techniques, use of materials and space typology has been rarely examined. This study explores use of material, construction and space typology in selected villages of North Bengal. From analyzing the space formation of villages it focuses on few selected dwellings to demonstrate these issues in detail. In Santal dwellings the socio cultural dynamics shape the physical spaces. This study attempts to analyze these subtle yet strong relationships through case studies. Structured observation and interviews with locals and experts were used to explore the space typology, process of the construction, use of building material, construction techniques and methods, etc.

1 SANTALS OF BENGAL: HISTORY AND CULTURE

There are about 45 different ethnic minority groups in Bangladesh comprising a population of 1.6 million, which is 1.10 percent of the national population (Sharif 2014). Santals, one of the major ethnic groups of Bangladesh, has been living in the northwest region of Bangladesh for hundreds of years. According to Bangladesh Population Census of 1991, the total Santal populace in Bangladesh is almost 261,746 (Rafique 2015). Most historians assume that the Santals, one of the oldest tribal group of Indian subcontinent came to Bangladesh from Indian state of Bihar, especially Santal Pargana, in search of employment and settlement approximately in the period between 1840 and 1940 (Biswas 1956, Culshaw 1949, Samad 2006). The 1881 census mentions that at that time Santal settlements were already present in the districts of Pabna, Jessore, Khulna and Chittagong (Rafique 2015). They inhabited the plain land of north Bengal (Bulbul 2012, Sharif 2014).

The word 'Santal' is derived from two words; *santa* meaning calm and peaceful and *ala* meaning man (Biswas 1956, K. T. Hossain 2008). Santals have a rich cultural heritage and a distinct cultural identity. Santals practice their ancestral pagan religion (*Sonaton Dharma*) (Anwar 1984, Rahaman 2012). They speak in their own tribal language, Santali (Bulbul, 2012). The Santals are talented in art and crafts as reflected in their beautiful wall paintings on earthen walls, housing architecture and wood works (Fig. 1) (Siddiquee 1984). Subject matter of studies on Santals ranges from ethnographic, demographic, political and social issues. Comparatively, the use of materials, construction styles and space typology has not been properly documented yet; this study attempts to address these issues.



Figure 1. Arts, crafts and cleanliness of Santal dwellings (Author).

2 RESEARCH METHODOLOGY

Few villages of Chapai Nawabganj, Rajshahi in North Bengal have been selected to study the above mentioned issues. The analysis starts from basic space formation of villages and then moves to few selected dwellings to document and analyze these issues in detail. Unlike common rural dwellings, the socio-cultural dynamics play an important role in space formation. The study explores the impact of these intangible elements on the physical spaces. It also explores the subtle variations in space formation in various dwelling typologies through case studies. Interviews and structured observation with locals and experts were used as research tools to explore the space typology, construction process, material, etc.

3 SANTAL VILLAGE FORMATION

Most of the Santal villages are in remote places of North Bengal. During the British colonial era, the *zamindars* (feudal landowners) had initially brought them here, from different areas of central India including Bihar for clearing up forests (Ali 1998, Khandoker 2000, Mondal 2016). According to elders of the tribe, Santals used to own larger areas of land in the northern part of Bangladesh which changed hands over the course of time for various reasons (Khandoker 2000). As a result Santali men and women work as hired day laborers at others' fields (Datta-Majumder 1956, Debnath 2010, Sarker 2014, Shariff 2008).

In search of better settlement and job opportunity, Santals have often migrated to new places where they might find some unclaimed land that could be cultivated (Kochar 1959). Because of this strong community bond, Santals have been able to sustain their traditional values and norms withstanding vigorous contact with external/urban populace since two or three centuries.

Santals live in their own villages as a group. Typically Santal villages (Fig. 2) are laid out on both sides of a street having about 400 to 1000 inhabitants each (Akan 2015). In present days context the Santals don't always get to live in separate villages. Rather they live with various groups; more or less separately in the tribal or low-caste quarters of mixed villages or towns. Santal families often have five to seven children (Hossain, Sadeque, & Shah Qureshi 1984). With parents, children and grandparents, there are eight to 10 people in every household (Adhikary 2010).

Observing Santal villages of Dinajpur, Cano states, "Their houses are made of mud and straw, both of which are cheap materials and abundantly available. They still use these materials because they do not have enough income to buy bricks and metal roofs to build houses…in contrast to other poor villages around the world that do not have waste management, the village was extremely clean without any single paper or plastic around" (Cano 2013).

4 DWELLING TYPOLOGY BY STRUCTURE

Santal dwellings have undergone significant stages of transformation over the years. The simpler single-sloped houses were gradually converted into multiple-sloped. Roofs originally covered with thatch of wild grass were later replaced with tile and galvanized steel in most cases. At present, along with simpler two-sloped roofed houses, there are four (*chaar chala*) or even eight slopes (*aat chala*) houses. Overall, Santals dwellings have a range of forms, from very basic to more complex organizations. However, they can be broadly categorized under the following three basic types:

4.1 *Buruj-khunti Orah*

Buruj-khunti Orah is a Santali word where *khunti* means a post or a piece of wood and *buruj* means a wall all around or a tower. This type of house has a high central post(s) to support the roof. The roof is supported by ridge beams (*orah*) resting on two king posts along both side walls (Figs. 3 & 4). Central post(s) (*buruj-khunti*) is/are placed at perpendicular on both beams. A long timber log (ridge beam) is placed on its top (Hembram 2016).

The ridge beam is generally a combination of two beams of specific size, so that the length of roof and room can be increased when necessary. Santal folklore shows that the use of *buruj* is the result of contact with the Turks who had invaded Santal territory in the past.



Figure 2. Cluster formation of a Santal village (Author).

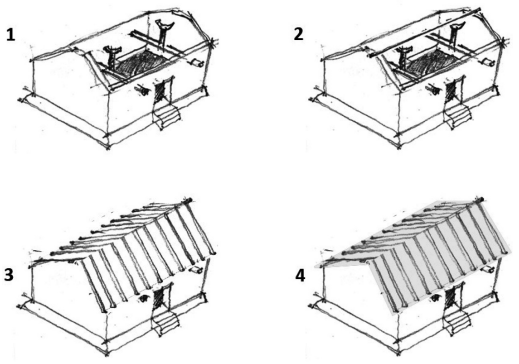


Figure 3. Construction stages of *buruj-khunti* houses (Author).

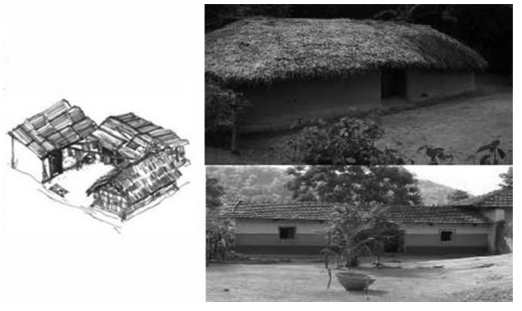


Figure 4. Left & top—*Buruj-khunti* house with hay roof, bottom—*buruj-khunti* house with tiles roof (Author).

4.2 *Aat-chala (House with eight sloping roofs)*

The simpler pattern of *buruj-khunti* houses were enlarged with eight slanting roofs locally known as *aat-chala*. However, the more common variation is known as *chaar-chala* or house with four slanting roofs. In the *aat-chala* variation, the ridge beam is supported on *buruj-khunti* for central load bearing. Here *buruj-khunti* is erected vertically on *'ura'*/*'dharna'* (beam/connector of two-side walls). The ridge beam is connected with *kalkah* (a sloped beam).

The members are tied at the middle by frames named *dhatya kat* and *dasi padh* to hold the frame and the roof (Figs. 5 and 6). *Seners* are the beats or thin members coming down to connect *dasi padh* and *dhatya kat* to hold hay stack, *khapra* or tiles.

4.3 *Raacha orah/gitich orah (courtyard house/ bedrooms)*

In Santali *raacha orah* means courtyard houses, *gitich orah* means bedroom and *daka orah* means kitchen. In this type of dwellings two *buruj-khunti* structures are erected perpendicular to each other

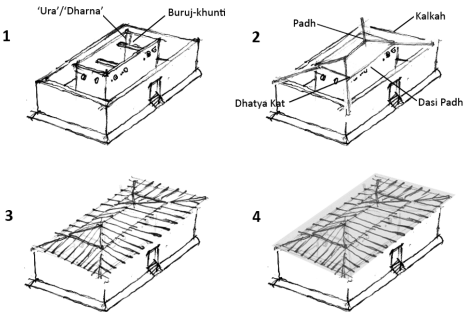


Figure 5. Construction stages of *aat-chala* houses (Author).



Figure 6. Left—roofs of *aat-chala* house and right—roofs of *chaar-chala* house (Author).

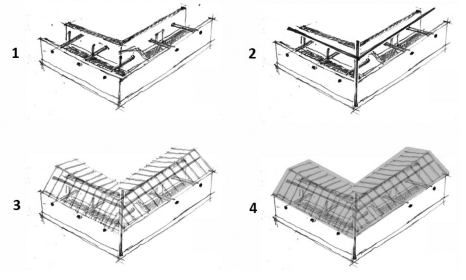


Figure 7. Construction stages of *raacha orah*/*gitich orah* houses (Author).

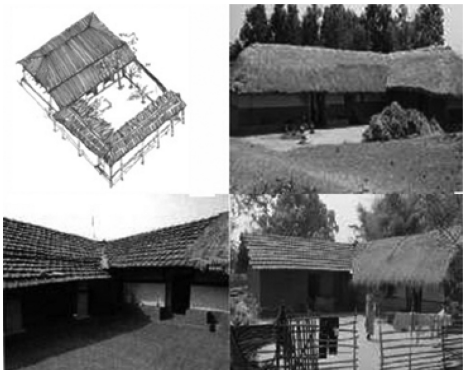


Figure 8. Top—hay roofed *raacha orah* (courtyard house), bottom left—*raacha orah* with tiled roof and bottom right—*raacha orah* with tile and hay roof (Author).

on a horizontal plane over the mud walls (Figs. 7 and 8). Inside the structure, there are *buruj-khuntis* on both wings, one of which is erected on a beam connecting the corners to support two perpendicular beams.

5 DWELLING TYPOLOGY BY SPATIAL LAYOUT

The simpler dwellings of Santals have a length of 7 *haath* (approximately 10 feet), 9 *haath* (13 feet) or 11 *haath* and the breadth of 5 *haath*, 7 *haath* or 9 *haath*. The house is divided into: *bonga orah* i.e place of worship, *gitich orah* i.e the bedroom, *gora orah* i.e the cowshed, *daka orah* i.e the kitchen (Hembram 2016). In Santal dwellings courtyard is the most prominent space of the house. All the daily activities center on the courtyard. An important feature in Santal dwellings is a small domestic garden. Generally the kitchen is situated at one corner of the courtyard, a little detached from the main house proper. In many dwellings, *kuti* (rice stores) is located at a corner of courtyard. The livestock also stay in the courtyards, often housed in a separate wooden structure. From case studies two major types of dwellings can be categorized by spatial layout. They are as follows:

5.1 *Enclosed courtyard single storied*

The first homested has an L shaped layout (Fig. 9). The major spaces are clustered around an irregular shaped courtyard.

The courtyard is enclosed with a low mud wall for privacy. There are a few large trees and a small garden in the courtyard. The small entry to the courtyard leads to an informal verandah used as a living room. The rest of the rooms are laid out in such a manner that the more private spaces are not easily visible.

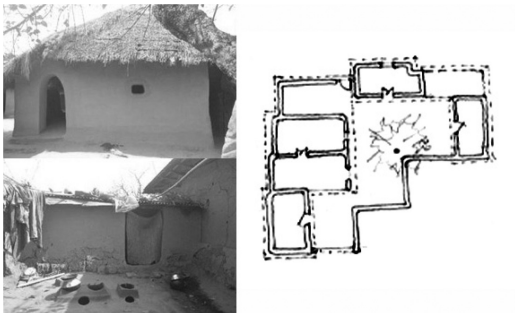


Figure 9. Dwelling of Philip, Lily and Sunil's dwelling (Author).

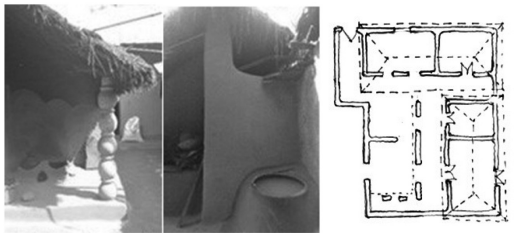


Figure 10. Dwelling of Nachon's dwelling (Author).

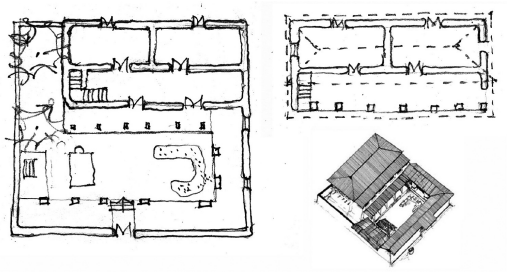


Figure 11. Ground floor and first floor plan and axonometric view of Sharothi's dwelling (Author).



Figure 12. Images of Sharothi's dwelling, source: author.

The second dwelling has columns on the *dawa* (semi open veranda) are decorative (Fig. 10). The rectangular layout has a few bedrooms and a cowshed clustered around a rectangular courtyard. The courtyard is enclosed with a low mud wall for privacy. A small entry leads to the courtyard. A corridor with wall is used for structural purposes as well as to provide privacy to the rest of the rooms. There is a secondary entry beside the cowshed used as a service entry.

5.2 *Enclosed courtyard two storied*

The homested shows both traditional (small openings, enclosed courtyard, arched doorway) and contemporary features (galvanized steel roof, concrete columns, framed windows) (Figs. 11 and 12).

The dwelling has a square layout. An L shaped colonnaded veranda (walled on exterior and colonnaded in the interior) encloses the courtyard. Several service and supporting activities such as storage, cooking, cowshed, etc. take place in the colonnaded veranda and the courtyard. A small entry leads to the courtyard at the center of the L shaped veranda. A two storied structure with a *dawa* opens to the courtyard. There are two bedrooms at each level. The upper floor is accessed with an L shaped narrow mud staircase supported by mud walls. The narrow room in between the *dawa* and bedrooms on the ground floor is used as a multipurpose space. The twin semi-open layers separate the bedrooms from the courtyard and ensure privacy.

6 MUD CONSTRUCTION: VERNACULAR WISDOM IN USE OF MATERIAL AND CONSTRUCTION

Since their earliest ancestral times, entire set of construction materials come from site (from the villages and surrounding forests) in traditional Santal houses (Somers, 1985). The mud and thatch dwellings among the non-Santals differ in appearance from those built in the Santal manner. Santals follow age-old vernacular techniques in their mud construction. Some of the important stages (Fig. 13) are as follows:

6.1 *Preparing the plinth*

Site for most of the Santal dwellings are on plain land as the flat base can minimize foundation work required and also allows maximum stability to the layers of the wall. After the base is cleared and cleaned, spade is used to dig up earth to construct the plinth. Earth is churned with water resulting in mud for stepping. The plinth is left for seven days to dry in sun.



Figure 13. Various stages of mud construction in a Santal dwelling (Author).

6.2 *Preparing mud for wall construction*

Earth collected from vicinity in a pit is then churned with water by stepping, the process is locally known as *chana*. The mud is then dried for seven to fifteen days. The mud is allowed to settle and the pit is covered with clothes or polythene.

6.3 *Constructing the wall*

The prepared mud (chana) is taken from earth pit and is churned again by applying pressure with help of continuous stepping by two to three workers. The churned mud is then dug with spade. Lumps with the cob are formed and smoothed out. Cob is not slapped on, to prevent moisture drawing out of the walls, it is naturally cured. Care is taken to keep the sides straight with hand made rulers. As new layers are added, some holes are poked into the top. When the next layer is added, bottom of it is sinked into the holes for more stability.

6.4 *Wall thickness*

The Santal houses have lower walls than usual rural mud houses. Their wall thickness is generally inversely proportional with the height of the structure. As a thumb rule, the wall thickness ranges from sixteen to eighteen inches at plinth level. Only for two storied houses, which is rather rare; the height is above 12 feet and wall thickness reduces at the upper level to approximately 10 to 12 inches. All the walls (peripheral and partition) are constructed as loadbearing walls.

6.5 *Upper floor*

A mud stair case supported by a wall is provided for vertical circulation to upper floor. All peripheral and partition walls follow the same layout on the upper floor for loadbearing. Rough bamboo or wooden plank floor is used on the upper floor. To reduce noise and ensure privacy of ground floor, a thin layer of mud is applied to cover the gaps of the bamboo or wooden floor.

6.6 *Surface finish*

After the mud wall dries enough, the natural cracks created by seasoning are filled with mud slurry. Several coat of mud slurry is provided on all surfaces. To protect the wall from further cracks, husk of grains are incorporated with the mud slurry during application of the first coating. This layer protects the walls from moisture and rainwater and gives a polished look. After the coating dries up, Santals paint the exterior walls with floral and geometric patterns of various colors.

7 CONCLUSION

Santals have been living in pristine natural surroundings of North Bengal with their distinct lifestyle and culture. The forces of nature influence their culture and dwelling formation significantly. The construction style and space formation studied here is a result of generations of vernacular wisdom. The dwelling typology (by structure and space formation) shows evidence of the emergence of various socio-cultural patterns as expression of their collective identity.

Seemingly simple decisions in space typology and construction techniques have deep rooted meaning. They reflect their simple way of living. This study attempts to uncover various hierarchical stages of their life, starting from the village formation to the smaller details at dwelling level. Even though Santals could withstand the external influences and still maintain their norms and lifestyle until now, things are changing gradually. Amidst this context, it is even more important to document and analyze their authentic way of life, social formation, and vernacular construction style and space formation. Further studies are required to explore other significant aspects of their built environment.

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The study and analysis of the adaptation of earthen constructions in Hadhramaut (Yemen)

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ABSTRACT: The Hadhramaut region located in the southeastern territories of Yemen is well known for hosting an ancient display of native construction techniques. In addition, it has recently captured the attention of researchers because of its ability to meet recommended environmental standards. The considerable approval of the international community regarding its potential future benefits has led to a more widespread use in the sphere of contemporary construction (International Congress on Housing, Ural, and Krapfenbauer, 2013 1005). This paper elaborates the study and the in-depth analysis on the adaptation of earthen construction in Hadhramaut in Yemen, placing a primary focus on advanced areas of construction, as well as primary conservation techniques.

1 INTRODUCTION

In August 2014, a study visit was conducted in the mountainous regions of Yemen. The primary focus of this visit was to guarantee an elaborate and conclusive inspection and in-depth study of the local earthen architecture. Additionally, the study aimed to examine the primary construction techniques in the Hadhramaut region. This initial and productive study of popular mud brick architecture was carried out in Tarim and Shibam. These major cities, with their well-established local commercial institutions and skyscrapers built using readily available mud bricks, stand out in the region, as they are easily accessible within the valley.

Construction with mud brick in the region of Hadhramaut has long been present and local builders have been admired worldwide for their primary role in maintaining higher environmental standards (Cooke 2015: 217). Part of the research involved comprehensive interviews with locals and contractors to further the in-depth understanding of the discipline. The incorporation of westernized construction technology and its incapacity to resist the harsh conditions of the Hadhramaut climate has further contributed to a revival of the ancient use of earthen materials which has proved fruitful, especially in the reinforcement of contemporary cement and glass technology.

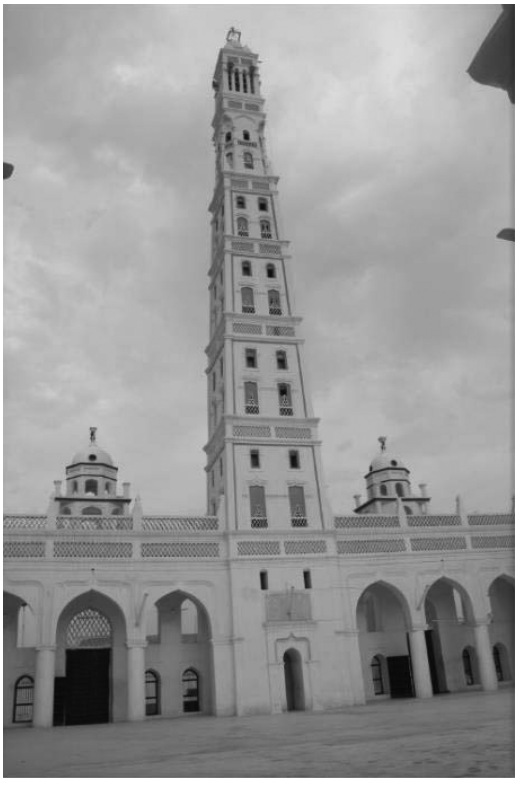


Figure 1. Mihdhar Mosque in Tarim (Alaidarous).

2 HADHRAMAUT, YEMEN

Yemen, an independent state, is home to three major cities of Seyoun, Shibam, and Tarim, located in the vast Hadhramaut Valley. The Hadhramaut valley has gained considerable admiration worldwide for its vernacular constructions and architecture, which have survived centuries of development and major revolutions in terms of building and construction architecture

(Carswell 2012: 765). Some of the cities have attracted international attention as the home of the renowned Museum of Hadhramaut as well as housing the local offices of the well-known General Organization of Antiquities and Museums characterized by the massive expanse of mud brick constructions. In contrast, Tarim, like other cities, has not gained much public attention but is well-known as the home of the massive Mihdhar. The mud-brick construction of the Mihdhar is well known as the tallest in Yemen. Tarim is also home to the earthen mansions possibly constructed in previous centuries and reserved for the wealthy. Therefore, earthen material constructions in Hadhramaut have gone on to nurture the art of the Tarimi masons, local carpenters and the famed crafts in lime that have been successfully passed on and preserved through the generations. This has further helped in the preservation of possibly 80 percent of these skills to date.

3 EARTHEN CONSTRUCTION IN YEMEN

Given the harsh climate of Hadhramaut, the economy of the valley is largely dependent on the earthen material industry. The solid expertise in the Valley regions of Hadhramaut is often readily and cheaply available, unlike that in the West. Modern constructions that would require Western reinforcements such as steel bars or other artificially produced materials often cost up to 31 percent more than the original cost. As opposed to construction procedures in other parts of the world, in Hadhramaut, the general skeleton of the intended construction is often drafted by the individual responsible for initially commissioning the construction. The main ground floor and that immediately above it are often constructed from adobe (Roy 2006: 19). The ground floor of the construction is often designed incorporating an adobewall 3–4 meters high. Additionally, a foundation wall in the recommended height and width for a specific thickness frequently incorporates adobes at ground level. The walls of the subsequent floors tend to be constructed to ensure that they are less thick and higher. The second floor is often characterized by stretcher coursing in a deliberate design.

Some of the research findings were primarily obtained through consultation. Most of the locals in the valley held similar views on earthen material constructions in the Hadhramaut region, leading to immediate conclusions on certain fundamental principles and views. Some of the local views stressed the fact that some earthen houses were of considerable spiritual value to the locals. The majority held that these reflected the personal contributions of dedicated, skilled, passionate, and hard-working individuals to the immediate environment that was to be their residence. Others similarly felt that the grouping of earthen housing could be the source of a sense of importance and value for local residents, helping young people to develop self-discipline. This promoted a more rapid transfer of skills between individuals through observation, in opposition to the West where the monopoly of skills is geared to the market. Additionally, such regional earthen construction projects promoted individual self-esteem which was important to the development in other areas of culture and to better the entire community. Communal earthen house constructions also played a major role in promoting the renewal of the community spirit which was key in the successful constructions of earthen structures, especially mud brick skyscrapers.

Earthen constructions are generally naturally insulated (Rael 2009: 39). This gives earthen houses an initial advantage of all-weather seasons by structurally promoting warmth in the winter season and cooler atmospheric conditions during the summer season. As opposed to Western constructions, mud brick houses are more durable and resistant to external threats from nature and atmospheric conditions. They are stronger when constructed to standard, a claim backed by their proponents who point out that they have the structural capacity to withstand higher magnitudes of earthquakes. It has been established that earthen houses contain limited basic chemical compounds and therefore the low risk of allergic reactions makes them recommendable worldwide. The primary cost of building mud constructions is limited and relatively affordable compared to the cost of contemporary Western structures characterized by the initial acquisition of commercial products which are often expensive in relation to labor costs, usually the primary cost in the construction of mud houses.



Figure 2. Adobe molding in Tarim (Alaidarous).

4 CONSTRUCTION AND BUILDING MATERIALS

In the Hadhramaut region of Yemen, sun-dried mud bricks are widely incorporated in the building and construction industry. The primary component of the product is often a mixture of chopped straw, water, and soil. These materials are measured, manually mixed, and molded to form standard blocks which are often in recommended sizes. These molded bricks are then dried in the hot sun, usually for a period of a week or more depending on the nature of the constructions and the local conditions, which can vary from one region to the other (Sayigh 2014: 505). The current blocks are of good quality despite being more likely to crack as the straw rots. In order to guarantee the durability of these buildings, each floor is often made manually sandwiching these hardened blocks between the initial stone foundations, built in courses dampened with lime. These bricks are characterized by a greater degree of protection and ease of construction compared to concrete blocks and baked bricks and mostly stand out for their ability to last longer provided that the uniform external layer is kept intact.

During construction, width and height are structurally varied to ensure a uniform distribution of the compressive strength across the construction arising from a diagonal demarcation. Each wall after ground level is therefore thinner than the preceding one. Subsequently, Tephrosia Dura is incorporated into every fifth course of adobe during construction to help increase the primary tensile strength. The prime material used widely for the purposes of interior decoration is the famous earth from Shinnan. The renowned Tarim constructors are divided into three major groups for the purposes of convenience, those responsible for the constructions, then the Hadrah who do the lime rendering, while the third and final group is often mostly responsible for the task of renovation. Fired clay from Shafaq is regularly incorporated into ceramics but mainly used for the claustra screens finishing off the roof parapets. Mud extracted from date palm soil is mixed into a smooth paste with available manure and other materials before firing.

The main conservation techniques also often involve the application of basic methods to ward off the effects of progressive damage. Additionally, they are often incorporated to occasionally help in the repair and subsequent restoration of already



Figure 3. Shibam buildings (Alaidarous).



Figure 4. Restoration work in Aljonaid house in Tarim (Alaidarous).

damaged points (Cooke 2015: 191). In order to ensure that the quality of the initial structure is maintained, it is important to guarantee that the main techniques involved in the restoration of dilapidated earthen structures are well considered and implemented. In addition to the above, a comprehensive history should also be edited to accurately establish primary flaws. A team of competent experts should also be brought in for wider consultation to guarantee that the proper channels and laws of nature are taken into consideration in order to boost the probability of success in the event of restoration.

5 RESTORATION TECHNIQUES

Before considering the elements used in the restoration, especially in the case of cracks, it is vital to first analyze the basic factors that have led to the formation of the cracks. Efficient functional data collection relating to the surroundings and original foundations should be ensured. After establishing this causative method, it would be advisable to proceed with the best possible restoration actions incorporating heightening or repairing, thus avoiding methods that would repeat the initial problem and subsequently promote the appearance of other secondary structural malfunctions.

Following the temporary reinforcement of the structural elements in Hadhramaut, precise data are gathered on its subsequent state and the affected structure is fully described. For instance, it is important to first ensure that temporary shoring is given adequate room prior to the repair schedule. The causes of the pathology should be definitively established. These could result from natural factors such as rain erosion or temporary overloading, or could also be the possible result of different soils in the foundations promoting compacting reactions. It has also been established that walls with relatively high levels of humidity are more prone to possible collapse as a result of the formation of cracks. Shoring is employed primarily when it is not possible to successfully repair damaged points. Additionally, it is often used when renovating buildings which are structurally weak and in danger of collapse.

There are occasionally problems with foundations in Yemen when the foundations of the structure in question are defective and in need of urgent renovation. When these structural problems arise it is advisable to direct most of the restoration toward the possible improvement of the basic foundations and subsequent incorporation of standard procedures, further aiding the modification of the affected soil properties. It is important—at times crucially so—to adequately examine the secondary movements possibly resulting from the deformation of the primary structure. In-depth examination often helps in the initial determination of the nature of the movement, ascertaining whether it is mostly in the affected foundations or in the ground itself, which would subsequently increase the risk of future damage. Basically, it is vital to take measures to reduce movements in the affected ground before incorporating any further principal mechanisms. This is because any attempt at restoration prior to measures stopping ground movement would be futile and ineffective. The repair process should therefore effectively and efficiently incorporate the experience of local builders with a knowledge of earthen behavior.

Foundation repairs are often necessary when there is a change in the design in the intended use of the primary building, in the unfortunate discovery of a possibly weak foundation, and finally, when there is a change in the structure and the properties of the affected soil. Any major process involving the foundations could either be directed at the possible repair of the affected part or address the whole with a general and more effective replacement. The restoration process can be conducted by increasing the depth of the foundations using an extra layer of soil which is harder and more stable than the original. The repair process could also be successfully achieved by augmenting the width of the foundations. This adjustment would reduce the stress experienced per unit region by effectively distributing the resulting weight across a wider surface area in the structure. In the above processes maximum care should be taken to ensure primary protection of the earth foundations from the actions of natural water below causing rising damp. Subsequently, jet grouting could be effectively used to ensure the improvement of the ground directly below the affected construction.

The holes and gaps often seen in walls are caused by erosion from moisture, the expansion of unfilled holes and cracks and frequently from accidental damage involving humans and animals. The moisture resulting from humidity generated by surface vegetation encourages efflorescence deposits and also contributes significantly to the initial formation of gaps and holes. Filling these spaces with earth mortar and adobe is not recommended since it exacerbates the formation of other secondary defects resulting from spontaneous reactions. Repairing holes and gaps in mud walls is not easy because the materials tend to contract as they are drying due to water evaporation and subsequent compaction from overloading. This shrinkage can be reduced when gaps are filled with sand from sandstorms followed by rain or with other more efficient methods which involve adding sand to the initial mortar to stabilize mud.



Figure 5. Lime rendering protecting roofs of Shibam houses (Alaidarous).

When collapsed sections of wall are reconstructed they are uniformly rendered once the new materials have dried off. An initial water-resistant barrier is needed to protect the wall from the action of water. Another effective permanent solution to erosion in walls is the use of interlocked baked clay tiles and slates or lime rendering on rooftops.

6 CONCLUSION

The above outline of initial details on the areas where construction and effective preservation techniques are employed in the region of Hadhramaut, Yemen, is drawn primarily from observation, followed by one-on-one interviews with the local population. Cross-referencing was incorporated prior to the detailed report for purposes of accuracy. From the above, it is patent that the ancient constructive techniques used to date are equally effective and should thus be incorporated into modern techniques producing a better more durable housing structure able to withstand the harsh climate. This could be achieved by either reinforcing contemporary techniques with ancient ones or adapting ancient techniques to modern methods.

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Vernacular houses of Stratonikeia: Architectural typology, materials and techniques

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ABSTRACT: The historical site of Stratonikeia is settled on the west of Turkey. It is acknowledged basically by its ancient ruins, however no more insignificant than the monumental ancient remains the vernacular houses standing on and nearby the site display distinguishing properties. This study aims to put forward these properties of the vernacular houses enriching the heritage values of the historical site. Vernacular houses are formed very primitively by native people under the guidance of illiterate builders, and with the help of simple tools and materials. Behind the apparent simplicity and beauty of them there is a reliable information-transmission system that works by the codes in the minds of the native builders. The aim of this paper is to decipher these codes by identifying the building patterns of the vernacular houses. Its contribution to knowledge intends to establish a holistic approach for the conservation and sustainability of Stratonikeia as a multi-layered historical site.

1 INTRODUCTION

Stratonikeia is a multi-layered historical settlement which displays distinguishing togetherness of ancient remains and vernacular houses within a magnificent natural landscape. The settlement is located at Yatağan district of Muğla province on the west of Turkey. This rural area is 37 km far from the city center and surrounded by hills on the south and a coal mine on the north side (Fig. 1).

The vernacular village (Eskihisar meaning old_ castle) is settled over the archeological ruins of Stratonikeia which is considered as one of the most important settlements of Caria Region at Hellenistic period. The history of the area dates back to Chalcolithic period and it's still possible to see the finds of Hellenistic, Roman and Byzantine periods on the excavation site. Thereby the rich ancient remains the site is acknowledged basically as an archeological site however it is proposed to be evaluated as a multi-layered cultural landscape regarding the diversity of the heritage it comprises (Avsar & Genc 2016). Vernacular houses are integral part of Stratonikeia no more insufficient than the ancient remains. The outstanding property of the site is the togetherness of various examples of heritage from different historical periods. There is considerable amount of studies about the ancient remains. However, the vernacular heritage of the site has not got the attention it deserves yet. In this study, it is firstly aimed to evaluate the architecture of the vernacular houses of the site entirely, second underlie the importance of it in conservation studies of Stratonikeia and third contribute to the documentation of rural heritage of the region. The methodology of the study is constructed mainly on site survey. The plan types, layouts and building materials of the vernacular houses were examined on-site and then analyzed in comparison with their similar in the region.



Figure 1. Location of Stratonikeia (Google earth).

2 STRATONIKEIA

The archeological research on the close region around Stratonikeia reveals that the area has preserved its importance since Chalcolithic period.

Its special location in between important cities such as Alabanda, Alinda, Aphrodisias and Halikarnassos and its rich natural water supplies and fertile land have provided it to be inhabited continuously. The oldest finding in the excavation site is a grave which has been built at 2000 BC. Among the other ruins and traces of following centuries, it's obviously seen that the monumental structures had been built during Hellenistic period and reached its glorious period at 2nd century AD. The ancient city of Stratonikeia had a Hippodamos grid plan. The unearthed buildings of Hellenistic and Roman Periods are North Gate, Basilica, Gymnasion, Bouleuterion, Roman Bath, Augustus Temple, Agora, Amphitheater, West and North City Walls and Colonnaded Road. After AD 325, by the Christianity period, new constructions and renewal of old Roman buildings started and the city reached its largest area and population during the early Byzantine period. Despite this enormous growth, the regression of the city begun at the second half of 7th century AD due to several wars and disasters like earthquakes and epidemic. However, the city managed to survive by means of the opportunities it had due to its special location (Söğüt 2016: 1–4).

By the Principalities period at 13th century AD, the settlement moved from the north-east side of the city towards the north-west side and developed around the water supplies. It reached its glorious period again—after early Byzantine—by Ottoman period with its new name Eskişar (old_city). The layout of the village was shaped at this period with its religious and public buildings and vernacular houses within the natural landscape. By the Republic period, the village had its new name Eskihisar (old_castle), and preserved its vernacular architectural heritage with the addition of new buildings. Although the village was one of the most advanced settlements around, the earthquake in 1957 brought about the migration of the villagers to the north side of the settlement. Then the exploration of a widespread coal mine under the settlement encouraged the second migration to the new village constructed by government. Even so, some inhabitants stayed in the old village which was excluded from the coalmine activities because of its architectural and cultural heritage value. Today although there are a few families who continue to live in the village the settlement is substantially abandoned and need urgent precautions for its preservation.

3 VERNACULAR HERITAGE OF THE SITE

3.1 *The village*

The vernacular village of Eskihisar (old_castle), standing on the remains of Stratonikeia, is one of the specific examples of the traditional settlements of Ottoman and early Republic period in terms of its original architectural character and fabric. Evliya Çelebi, the famous Ottoman traveler of the 17th century, describes the village as a settlement of houses with flat soil roofs in big gardens surrounded by a beautiful natural environment of greenery and wetland. (Çelebi 2005: 108). The sinuous streets are shaped amongst the stone garden walls behind which the olive, pomegranate and fig trees are located around one or two storied houses. The organic layout of the village provides surprising spaces and vistas as the narrow streets connect to small public squares or reach spectacular landscapes.

The entrance to the village is on the west part of the settlement through the traditional square (Fig. 4). The square that is covered with authentic stone pavements and shaded by historic plane trees, is surrounded by buildings of recent history. The Seljuk Bath, Ottoman Mosque, traditional coffee houses and shops like bakery, tailor, dentist, smithy, shoe shops are placed around this impressive square. Although abandoned today the presence of vernacular traditional buildings together with the religious public buildings reflects the



Figure 2. Aerial view of the village showing remains of ancient gymnasium and the vernacular houses together (Stratonikeia excavation team 2016).



Figure 3. Ancient remains and rural houses together (Stratonikeia excavation team 2016).



Figure 4. Village square with traditional shops and plane trees (Stratonikeia excavation team 2016).

wealthy social and economic life of the settlement. It is still told by the elderly of the region that the village square of Eskihisar was a famous trading and social area visited by the locals and for example the famous tailors of the notables had shops here. Both the standing architectural heritage and the oral information gathered around reveal that Eskihisar has continued the importance of its ancestor, ancient Stratonikeia, although it reduced in size and scale.

3.2 *Vernacular houses*

Vernacular houses are buildings that respond to the basic requirements of their owners together with the restraints of locality and climate. They are, developed by ordinary people, to maintain their physical life but while doing this they also develop a harmonious relationship with their surroundings. The builder does not draw the building but he definitely knows how and what to build as he learns from his ancestors. A building as an outcome of craftsmanship is transformed gradually through innumerable mistakes and successes in many centuries within a process of trial and errors. At the end of this slow and patient search, an amazingly well-balanced structure, also responsive to the user's needs, is produced (Aran, 2000).

Locality that points to a unified perception of all characteristics of terrain, climate and water resources is an overall concept in evaluating the vernacular architecture. What determines the positioning of a building is its locality. The native people carefully position their houses on the ground and also they prepare the ground for their houses. The site gives the building its orientation in relation to the other houses, to other settlements and to the landscape. Climate has a complementary role in the formation of a building. The locality is selected and prepared for building, but climate is to be controlled by the building (Aran, 2000). Running from the above suggestions the vernacular houses of Stratonikeia will be evaluated according to their locality which determines the building patterns encoded in the minds of the native builders.

3.2.1 *Form and design*

The success of vernacular houses is related to the fact that the builder and the indigenous people have to choose between a limited number of alternatives which are away from the artificial restraints of modern tastes and styles. The vernacular house is simple and functional. The priority of the indigenous people is to house in a shelter responding to climate, ground, their agrarian requirements, and cultural praxis.

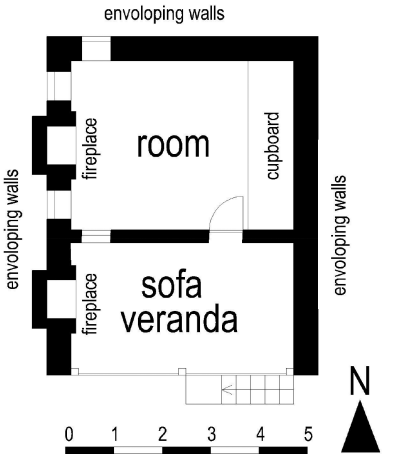


Figure 5. The plan of the basic unit.

Basic unit: The simple and basic unit observed on the study area is composed of a square room and a veranda in front of it. This unit is fragmented into its building patterns.

1. U shaped enveloping thick stone walls
2. Square room with a fireplace
3. Rectangular shaped semi-open veranda (sofa)
4. Elevated wooden floor
5. Bulged fireplace with flanking windows
6. Entrance through south and courtyard
7. South, southwest facing courtyard
8. Pitched roof with tiles

Enveloping thick walls protect the house from harsh weather conditions and wind from north direction while ensuring a comfortable inner space for the household. Narrow windows are placed especially on the opposite direction of the predominant winds preferably through the landscape. The enveloped inner room is a multi-functional space used to sleep, cook and eat. The fireplace placed on the opposite side of the door is used for both cooking and heating. A wooden cupboard is suited behind the door which is used for granary and storage. The adjacent side wall of the room to the sofa (veranda) is thinner, timber framed and filled with mud-brick and a window is certainly placed near the door.

Rectangular semi-open veranda (sofa) is as important as the inner room for the rural people. It is not only a transition space but also a semi-public space where the household greet their guests. Insofar,

as the weather conditions permit, it is cooked, meals are held and household gather on the veranda. On some examples, a wooden balcony project through the courtyard which is privatized for washing dishes or sitting area. Most of the verandas observed on the village are now enclosed with timber framed walls.

Both the floor of the veranda and the inner room are elevated from the ground by bearing on the body walls in order to isolate the living spaces from ground water. By this way an empty space is obtained under the wooden floor which also works as a thermal insulation board.

Bulging fireplace with flanking windows is a consequence of the inner design of the room. The fireplace is pushed outside in order to gain a precise and defined inner space. On the other hand, two windows are placed on both sides of the fireplace which let the people sitting or cooking view outside.

The entrance of the house, accordingly the veranda, faces south or south-west direction which thereby allows sunshine and daylight enter the inner room and veranda during the whole day. Thus, a comfortable living area is obtained. It can be conveniently proposed that the orientation of the house through south direction is a constant rule in the mind of the native builder.

The courtyard developed around the houses in varying sizes may be evaluated as an extension of the house rather than an independent open area. The house of the indigenous people is not only the enclosed shelter but the whole close, semi-open and open areas defined in the courtyard. Thereby the design of the courtyard is as important as the house itself. All the enclosed spaces, either the house or the storage & barn, are preferably settled adjacent to one side of the courtyard in order to obtain a practical area for horticulture. A caisson well together with a small storage pool is constructed on somewhere near to the house. The immediate open area in front of the house, adjacent to veranda is usually paved with stones in order to keep the inner living spaces from mud and dust of the garden and it is preferably shaded by a grape arbor as an extension of sitting area of veranda. The courtyards are defined with high stone walls in dense neighborhoods whereas through the sparse areas they are hedged under eye level.

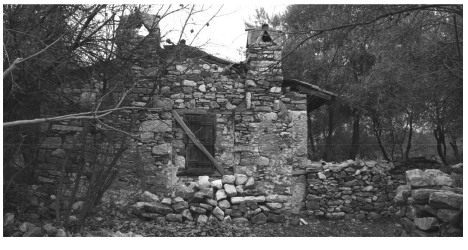


Figure 6. View of a basic unit from west direction (Authors 2017).

The roofs of the basic unit are now observed as pitched and tiled however it is widely appreciated that they had been flat roofs covered with mud until the introduction of tiles to the region.

Consequently, it may be proposed that in building a basic vernacular house in Stratonikeia the basic codes in the minds of the native builders which determine the form and design of the house together with the settlement are grouped in four items; 1- The orientation of the house through south. 2- The U-shaped enveloping walls protecting the inner spaces from weather conditions, 3- Elevating the floor of the house from the ground and 4- Leaving a practical area around the house for horticulture.

Variations of basic unit: The vernacular houses which seem to have different plan types than the basic unit are proposed to be evaluated as variations of it because the building patterns mentioned above are valid also for them. What differs is basically the size and need of the family for additional storage or living areas.

The common solution for an additional storage area is elevating the ground floor up to 2 meters. In this case the house can be evaluated as a two-storied basic unit where the veranda on the ground floor is usually closed but on the second floor it is left open (Fig. 7, 8). The solution for an additional living space is observed by duplicating the basic unit horizontally (Fig. 7). In this case the semi-open veranda elongates to cover both of the facades of the inner rooms. In a few examples, horizontally-duplicated basic unit is built in two stories where the ground floor is again left for storage or barn for animals.

3.2.2 *Houses of landlords*

The basic unit proposed as the prototype of the vernacular houses of Stratonikeia and variations of it respond to the requirements of the rural

Table 1. Relation of building patterns of the basic unit with the determinants.

	Climate	Ground	Function	Building materials
Walls	+			+
Room		+	+	+
Veranda	+	+	+	
Elevated floor		+		+
Fireplace			+	
Entrance	+	+		
Courtyard	+	+	+	
Roof	+			+

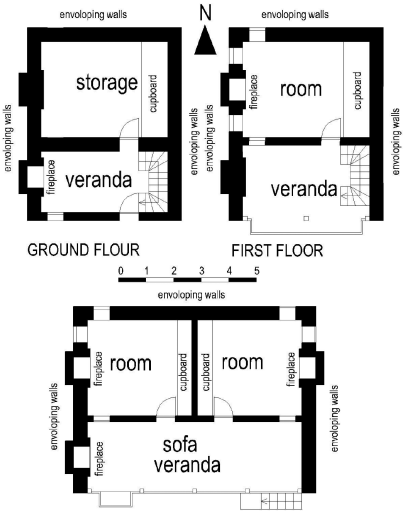


Figure 7. Variations of the basic unit (Authors 2017).



Figure 8. Basic unit with the additional storage on the ground floor (Authors 2017).

people and built by either native builders or the owners themselves. However, the houses of the landlords who are the notables of the region as directors display different characteristics. Their houses respond more to the requirements of ruling class than the rural people. On the other hand, these houses are usually built by the famous masters of the time who are specially assigned to reflect their own tastes and styles by the landlords. There are three landlord houses still standing on the village. All of them are two-storied, relatively very big, made of cut stone or rigorously plastered and constitute a cluster including independent servant and guest houses, barns, special bathrooms etc (Fig. 9).

3.2.3 *Building materials and techniques*

The vernacular houses are masonry structures constructed with basically stone and timber. The enveloping thick walls are made of rubble stone,



Figure 9. House of landlord Abdullah Aga (Authors).

sometimes jointed with brick, and always supported by bonding timber. The wall between the inner room and veranda is timber framed which is filled with mud-bricks or rubble stone. The corners of the enveloping walls are edged with cut stones or marbles which are quite likely the re-used ancient materials in order to stabilize and strengthen the structure. The garden walls are also built with rubble stone, usually attached to an outer wall of the house. Chimneys are typical elements of the vernacular houses ascending on the narrow side of outer wall and made of rubble stone, and covered with a characteristic tile cap. All masonry stone walls are bound with lime and earth mortar, and the surfaces are left un-plastered. The only plastered outer surface is the timber framed inner wall between the veranda and the room. Also on the examples of duplicated basic units, the inner wall between rooms is timber framed, filled with mud-brick, and plastered.

The floors are made of timber beams and covered with wood sheathing. The houses have hipped roofs which are also constructed with timber elements and covered with traditional roof tiles. The window and door frames are all made of timber like most of the other finishing and decoration elements such as cupboards, inner staircases, and window shutters.

As the settlement is deserted, the houses have various deteriorations due to weather conditions and lack of maintenance. On the other hand, this situation makes it possible to observe the original details of the building materials and techniques, as they haven't faced any harmful interventions.

4 HERITAGE VALUE OF THE VILLAGE AND ITS SUSTAINABILITY

The historical background of the village starting from 2000 BC and its multi-layered character distinguishes it among all other vernacular settlements in Turkey. Its heritage value does not only rely on the archeological remains or rural natural/vernacular environment but the association of all. This exceptional formation refers to the term 'cultural landscape' which is defined

in World Heritage Convention 1992 as 'a diversity of manifestations of the interaction between humankind and its natural environment'. Regarding the integrity of its values, Stratonikeia may be proposed as an "associative cultural landscape" depending on the third category of the convention.

The inclusive definition of the village as a 'multilayered cultural landscape' requires extensive asassessment of its values to determine the proper conservation principles and providing its sustainability. Its identity value emerges from the unique togetherness of ancient remains, monumental buildings, vernacular houses, traditional buildings, fertile fields, and natural environment. And this identity can be preserved by the appreciation of all items at the same level, without putting one above another.

However the dominant perception of the village as an ancient archeological site before both the laws and locals has grown the basic dilemma for its sustainability and preservation. In Turkey heritage preservation laws give prior importance to the archeological sites before the subsequent settlements on or nearby them. Therefore Stratonikeia is officially defined only as an archaeological preservation area and except the registered monumental buildings there is no existing policy for the conservation of vernacular fabric. Fortunately the archeologists and the conservation experts working on the site are aware of its importance as a multilayered historical site so they are trying to develop a balanced way of conservation attitude. Besides their primary works on ancient finds they have restored two of the landlords' houses. But the endeavor of the team can only provide a single building preservation, not the integral conservation of the whole.

The Charter on The Built Vernacular Heritage 1999 indicates the serious problems that vernacular settlements face globally and explicates the importance of inter-disciplinary studies. Besides the indicated global factors, due to its location and formation, Stratonikeia has faced unordinary incidents, such as migration, which has caused rapidly increasing deteriorations of buildings. The vernacular houses and other traditional buildings need to be maintained/repaired/restored and re-used/refunctioned/exhibited in a short period. There are various factors, either tangible or intangible, that should be considered to achieve appropriate and comprehensive conservation decisions.



Figure 10. Stone work of the vernacular houses (Authors).

Paul Oliver argues that vernacular architecture is sustained architecture, sustained over generations by the persistence of traditions, but subject to appropriate modification as changes in the needs of different societies have arisen. The vernacular village of Stratonikeia has been emptied but the locals still continue to farm on their lands, which may be utilized as an advantage situation for the re-use of the abandoned houses. It is clear that the most functional and efficient way of sustaining vernacular houses is to let their locals continue to live in them in one way or another. In the studies for the sustainability of the village the prior method may be proposed first to make a profound research and a conservation management plan accordingly.

5 CONCLUSION

In this study, first the vernacular houses of Stratonikeia has been researched in order to understand the inherent design principles encoded in the minds of the native builders. The proposed prototype as basic unit is the primitive house responding to requirements of the indigenous people together with the locality and climate. The building patterns deciphered in the design of this unit are valid for all the variations and they draw the basis of the guidelines for the experts who will keep studies for conservation and preservation of these houses. Secondly, the heritage value of the village as a multi-layered historical site composed by various heritage buildings from different historical periods is insistently underlined. The aim of the authors in doing this is to take attention to the interpretation of heritage in Turkey that values ancient and monumental buildings more important than the vernacular ones. Stratonikeia displays a unique laboratory for heritage experts who intend to tackle with the conservation phenomenon by standing at an equal distance to all historical and cultural experiences of the humankind.

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Ksar Taghit: Earthen architecture between authenticity and changes

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ABSTRACT: Taghit is a ksar in a small oasis town; it highlights the know-how on which the architectural typology of the place is based. The fortifications provided a good defense system, the public spaces reveal a rich community life, the road network and the building materials reflect an optimal management of the harsh climate. This secular symbiosis between built environment and ecosystem is nowadays threatened by an inadequate urban development. Socioeconomic changes have given way to uncontrolled introduction of inappropriate building materials and equipments, which have pushed the occupants of Taghit away from the ksar. This situation is causing multiple damages to the buildings and the ruin of most of the town. It is clear that this heritage must be protected to enable future generations enjoying this ancestral legacy. For this reason, this paper wishes to describe the potentialities of Taghit as well as the first actions required to maintain this threatened place.

1 INTRODUCTION

Earthen architecture is one of the most original expressions of man's ability to shape his environment by valorizing the use of local resources. It plays a preponderant role in the revelation of local identities and presents perennial construction techniques. It is attracting increasing interest because it allows achievements that contribute strongly to social, cultural, environmental and sustainable development.

In Algeria, the populations of arid zones have long been developing coping strategies with their hostile environment. They have designed their living spaces in an intelligent way that meets the geographical, climatic and cultural requirements of the region; using local materials often earth that has asserted itself in the field of urbanism and architecture by a perfect adaptation to the site.

The Ksour are part of the human creations in which the human genius manifests itself: built using earth, those ancestral cities of the desert do represent an inestimable source of reference with their ingenious durable architectures. The noticeable presence of specifically local signs and paradigms reflects a socio-cultural and an eco-systemic context, and an outstanding landscape (Abdeldjebar Layachi 2016). Moreover, being a transit of the great desert caravans, linking North Africa to the rest of the continent have made of the city of Taghit a strategic area in the south-west of Algeria.

This architecture embodied a great expertise that fitted perfectly into this hostile environment. Yet currently many factors led to the degradation of the site.



Figure 1. Aerial view of ksar Thaghit.

Most notably, natural aging, abandonment and the dramatic lack of maintenance rearrangements by the introduction of incompatible materials. These factors may well bring about the loss of the architectural know-how that characterizes the site.

This research paper is part of a doctoral thesis in architecture, which aims at the valuing and appreciation of the constructive know-how related to the earthen architectures of the ksour of the south-west of Algeria. In order to approach this study several observations have been adopted and investigations and interviews supported by critical reading have been conducted.

2 TAGHIT OASIS, A RICH AND DIVERSIFIED ECOSYSTEM

2.1 *Strategic location*

Taghit is a small oasis in the desert regions of Saoura, more than 1000 km South-West of the capital city Algiers and less than 90 km south of Bechar province (Fig. 2), at the east of old trans-saharan trade routes connecting Algeria to Niger.

2.2 *Remarkable natural and architectural potential*

Taghit comprised several ksour, from which the ksar of Taghit is the only one remaining, therefore listed as national architectural heritage and a palm grove which extends on 20 km along the bank of *oued* Zouzfana between mount Baroun and the dunes of Grand Erg Occidental.

Its Saharan climate is known for its aridity with weak and irregular precipitations, sometimes causing a flooding. Besides its high temperatures, it is characterized by intense luminosity and strong evaporation.

Taghit is a luxuriant environment where water, vegetation, habitation and men constitute a rich ecosystem Appreciates of:

– Its natural diversity: palm grove of more than 120,000 date-palms, oued Zousfana, Djebel Barroun, dunes of Grand Erg Occidental, flora (Acacia, Tahla, Rtam …), fauna (scorpions, sandfish..), birds (Oriental turtle dove, lanius..), animals (Jerboa, Gondi, Fennec, Gazelle…)..
– Its humain establishment: rupestral engraving, underground living, ksour (Taghit, Zaouiya el fougania, Berrebi, Bakhti, Zaouia el tahtania...)

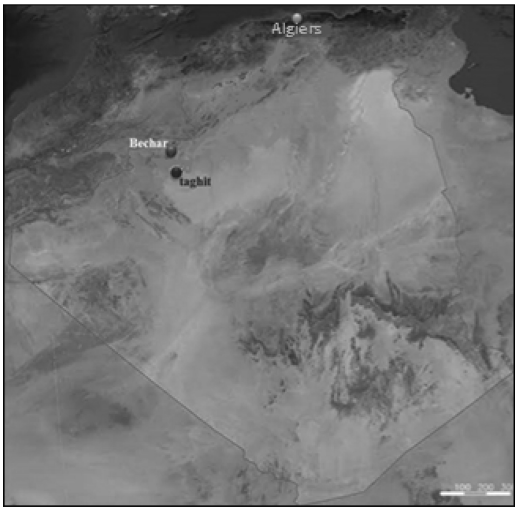


Figure 2. Border town offer possibilities for trade exchanges.

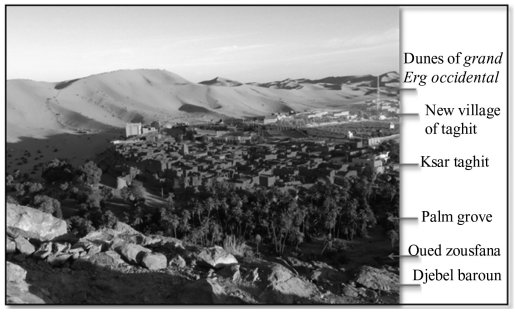


Figure 3. Harmonious integration in the landscape.

3 KSAR TAGHIT, MILLENIAL LIFE CENTER

Ksar Taghit was built in the 14th century in red earth on rocky plateaus dominating oued Zousfana and its palm grove, west of the dunes of Grand Erg Occidental (Berbache Wahiba 2012).

The outer wall is pierced of two gates: *gabli* (southern) and *chargui* (eastern). It warrants both the defense of the community and the social unity of the ksar.

It contains about 120 houses, a mosque, and a public square (*tadjmiit*) which opens on two other squares (Berbache Wahiba 2012). These places have an important social and economic role; they concentrate most of the encounters and exchanges, in particular the commercial ones.

The road network branches out from the main street (*darb*) to narrow alleys (*zqaq*) which serves impasses leading to the habitations. Most of those streets have an offset design. But this tree organization allows for progressive transitions from public to private spaces. Thus, the qualities of privacy, hygiene and comfort are preserved (Moussaoui & Abderrahmane 2002) (Fig. 4).

Ksar Taghit did not result from prior planning, but as the other ksour do, of a process of continuous evolution (Benouhamed Tarek et al 2006, in pelerinage aux sources de notre humus) according to socio-economic needs and demographic growth. However, all the extensions carried out over time were made in accordance with the characteristics of the primary core (Fig. 5).

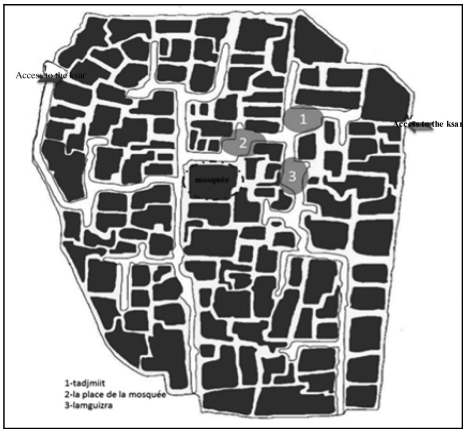


Figure 4. Organization of ksar Taghit.

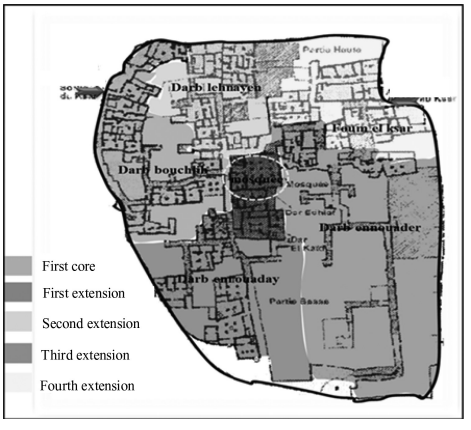


Figure 5. Genesis and evolution of ksar Taghit.



Figure 6. Treatment of the main entrance and the facades express the modesty and the spirit of equity of the people living in the ksour.

4 THE CONSTRUCTION KNOW-HOW AS A PRODUCT OF THE LOCAL GENIUS

Earthen constructions are harmoniously integrated to their natural environment, in extreme conditions, while respecting the cultural values of the community living there (Figs. 6–13).

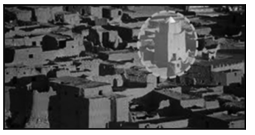


Figure 7. The centrality and verticality of the mosque.



Figure 8. Ayn ad-dār « the eye of the house » Aeration and indirect natural lighting.



Figure 9. Developing of *derb* (alley) with *dkakan* (stools) where the passers can sit in a shady.



Figure 10. Strength of the social bonds: A well with its water sharing system.

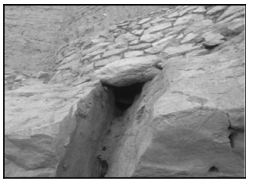


Figure 11. Covering of a cesspool draining off.

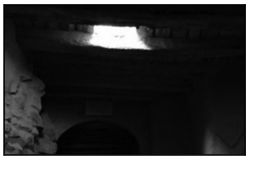


Figure 12. Refreshing halt and skylight.



Figure 13. Public space at human scale, facilitating and enhancing the community life.



Figure 14. Natural decay.



Figure 15. Lack of maintenance.

5 VERNACULAR ARCHITECTURE IN MUTATION

The multi-secular symbiosis between buildings and ecosystems is now threatened by many new facts. Most notably, the abandonment of the houses by their former occupants, who no longer work on the palm groves left them subject to degradation. Add to this the lack of the means to maintain the buildings, on the one hand, and the desire for modernity on the other hand that have led to significant degradation and even ruins (Figs. 14–15).

Another fact is the abusive urbanization using materials unsuitable for the local climate and environment. An uncontrolled and disrespectful urban sprawl has disfigured natural landscapes (Figs. 16–18).

Moreover, the continuing neglect of palm groves and natural components affects the ecosystem itself (Fig. 19).

In addition to this degradation of the material heritage, there is also the disappearance of innumerable know-how, due declining local use. As a consequence, the community is losing its immaterial heritage, and its multi-secular relation of the individual to his natural environment.



Figure 16. Disfigurations of natural landscapes.



Figure 17. Improper rearrangements by the introduction of incompatible mat.



Figure 18. No integration of the urban fabric with its landscape environment.



Figure 19. Negligence of palm grove.

6 MAIN CONCLUSIONS

The current state of degradation of these enclosed areas threatens not only the ksour themselves and their ecosystems, but also all the know-how which has been demonstrated in the area along the centuries. Their effectiveness in that peculiarly harsh environment has gained the city a specific identity.

As a consequence of this cultural dimension, this situation has a considerably significant impact far beyond its consequences on the livelihoods of the concerned social groups. Moreover, the mere view taken by the urban populations of these abandoned human settlements is a highly prejudicial rejection.

However, some timid attempts at reconversion clearly show that it is possible to reconcile these disparaged architectures with the requirements of a comfortable village life and of a local development using the best of the traditional resources.

It is therefore worthy of interest to examine the perspectives of a restructured trans-Saharan trade, of a local tourism and of a small-scale production by artisans valorizing the local know-how: a new direction of research that deserves special attention.

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Supplemented rammed earth in the northwestern regions of Valencia

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ABSTRACT: The traditional earthen techniques used in vernacular architecture are the result of the convergence of geographical and cultural factors as well as the availability of materials in a given territory. These constructions are consequently characterized by their adaptability to the environment and the functional conditions of their time. In the framework of a wider research project, this communication is focused on the study and cataloguing of supplemented rammed earth architecture in the regions of "La Serranía" and "Requena-Utiel" (Valencia). Although the identified types have usually a set of common features, there are some constructions with singular details that highlight the presence of different anonymous builders. A deeper knowledge of these constructions and how they were built would be essential to guarantee their conservation and prevent their replacement with standardized techniques. Consequently, the aim of this research project is to promote the intervention in earthen heritage according to sustainability and compatibility criteria.

1 INTRODUCTION

In the Iberian Peninsula, traditional architecture provides a clear example of adaptation to the geographical and climate reality of a specific region and the optimization of the natural resources available within it. The study of this heritage has again and again been edged out due to a preference for monumental architecture, while traditional architecture itself has been progressively abandoned owing to the depopulation of rural nuclei in different parts of the Peninsula, especially more continental areas.

Although these constructive solutions use the many and various materials sourced locally, it is striking to note how often earth has been used as a basic material for the construction of residential and auxiliary buildings. In addition to being an excellent example of sustainability, the wide range of constructive techniques offered by earth leads to a wealth of architectural solutions reflecting the know-how of anonymous builders.

This study is part of wider research on traditional earthen architecture developed within the framework of the Project "SOS-Tierra: Recovery and rehabilitation of traditional earthen architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention". This research has been used to study and catalog a large number of traditional earthen buildings in the Iberian Peninsula. The results obtained for a specific typology and a given area are presented below: supplemented rammed earth in the regions of La Serranía and Requena-Utiel, in the northwest of the province of Valencia.

These inland regions are the largest in the province and are characterized by their harsh relief, and the river Turia in La Serranía, or the plateaus separated from the Central Plateau by the river Cabriel, in the case of Requena-Utiel. Given the abundant natural resources and economic systems based on the primary sector until the mid-twentieth century (Rodrigo 2000), a considerable amount of earthen buildings were constructed in these regions, especially rammed earth incorporating other local materials.

2 OBJECTIVES

Given that it is necessary to understand traditional earthen architecture in order to conserve it, this research has mainly focused on the valorization of this architecture, offering an overview of its occurrence in the northwestern regions of the province of Valencia.

This research thus aims to catalog the traditional earthen buildings and carry out a detailed study of characteristic constructive solutions based on the information collected in situ, oral accounts, and specific bibliographies. The comparative analysis of the different techniques will help to define the specific characteristics of supplemented rammed earth in La Serranía and Requena-Utiel, to be used as a basis for future research on the guidelines for the protection and conservation of this heritage.

3 METHODOLOGY

The methodology of this research is based on the collection and cataloging of information obtained from direct and indirect sources, and the subsequent detailed analysis of representative case studies of the constructive techniques identified. Thus, the following research phases are proposed:

1. Collection of documentary information on the territorial framework and the traditional constructive solutions in the area studied.
2. In situ data collection and inventory of information using a pre-prepared fiche. The inventory fiches form a database that can be expanded in subsequent research, and collects general information on buildings, as well as information relating to constructive techniques used.
3. Analysis of case studies reflecting the variety of traditional constructive techniques and architectural typologies associated with them in the regions studied.
4. Drawing conclusions based on the inventory data and results of the detailed case studies.

Given that the fiche used (Fig. 1) in the inventory phase is an essential tool in the research, the fields contained are specified and structured into two blocks.

a. General data: For each building, identified with a numerical code associated to a municipality and nucleus of population, and including address, GPS coordinates, location, general photographs, urban insertion (detached, between party walls, on a corner), building type (traditional dwelling, agricultural construction, stately home, farmhouse or other), current use (permanent residence, seasonal residence, equipment, storage, agricultural, in disuse), number of stories and facades and orientation.
b. Constructive techniques: Once the type of constructive techniques has been identified, it is chosen from the different groups of variants of simple rammed earth: supplemented on the outer faces, with joints or combining both, with joints and supplements on the outer faces. If the building cannot be accessed for measurements, the measurements of the rammed earth modules are included. This block also contains detailed photographs of the constructive technique, a diagram of the rammed earth variant, and the specification of a masonry plinth when applicable. Finally, an observations section is reserved for recording other data of interest on constructive solutions.

The methodology used could also be applied to extend the study of traditional earthen architecture in other regions with the simple recording of data using fiches and the graphic results obtained.

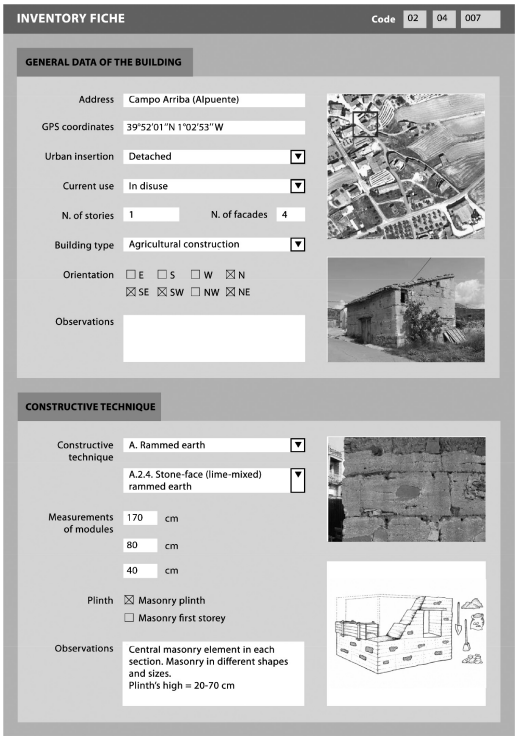


Figure 1. Inventory fiche (Authors).

4 RESULTS

Although this paper focuses on the traditional supplemented rammed earth architecture in the regions of La Serranía and Requena-Utiel, the research carried out throughout the region examines the wide range of traditional earthen constructive techniques. To date 263 buildings have been inventoried, 259 of which are different rammed earth variants and tend to be found in urban nuclei.

This means that rammed earth is the most commonly found earthen constructive solution in municipalities and is part of the structural and enclosure solutions of different types of building, from auxiliary rural constructions to more important dwellings at a higher economic level. In order to improve resistance and durability a wide repertoire of formal, material, and dimensional solutions of this constructive technique has appeared over time. The type of earth, the characteristics of the rammed earth (formwork) and the finish establish the difference in the execution of these walls (Vegas et al. 2014).

According to the classification referenced (Vegas et al. 2014), rammed earth can be simple or include supplements on wall faces, joints, or both, thus establishing four major groups of variants. Leaving aside the simple rammed earth constructive solutions (simple rammed earth and supplemented rammed earth), it is observed that the different variants of supplemented rammed earth make up 65% of the total of buildings inventoried in the area studied. 57% of the whole rammed earth buildings with added materials are supplemented on the outer faces, 22% incorporate joints, and 21% combine both (Fig. 2).

It can also be seen that the geographical distribution of buildings (Fig. 3) in supplemented rammed earth does not only obey local geographical conditioning factors, favoring greater availability of the locally extracted constructive materials, but is also determined by the economic status of owners, or even the wealth of the population nucleus in general. Thus, the number of variants of supplemented rammed earth identified is higher in La Serranía than in Requena-Utiel.

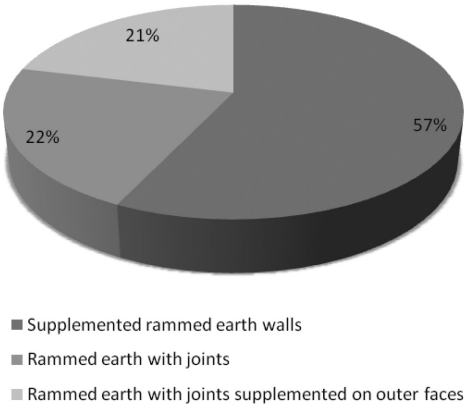


Figure 2. Supplemented rammed earth variants in the regions of La Serranía and Requena-Utiel (Authors).

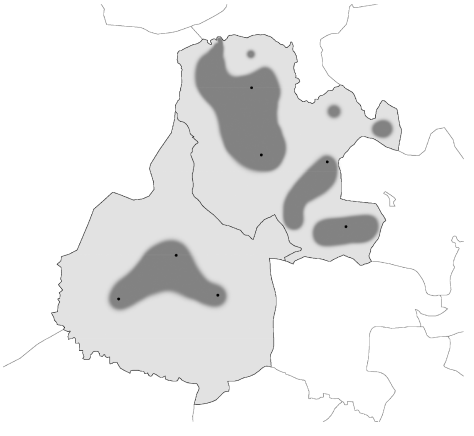


Figure 3. Geographical distribution of supplemented rammed earth in the regions of La Serranía and Requena-Utiel (Authors).

The constructive characteristics of the rammed earth variants found in the area studied are detailed below along with the specific types identified in the various groups.

4.1 *Supplemented rammed earth walls*

Supplemented rammed earth walls are a variant where the rammed earth surfaces include elements improving their protection against weathering. These supplements are usually added to the outer surface of the construction, which is more exposed to the elements.

The supplements are placed in the interior of the formwork before tamping every layer of earth, which can also include lime in the mix (below 20%). This lime-mixed rammed earth is known as *tapia real*. The supplements can be masonry, brick, gypsum or lime mortar, giving rise to different variants.

Lime-crusted rammed earth (López 1999), is characterized by a coating or layer created by placing handfuls of lime mortar in each layer against the formwork, improving the protection of the outer face of the wall. This lime mortar can adopt a simple wedge-shape on the outer faces of the wall or can be also extended between layers throughout the section. It should be noted that given the abundance of gypsum kilns in some areas and the location of gypsum monolithic rammed earth in nearby regions (Vegas et al. 2009), the use of this bonding agent is not in the place of lime is not completely discarded.

In addition, brick-faced or Valencian rammed earth (Cristini 2012) is an improved variant of lime-crusted rammed earth, as it incorporated solid brick pieces inside the rammed earth wall, placed against the outer face in each layer. These pieces are placed on each stretching or heading course, respecting regular intervals depending on the height of the measurements of the rammed earth wall section. The brick used is often from the demolition of other buildings. Its function, while widely debated, is to help connecting the outer layer of lime and the inside of the earthen wall.

The most common variant in the region in terms of rammed earth supplemented on the wall face has a stone facing, using masonry inside the formwork against the outer face. This variant, locally known in the region of La Serranía as *tapia serrana*, usually includes lime mixed with earth.

The masonry used in this variant is in different shapes and sizes, and its position in coursework is usually conditioned by the characteristics of the stone and the size of the formwork. The masonry is carved on its outer face at least, but this is not necessary for the remaining faces.

A subvariant of stone-faced rammed earth, not featured in the manuals consulted, has been found in a small area of the region studied. This type of rammed earth incorporates a single masonry element in the central position in each rammed earth wall section (Fig. 4). Compared to the greater stability and durability sought by incorporating stone facing to connect the wall face to the interior as was done with the brick-faced rammed earth wall, in this case it seems this solution only answers to aesthetic reasons.

4.2 *Rammed earth with joints*

The rammed earth wall can incorporate joints between the units built within the wall. Given the abundance of local natural resources for construction materials, the joints can be either of gypsum or lime mortar. It must be highlighted that rammed earth walls with joints tend to be lime-mixed rammed earth walls. Four different types can be distinguished based on the material used and its positioning.

Rammed earth with horizontal gypsum joints presents a continuous layer of gypsum between courses, regulating the surface supporting the upper formwork and facilitating the positioning of the lower putlogs of it. The hardened gypsum protects the interface between courses and the putlog holes as weaker parts of the wall. As in the case of lime-crusted rammed earth, it cannot be ruled out that the mortar used in the joints is lime rather than gypsum, as this is abundantly found in the region and traditionally connected to earthen architecture.

Gypsum can also be used for shaping the corners and jambs of the openings in traditional earthen architecture, thus obtaining rammed earth with gypsum *rafas*. These are small internal pillars the same height as the rammed earth wall section, which are shuttered in the formwork of each course, possibly converging on a vertical axis. These elements, sloping or undulating, are usually executed in alternating courses between perpendicular walls so that their axis coincides with the edge between wall faces.

The combination and evolution of the two variants described above result in rammed earth with gypsum *brencas* as well as with *rafas*. The *brencas* are added undulating or half-moon shaped joints made of gypsum (Fig. 5). The *brencas* usually coincide with the putlog holes guaranteeing that they will be completely covered and therefore protected from the elements.

Using the same concept as that of rammed earth with gypsum joints, the rammed earth walls with layers of stone incorporates stones between courses to create a regular supporting plane for the upper rammed earth wall sections and facilitate the insertion of the lower putlogs of the upper formwork. In the region studied, the stone layers can appear in all the courses or in alternating ones, depending on the availability of materials.

4.3 *Rammed earth with joints supplemented on outer faces*

The abundance of different prime materials in La Serranía and Requena-Utiel gives rise to a variety of constructive techniques of traditional rammed earth architecture based on different combinations of materials to supplement the walls. It is observed that the wealthier the original owners of



Figure 4. View of an agricultural building with walls in stone-faced rammed earth with a central masonry element in each section (Campo Arriba, Alpuente) (Authors).

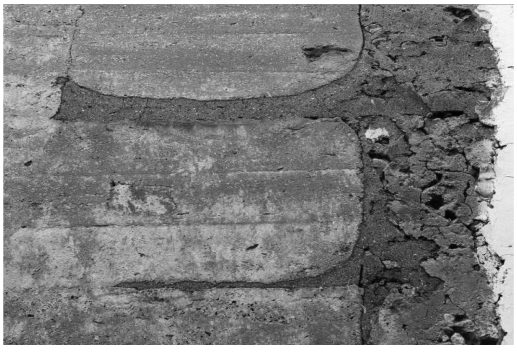


Figure 5. Detail of a rammed earth wall with gypsum *brencas* and *rafas* (Chelva) (Authors).

the buildings, the greater the number of materials added to earthen constructions.

Thus, in the region studied it is not uncommon to find buildings with constructive techniques born from the combination of rammed earth variants described in previous sections, especially in the region of La Serranía, where gypsum and masonry take on a special role. These constructive techniques are generally concentrated in more heavily populated nuclei with greater economic development, although in fact they are geographically scattered throughout the region.

The occurrence of lime-mixed rammed earth with stone-faced rammed earth with gypsum *rafas* is more frequent in areas near the south of Aragon, where constructions with this sort of technique are common (Vegas et al. 2009). In this variant, the masonry is placed in courses against the outer face.

Lime-mixed rammed earth with gypsum *brencas* and *rafas* is a variant similar in appearance to the previous type, although the gypsum protects the horizontal joints of the wall from the elements.

An exceptional case is that of the brick-faced rammed earth with gypsum *rafas*, as only one example has been identified in this territory. It is the only example of unique constructive techniques found in the region.

There are also few examples of stone-faced lime-mixed rammed earth with an extra flat stone

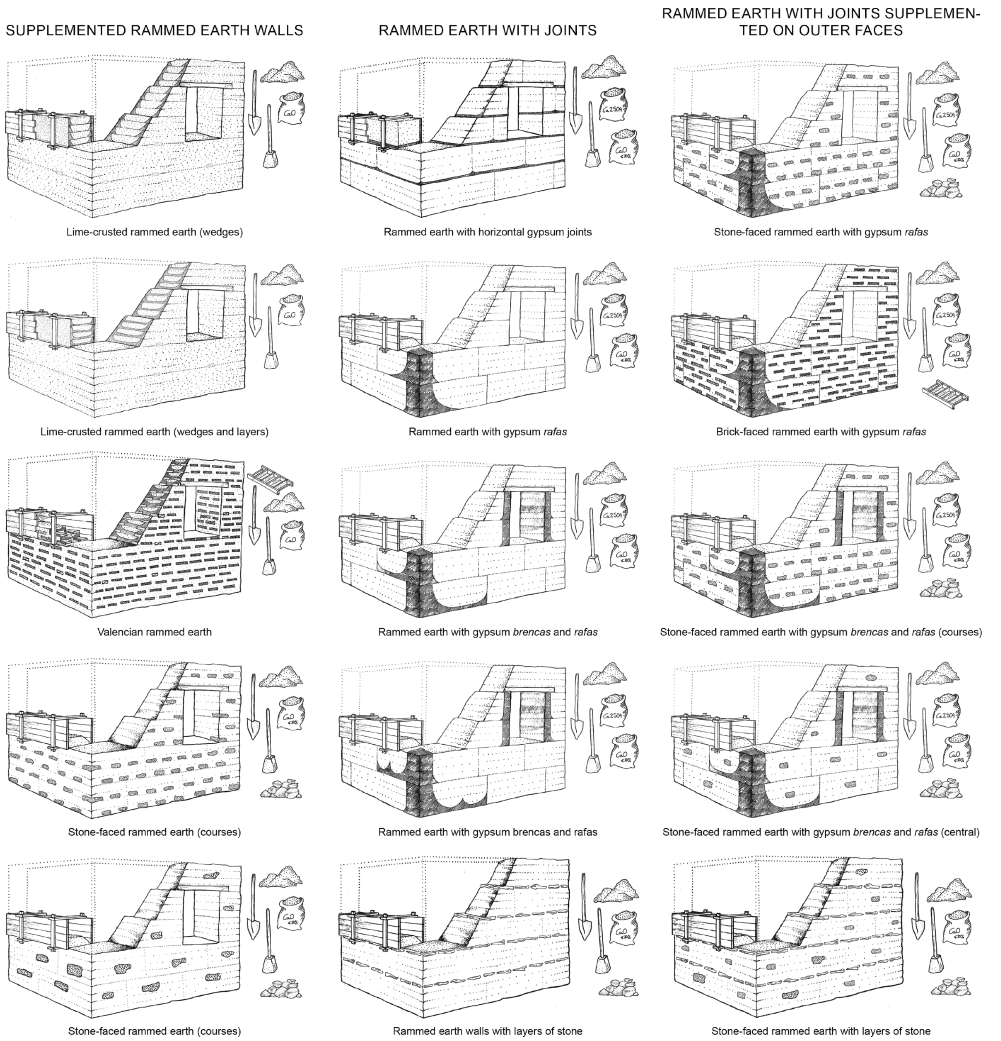


Figure 6. Construction diagram of the rammed earth variants in La Serranía and Requena-Utiel (Authors).

layer between courses, using a single local material to supplement the earth constructions. However, limestone appears in different formats depending on the part of the wall to be supplemented: in the shape of long flat stones in horizontal joints between rammed earth wall sections and in various other shapes on the outer surface of the wall face, either in courses or in a central position in each rammed earth wall section.

5 CONCLUSIONS

This study has focused on the constructive cataloging and characterization of supplemented traditional rammed earth architecture in the regions of La Serranía and Requena-Utiel, in the northwest of the province of Valencia, where earth is often used in combination with different local materials. Thus, although the research has not yet been completed it can be stated that the region studied includes a wide range of variants of supplemented rammed earth (Fig. 6) in large areas of the territory, both in main population nuclei and in small rural settlements.

In view of the data extracted from the inventory of earthen buildings, the solution of supplement the faces of rammed earth is more frequently seen than others incorporating joints or using both solutions simultaneously, probably due to the exposure to the elements.

Moreover, in the region there are many examples of different variants of rammed earth with joints, as these techniques aim to protect the weaker points of the walls while offering constructive solutions of great architectural beauty. The easiness of the constructive process is especially reflected in the shape of the gypsum undulating supplements.

Given the necessary economic and constructive conditions, the combination of variants with rammed earth with joints supplemented on the outer faces can provide more durable solutions.

The abundance of traditional materials including lime, gypsum, or stone in different parts of the region, along with the influence of constructive techniques used in nearby regions, conditions the geographical distribution of supplemented rammed earth constructive solutions in the regions studied. Thus, brick-faced rammed earth is more commonly found in the south of La Serranía given its proximity to regions near the coast, while the use of stone or gypsum as added materials is generally associated with more continental areas such as Requena-Utiel or the north of La Serranía.

Vernacular architecture, especially that built using different rammed earth techniques, is the result of the adaptation of constructive solutions to the geography, climate, culture, and economy of a specific region, and has satisfied the functional needs of inhabitants with a wealth of aesthetic solutions. However, this anonymous heritage of great constructive, historical, and architectural value is gradually and quietly disappearing or transforming in different ways from the original, depending on each case, and witnessed by the descendants of those who built them.

ACKNOWLEDGMENTS

The authors wish to thank the residents of the towns and villages of La Serranía and Requena-Utiel for their collaboration throughout the data collection process, as well as for the historical information relating to these traditional constructions.

NOTE

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Earth construction in prehistoric settlements of southern Portugal

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ABSTRACT: The use of earth in the construction of prehistoric habitat structures has been, to date, a little deepened theme, although the presence of its traces is often recorded during archaeological works. This omission is quite comprehensible, since the recognition of the relevance of earth building materials to the understanding of archaeological structures is relatively recent. So, with the developed research from a PhD thesis in Prehistory, the author tried to contribute to a better understanding of prehistoric architectures in southern Portugal, through the study of the available remains, and adding clay based materials to the incomplete "puzzle" of domestic structures. Case studies included laboratorial analysis of traces of clay based materials such as earth mortars covering and filling vegetable structures and renderings, mudbricks and massive walls, and provided a better characterization of construction techniques and materials. This permitted some new interpretations of the structures and contributed to their hypothetical reconstitution.

1 INTRODUCTION

The present article is based on a larger research from a PhD thesis in Prehistory (Bruno 2011), regarding prehistoric domestic architectures from southern Portugal and involved the study of structure traces from a considered set of archaeological sites, from Ancient Neolithic period to Bronze Age. The study allowed characterizing some of these architectural remains, considering aspects like shape, typologies, materials and building techniques.

Specifically regarding earth materials, different building techniques were identified:

- Modelled earth, used in walls;
- Stacked earth, used in walls;
- Earth mortars filling and rendering vegetable structures;
- Earth mortars binding stone masonry;
- Earth mortars rendering pits;
- Mudbrick masonry.

The most antique techniques seem to be modelled earth and earth mortars rendering pits, identified in Ancient Neolithic. The other techniques were only identified since the Chalcolithic period, but, apparently, only earth renderings, mortars binding stone masonry and covering and filling vegetable structures seem to be used in Bronze Age.

Case studies selection was based on the existence of relatively well documented structures, as well as the availability of large quantities of samples for study. The analyzed materials were composed by different types of traces: small clayish fragments coming from renderings of pits and modelled walls of combustion structures, from Neolithic period; fragments of clayish mortars with branch prints, coming from covering and filling of wooden structures, from Chalcolithic and Bronze Age; manual, and perhaps moulded mudbricks, belonging to a wall of a Chalcolithic settlement; big fragments of a Chalcolithic hut wall, apparently made of stacked earth. All materials were burnt by fire, which permitted their conservation to the present.

2 TERRITORY

The studied area (Fig. 1) correspond to current southern Portuguese territory (Alentejo and Algarve regions) and is limited north by Tejo river, east by the Spanish border, and west and south by the Atlantic Ocean.

Plain landscapes dominate, mostly less than 400 m high, with occasional elevations. Geologically, the territory is generically characterized by the presence of Paleozoic metamorphic and igneous rocks (in interior Alentejo region), Mesozoic sedimentary rocks in coastal areas and recent sediments associated to the ancient basins of Tejo and Sado rivers (Ribeiro 1945). Tejo, Sado and Guadiana are the main rivers of the region.

The climate is typically Mediterranean, with high temperatures, strong insolation and absence of rain in summer. However, in the Atlantic coast, relative humidity is higher and temperature moderate, comparing to interior Alentejo. The warm and luminous weather goes on until autumn, despite lower temperature and the occurrence of some



Figure 1. Location of the study area in the Iberian Peninsula.

rain. Generally, rain falls strongly from December to March.

Plant life, conditioned by climate, is mainly composed of Mediterranean species: evergreen trees and bushes like cork trees, holm oaks, pine trees (specially stone pines), arbutus trees, heathers, laurels, lentisks, butcher's brooms, oleanders, canes, rock roses; aromatic plants from dry soils like rosemary, lavender and thyme; planted trees and bushes like almond, fig, carob, orange and olive trees and vineyards.

3 BUILDING TECHNIQUES

3.1 *Neolithic (c. 5500–4000 B.C.)*

Archaeological interventions in Neolithic dwellings of southern Portugal revealed very little about their habitat structures. On most part of the excavated sites survived mainly its negative traces—pits, post holes and, occasionally, hut bottoms.

Consequently, most researchers believe that Neolithic dwellings were essentially made up of perishable materials (vegetable structures, furs and raw earth), hardly preserved until nowadays; the probable seasonality of these occupations is also referred by some authors as a reason for such weak investment in domestic architectures.

There are, however, a few sites with vestiges of clay mortars that allow some reading of what may have been some of the constituent elements of Neolithic habitat spaces. Regarding the constructive use of earth, two techniques were detected using clay based mortars: rendering of pits used as storage bins, and modelled thin walls, of culinary ovens.

3.1.1 *Earth mortars on coatings—Defesa de Cima 2 (Torre de Coelheiros, Évora)*

A fine example of clay mortars rendering pits was detected at the Ancient Neolithic site of Defesa de Cima 2, located near Évora (Alentejo region).

The settlement was built over an eruptive granitic rocks substrate. Excavations that took place in 2005 and 2006 showed a large set of anthropic origin pits, with oval and circular plan, with 0.60 m to 0.90 m of diameter, and maximum conserved deeps of 0.83 m.

These structures were partially destroyed in their top levels. Many of them were interiorly rendered with clay mortars, with about 2 to 3 cm thick, exposed to combustion after application (Fig. 2). Although flora traces were not found in the pits interiors, archaeologists believe that they were used as storage bins. Burning interior coatings would provide the preservation of stored products, by protecting them from the soil humidity (Santos & Carvalho 2008).

Similar structures, with traces of clay coatings, were detected in Ancient Neolithic sites of Salema (Santiago do Cacém, Setúbal, Portugal), Buraco da Pala (Mirandela, Bragança, Portugal) and La Colata (Montaverner, Valencia, Spain) (Bruno 2011).

3.1.2 *Modelled earth (Lajinha 8 - São Manços, Évora)*

Earth used in the construction of modelled thin walls was detected in Lajinha 8, also in Évora district. In 2007, archaeologist Rita Gaspar discovered several combustion structures partially excavated in the geological substrate, with semi circular plan and cylindrical profiles, rendered with clay mortars. These structures, executed on shallow pits, had circular and oval plan, with diameters between



Figure 2. Defesa de Cima 2: pit No. 5, with preserved clay coatings, during excavations (Filipe Santos).

0.60 m to 0.90 m and depths of 0.20–0.45 m; in the interior they contained thermoclasts and traces of lithic utensils. Some of them showed traces of possible roofing and were interpreted as culinary ovens; clay coatings had up to about 5 cm thick at the base. Laterally, the structures showed the walls basis, in the continuity of the pits coatings (Gaspar 2008).

This technique was probably also applied in the construction of the combustion structures detected in Ancient Neolithic settlements of Xarez 12, Carraça 1 (Reguengos de Monsaraz, Évora), Reguengo (Alter do Chão, Portalegre) and in the Early Neolithic phase of Perdigões (Reguengos de Monsaraz, Évora), all in Alentejo region (Bruno 2011).

The construction of these walls would involve the application of small balls of clay mortar previously kneaded in plastic state, in successive horizontal layers, and hand smoothed. The thickness of the walls, according to the available data, would be very variable: 2 to 30 cm in Xarez 12; 6 to 7 cm in Carraça 1; circa 8 cm in Reguengo (Bruno 2011).

The technique of modelled earth is still currently used in the construction of granaries and housing in some African countries such as Cameroon, Nigeria, Ghana and Benin.

3.1.3 *Analyses of materials*

Stereozoom microscope observation of samples from both settlements showed that mortars were extremely homogeneous, due to good kneading. Traces of organic materials, animal or vegetable fibers were not found. Granulometric analyses showed similar compositions, with dominance of fine aggregates (circa 85% of sands), followed by binder portions (8 to 13% of silt and clay) and large aggregates (1 to 7% of medium and small pebbles, mostly small pebbles).

3.2 *Chalcolithic/copper age (c. 3000–2000 B.C.)*

Based on intensive agricultural practices, new technologies resulting from the *Secondary Product Revolution* and the acquisition of copper metallurgy, new "agro-metallurgical" societies emerged in Iberian Peninsula, from the 3rd millennium B.C.

This led to population increase, with the enlargement of the occupied territories and number and diversity of settlements. At the same time that fortified settlements appeared, there were plain sites, some of them seemingly devoid of defensive systems, and others surrounded by sub circular moats, possibly complemented by defensive walls.

As to architectural vestiges of domestic structures, there are two main features to highlight: on one hand, the abundance of stone structures (traces of wall basements, mainly); on the other hand, the frequent presence of fragments of clay mortars with vegetable impressions, probably from the filling and rendering of wooden structures. The use of mudbrick masonry and the probable application of earth mortars in the construction of massive walls were also detected in this period.

Earth continued to be used on coatings of negative structures like storage bins or cisterns, and also in hut floors.

3.2.1 *Earth use on filling and rendering of wooden structures—São Pedro (Redondo, Évora)*

Regarding earth use on filling and rendering of wooden structures, probably belonging to walls or ceilings, several fragments of clay mortars with branch prints (most of them from the settlement of São Pedro) were analyzed. Unfortunately, it was not possible to clearly relate them with any of the identified constructive elements of the settlement's huts (stone basements and post holes, mainly).

Many of the fragments showed branch prints and, simultaneously, on their opposite faces, smoothed surfaces, some of them with fingerprints. Those final surfaces had plain, concave and convex forms, which suggest that coatings would be applied on the interior and exterior surfaces of the huts walls.

As to dimensions, fragments had maximum thickness of 2 to 8 cm and distances between branches and smoothed surfaces with about 0.9 to 2.6 cm. Branches had parallel, perpendicular and oblique directions between them, with diameters of 0.3 to 1.8 cm (Fig. 3).

Stereozoom microscope observation showed that mortars were extremely homogeneous, due to good kneading. Traces of organic materials, animal or vegetable fibers were not detected. Granulometric analyses showed that mortars were mainly

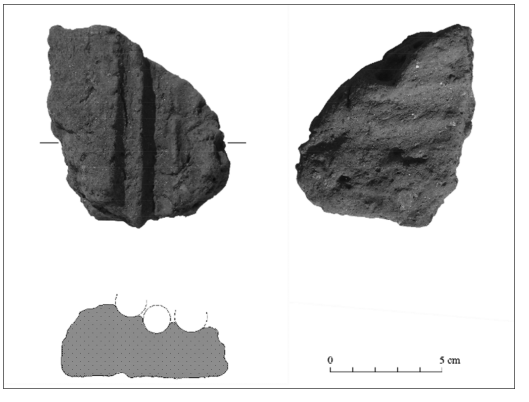


Figure 3. São Pedro: sample SP-04, with face showing branch prints and, on the opposite, smoothed surface.

composed by fine aggregates (c. 60% of sands), 36% of binders and only 4% of small pebbles.

Similar traces of clay mortars were detected in several Chalcolithic settlements in southern Portugal like Porto das Carretas (Mourão, Évora), Mercador (Mourão, Évora), Moinho de Valadares 1 (Mourão, Évora), Porto Torrão (Ferreira do Alentejo, Beja), Cerro do Castelo de Santa Justa (Alcoutim, Faro) and Alcalar (Portimão, Faro). In Spain, among many other settlements, it can be pointed San Blas (Cheles, Badajoz), La Pijotilla (Badajoz) and Los Millares (Santa Fé de Mondujar, Almeria) (Bruno 2011).

3.2.2 *Mudbrick masonry—Alto do Outeiro (Baleizão, Beja)*

Archaeological intervention in Alto do Outeiro revealed the existence of a Final Neolithic and Chalcolithic settlement surrounded by three sub circular waved moats.

The filling levels of moat No. 2 contained large quantities of fragments of mudbricks, probably belonging to a wall made upon a stone base, with 0.5 m of thick, adjacent to the moat.

Studied materials were selected from two different filling levels (units 90 and 101).

Materials from unit 90 were composed by several nodules of clay mortars reddish colours and a big mudbrick fragment. The four surfaces of the mudbrick fragment were plain, with straight edges, which suggest the use, on its manufacturing, of some kind of mould. One of the faces showed two finger prints that seemed to result from handling the mudbrick in plastic state. The fragment weighed 2.832 kg and measured 17 × 14 × 6.5 cm, showing two fractured faces (Fig. 4).

Materials from unit 101 were also composed by several nodules of clay mortars and a big mudbrick fragment of yellowish colour. The mudbrick fragment measured about 16 × 9 × 7 cm and had two fractured faces. The other four faces seemed smoothed, however not plain. Edges were rounded. The fragment weighed 2.476 kg.

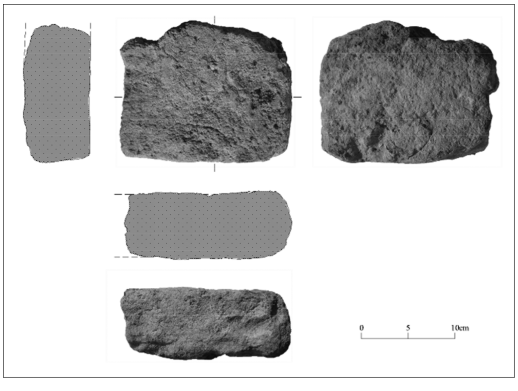


Figure 4. Alto do Outeiro: Fragment of mudbrick AO-706.

Laboratorial analyses were only made with samples from unit 101, clearly similar to mudbrick 729. This similarity was observed with stereozoom microscope, by comparison of several samples from the nodules of the two units and two samples from each mudbrick.

Disaggregating the samples for granulometric analysis was quite easy and showed that fragments were internally unburnt. Granulometric analyses showed that mortar was mainly composed by fine aggregates (74.57% of sands), followed by pebbles (22.38%) and only 3.05% of silt and clay.

Plagioclase and calcite were the predominant minerals, both in the overall and in the fine fractions of the sample. In the fine fraction, a relatively high proportion of quartz was also detected while, in the overall fraction, low proportions of quartz and of amphibole were registered.

The analyzed sample showed that this mortar was mainly composed by fine aggregates, with some pebbles and low percentage of silt and clay. Such a low amount of binder is, however, uncommon in mudbricks compositions. However, the presence of calcium carbonate (calcite) in large quantities acted in the mixture as a binder, contributing to stabilize the materials and, at the same time, to increase its resistance; perhaps for this reason, this mudbrick, almost raw, has been preserved until present time.

The presence of calcium carbonate in this fragment of mudbrick suggests the use of earth from local soils (calcareous clays), which incorporate in their profiles calcium carbonate concretions, resulting from the genesis of these soils (Cardoso 1965).

Examples of mudbricks with high percentages of calcium carbonate were identified in several Neolithic sites of the Rift Valley (Jordan), in Çatalhoyuk (Turkey), and in the Minoan settlement of Palaikastro (Crete, Greece), in accord with the local soils features (Politis, 1993; Doherty, 2007; Jerome, 1993). In Çatalhoyuk, the selection of soils containing calcium carbonates and lower quantity of clay may have been intentional, and this choice was observed in mudbricks coming from a specific phase of the settlement (Doherty 2007).

In Portugal, the use of mudbricks is also documented in two other Chalcolithic settlements: Monte da Tumba (Alcácer do Sal, Setúbal) and Porto Torrão (Ferreira do Alentejo, Beja). In Spanish territory, the presence of mudbricks was detected in La Pijotilla (Badajoz), Valencina de la Concepcion (Sevilla) and Marroquíes Bajos (Jaén), in this last site also applied in mixed masonry (stone and mudbrick) of defensive walls (Bruno 2011).

3.2.3 *Earth use in massive walls—Alcalar (Portimão, Faro)*

Alcalar settlement is located in Algarve, between Alvor estuary and Monchique Mountain, near the village of Mexilhoeira Grande, Portimão.

Besides two surrounding moats, excavations and geomagnetic prospection allowed discovering many domestic structures, mostly hut bottoms, combustion structures and storage bins (Morán 2001).

The analyzed materials were collected from the remains of a large hut, located in the settlement's central area. They were found upon the hut's stone base and in its interior and probably belonged to a massive earth wall that fell. This hut had oval plan, and a large masonry base (about 1.00 m thick). In the hut's interior existed a circular fire place, on torus form, made of clay mortar.

Chosen materials were selected from a pile of fragments found inside the hut, with about 1 m^3 of volume. Samples had orange colors and showed irregular textures, apparently rich in fine aggregates, with some pebbles of larger dimensions (limestones and shells). Many samples showed smoothed faces, sometimes with finger prints.

Stereozoom microscope observation showed that mortars had larger quantities of aggregates than the other analyzed materials and also more heterogenic compositions. Traces of organic materials, vegetable or animal fibers were not observed.

This technique seems similar to stacked earth. Yet, it was not detected any identical situation in the peninsula area for this period. However, in the South of France the technique of *bauge* is documented in several proto-historical sites (Chazelles, 1999).

3.3 *Bronze Age (c. 1500–800 B.C.)*

In the transition from Chalcolithic to Bronze Age, a strong demographic retreat occurred, possibly caused by a crisis related to a soil depletion phenomenon. This had consequences such has the abandonment of many of the existent settlements. In the studied area, traces of domestic structures are rare for this phase.

Final Bronze Age, on the contrary, was a period of great changes, mainly motivated by intense Atlantic and Mediterranean contacts. Fortified settlements reappeared and also new small open habitats, generally located in lower places.

Regarding domestic architectures, and although the number of identified sites is considerably superior to Early/Middle Bronze, its vestiges have been relatively scarce and only present in interior Alentejo. Constructive earth traces are mainly composed by mortars used on filling and coating vegetal structures, coatings of pits, stone masonry walls and floors.

3.3.1 *Earth use on filling and rendering of wooden structures—Rocha do Vigio 2 (Reguengos de Monsaraz, Évora)*

In Rocha do Vigio 2, archaeologists identified an oval plan hut, composed by interior stone base and an alignment of vertically placed stone slabs, defining its exterior perimeter; in the empty space between these two elements, probably existed a wooden structure that supported the hut's exterior walls. In the interior, a large quantity of fragments of clay mortars with branch prints were found, probably belonging to the filling and coating of its walls and roof.

Many of the chosen materials showed straw traces, apparently added to earth mortars. Sample No. 1103 (Fig. 6) is quite representative. It had 4.7 cm thick and showed a plank and four branch prints. The plank width was about 5 cm and branches diameter had 1 to 3.7 cm.

The presence of similar traces, associated to huts composed by alignments of vertically placed stone slabs, some with post holes or continuous



Figure 5. Alcalar: Fragments of materials found inside the hut.

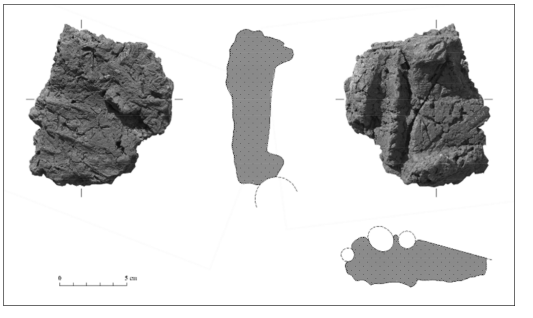


Figure 6. Rocha do Vigio 2: Sample no. 1103, showing a plank and four branch prints and on the opposite, a smoothed surface.

ditches, was detected in Castro dos Ratinhos (Moura, Beja), Alegrios (Idanha-a-Nova, Castelo Branco), Cabeço do Crasto (Seia, Guarda), and El Risco (Sierra de Fuentes, Caceres, Spain).

4 DISCUSSION

Analysis results suggest, in all cases, that mortars were produced with local materials.

Generally, samples morphologies and compositions revealed consistent with the probable building techniques—mortars exclusively used on coatings showed the lowest percentages of pebbles (Defesa de Cima 2); rendering and filling mortars (Defesa de Cima 2, São Pedro, Rocha do Vigio 2) showed highest percentages of clay than the earth mixtures used in the construction of monolithic walls of Alcalar.

To clarify still remains the reason why having good clayish soils in the vicinities, builders of Alto do Outeiro choose other soils for their mudbricks, with low quantities of clay and enriched in calcium carbonate. Perhaps they had an empirical knowledge about the role of calcium carbonate and lime as binder, and used it to produce more resistant mixtures, almost similar to the ones of lime based mortars.

As to chronologies and building techniques, the identification of common features between architectures of different sites allowed relating some typologies and technologies with certain chronological contexts. Regarding earth materials, the most antique techniques seem to be modelled earth and earth renderings, identified since Ancient Neolithic, the first one apparently used in the construction of walls of combustion structures and the second on rendering underground structures. These techniques lasted until Bronze Age, with the use of earth renderings as finishes of walls and floors, verified since Chalcolithic period.

Earth mortars binding stone masonry, as well as filling and covering vegetable structures, were only detected from Chalcolithic period, and its use is also documented in Bronze Age. However, in the studied area, the continuity of mudbrick or massive earth walls use (only detected in Chalcolithic period) was not confirmed for the Bronze Age.

5 CONCLUSIONS AND FUTURE DEVELOPMENTS

Archaeological materials exhumed in several prehistoric settlements of southern Portugal showed that earth mortars were largely used in the construction of domestic structures.

In fact, the abundance of clayish materials in most geographical contexts and the easiness in handling them made earth mortars use extremely frequent to prehistoric communities. Anyway, in this geographic context, only earth vestiges exposed to combustion survived until nowadays, which strongly limits the identification of other techniques, and also the extent of their use.

However, it has been possible to have a better understanding of some structures from the studied sites. Based on case studies' material analyses, it was feasible to draw some hypothetical reconstitution models of those prehistoric settlements.

To the future, the development of more case studies and data crossing will help to enlarge the knowledge about earth materials in Prehistory and maybe provide the identification of different building techniques.

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Vernacular construction techniques and earth employ in Arg-e-Bam (Iran)

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ABSTRACT: This research aims to address at the International Conference on Vernacular Earthen Architecture, Conservation and Sustainability SOStierra 2017, of traditional building methods and conservation in the ancient city of Arg-e-Bam in Iran, as the writers themselves checked in situ: almost completely destroyed by an earthquake in 2003, it was rebuilt using ancient local techniques. The recognition of World Heritage in 2004 has contributed to the process of rebuilt, with the cooperation of the countries of the international community since the site can be considered one of the few examples of architecture in red clay in the world.

1 INTRODUCTION

Arg-e-Bam is considered to be the largest building in adobe in the world, located in Bam, a city in the region of Kerman in southeastern Iran. Classified by UNESCO as part of the World Heritage, this enormous citadel on the Silk Route was built before 500 BC and inhabited until 1850. Its name in Persian means "fortress inside another fortress" and is characterized by more than twenty-two hectares of area and thirty-eight watch towers along the large perimeter walls. It is composed by a higher and a lower part; the lower one starts from the door, it includes Hashti, Bazar, Tekkieh, the mosque, the school, Zoorkhaneh, Karvansarai, Khanghah, Hammam and about 400 homes.

The upper part consists of the door, the royal stables, the barracks, the mill, the house of the commander and the governor. On 26 December 2003, the citadel was almost completely destroyed by an earthquake, along with many remains of Bam and the surrounding area. A few days after the earthquake, the Iranian President Mohammad Khatami announced that the Citadel would be rebuilt. The plan and the architecture of the citadel are accurately studied from different points of view. In this form of the citadel people may notice that the designer had planned the entire final form of the construction of the city from the first moments of the construction process.

During each phase of the construction process, the part already constructed formed a complete image and each additional part could be "sewn" into the existing part evenly. The citadel is located in the center of the city-fortress, to ensure a proper view of the city.

In the form of architecture in the city of Bam there are two distinguishable parts: the first is the one of the lords which is situated within the walls, including the citadel, the barracks, the mill, a four section house, a water well (dug in rocky terrain and deep almost 40 m), and a stable for 200 horses.

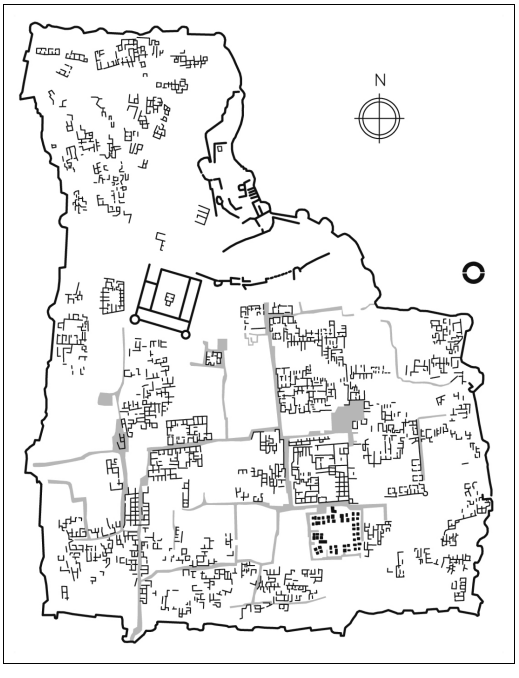


Figure 1. Arg e Bam: Planimetry (Michele Severini).

The second part is the one of the subjects. This part surrounds the part of the lords, where is situated the main access to the city-fortress and the bazaar alongside the main axes ranging from North to South (connecting the main entrance to the citadel) and about 400 houses with their public buildings (such as schools and places dedicated to the sport). The houses can be divided into three different types: the smaller houses with two or three rooms for poor families, bigger houses with three or four rooms for the middle class, some of which also include a veranda. At last you can find the most luxurious ones with more rooms positioned in different directions to be comfortable during all the seasons of the year, along with a large courtyard and a stable for the animals in the area. This type of construction can be found in small numbers in the fortress.

All buildings are made of raw clay bricks, according to the adobe technique. The safety system was conceived in an extremely accurate way in fact: when the city's doors were closed, nobody could enter, neither men nor animals. The inhabitants could continue living for a long period of time in isolation since they had access to a well, the gardens and domestic animals inside the fortress. When the fortress-city was besieged the inhabitants could continue to stay there while the soldiers could defend, protected by high walls and towers. In addition to the guard towers and the ornamented tops, deserve to be mentioned the wind towers; they are structures that, protruding from buildings, retrieve the wind and conveys it inside.

2 RESEARCH METHODOLOGY

In this research, the applied method is similar to a systematic observation process of the collected.

The starting point consists precisely in the acquisition of data in the survey site.

The key issue is the photographic campaign, together with the implementation of relief and planimetric restitution of the site itself.

The next step was characterized by the in-depth study of some traditional construction techniques, using a specific bibliography.

In conclusion the object of the investigation problem has been defined, then conceptualized and analyzed in relation to the use of specific construction materials (always in the geographical area).

3 HISTORICAL BACKGROUND

The city of Bam is located at about 1062 meters above sea level, and it is characterized by the presence of about 70,000 inhabitants; the province of Bam, with 19,480 sq km, has about 210,000 inhabitants. It is bounded on the north by the city of Kerman, to the east from the city of Zahedan, south of Iranshahr and Jiroft and west by Mashiz. This city includes Rain, Markazi, based on 1989 census, Narmashir and Rigan, and has 754 villages of which 578 are composed of more than 12,532 families. Bam is an agricultural area and one of the richest areas of the south-central Iran with regard to groundwater. Until Ghagiar period was called Arbaee Bam because each of the four areas (Darzin, Bam, Narmashir and Rigan) of Bam, could be considered, in the past, the most important cities.

The whole complex covers 200,000 square meters, including three parts separated by walls which are respectively the housing, the military and the government. The upper part, consisting of the last two parts, was built on the rock, and prevailed on the housing. All the houses looked out at the top in such a way to detect any outbreak of rebellion among the population.

The only open door still intact is the one set on the south side of the citadel, accessible via a bridge over the moat that runs around the outer walls. The construction of the upper part, probably dating back to the Empire period Ashkanide (60 BC) unified with the top part at the end of the war.

There is a legend that this city was founded by Bahman son of Esfandiar, a legendary king of Shahnameh, also called Ardeshir king Archemenide Empire. According to this story the founding date of this city dates back to the ancient Persians, or even at an earlier period. The discovery of the coins of the Ashkanide period, suggests that the legend and reality coincide.

The great ditch that served as perimeter of the walls was built to defend the city, it as a worked double-edged sword, as it was sometimes filled

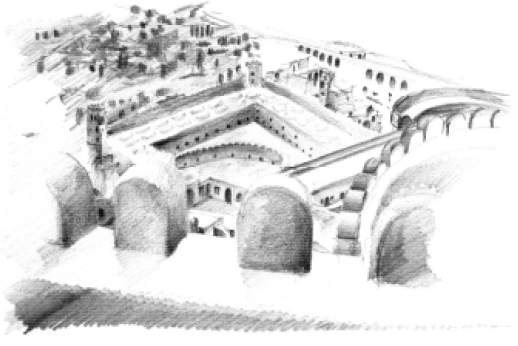


Figure 2. City of Bam (Hosseini Shirvani).

with water by the enemy, which caused some portions of the outer walls to collapse. The great wall, almost certainly built centuries before Islam, structurally consists of adobe, it is characterized by a variable height of about six/seven meters and was built on a mud platform, with thirty-eight towers of different sizes. Some parts of this great wall, which surrounds the city for about 2000 meters, have been ruined and rebuilt at various times, especially during the Mongolian period. Except for the north-west part, the rest of the exterior wall was built before Islam. It is hard to know the exact date of the southern door, the only access to the city gate.

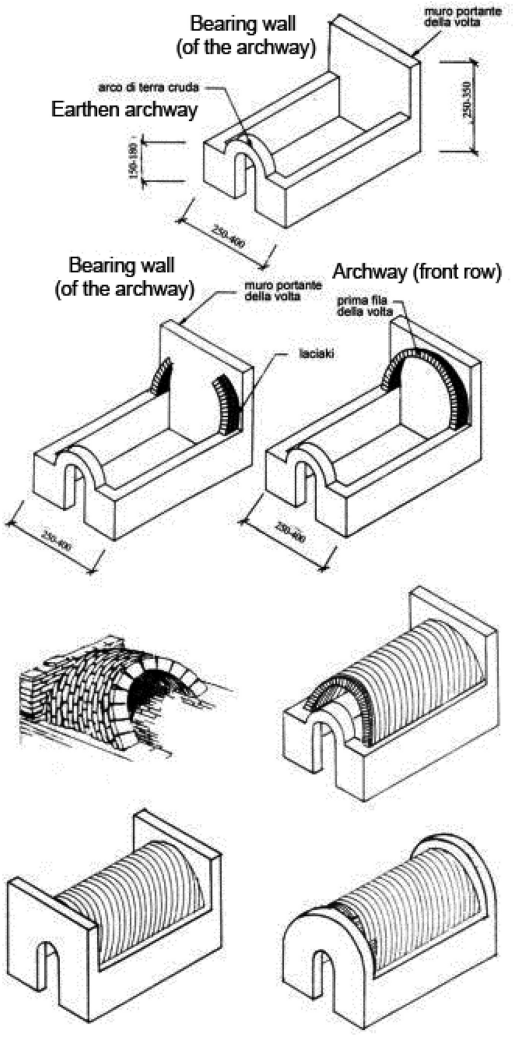


Figure 3. Bam construction techniques: Arches and walls (Hosseini Shirvani).

4 EARTH WALLS AND BRICKS: CONSTRUCTION TECHNIQUES

In archaeological research carried out over Silak hills, the use of mud brick in the construction of buildings can be dated back to 3000 BC. The construction of buildings with this technique was common in every epoch, because the earth was easily collected, processed, transformed, and then used for constructions. In general this construction method covers most of the buildings in villages, in small towns and in big cities, but especially in areas with little rainfall and hot dry climate and desert, appearing under the form of types like caravanserais, bazaars and mosques. Therefore Arg-e-Bam is also made of materials such as clay as a binder and raw earth bricks, but some parts are made of stone, brick and cooked by date tree, whose wood was used as beams. This citadel was inhabited since the beginning of the Sassanid epoch until the conclusion of Ghagiar's period.

The raw earth is produced in several ways: by mixing clay with water, then cut to size, or mixing clay mineral powder with stone dust and water, or forming a mixture of clay with straw and gravel (the presence of straw makes clay more resistant and gravel increases the resistance of it), from the earth taken from the ruins of old buildings in small or large pieces, from the fat crushed clay mixture with the ashes (which has little fat and its presence therefore acts as a waterproofing), from the mixture of clay with goat hair, camel wool and rice bran (which restricts the presence of cracks), with the mixture of animal excrements such as cattle (which gives resistance to humidity and compactness), from the clay mixture with certain plants tissue and finally by the clay mixture together with the fabric of date palm's leaves.

A mixture in the form of a tank called *akhoore* is obtained from the excellent clay packed in one of the methods mentioned above. The *akhoore* interior fills up with water and is left from twenty-four to forty-eight hours in order to penetrate into small particles of earth and make them swell. Consequently the whole is mixed and turned to be ready to fill the mold. In ancient times they were used molds of size $20 \times 20 \times 5$ cm and $25 \times 25 \times 5$ cm. There are also rectangular molds that contain two, four or six spaces to form bricks of $20 \times 10 \times 5$ cm in size. The preparation process takes place in the following way: the perfectly mixed and dense paste is inserted in the mold spaces, with a typing movement on the ground, making sure that the dough enters perfectly, thus avoiding blanks spaces. In ancient times the excess of the mixture was removed using the tended intestine sheep, but today this is done with steel fine wires or a piece of wood.

The soil surface, where the mold is overturned, must be clean and free of any impurities. The molds are then overturned on the ground to remove the tiles. On the mold surface, is spread a little ash or powder of clay or sometimes straw, to prevent the dough from sticking to the mold itself. Every two or three times the surface has to be cleaned by the separator materials, because these, in contact with the dough may swell and disrupt the operation of the mold. To erect the wall, made by individual bricks in raw earth, after having provided for the isolation and the protective layer, the process starts with the overlap of the elements accompanied in mud, bearing in mind that in the green brick layer the space between an element and another must be covered from the top layer for a better bond. The mud must be accompanied by the sand grains, because otherwise it alone would crush under the pressure of the wall.

In order to proceed for the plastering of the wall, you have to build a strong and stable scaffold then clean the work surface by spraying water; when this operation is completed a 7 or 8 mm layer of quick-setting gypsum mortar is spread on the surface. After being mixed with water this is arranged by hands of a trowel and with an angle and a precise direction it begins to spread from the bottom up to a thickness of about seven millimeters. This type of plaster hardens quickly, so it is possible prepare small quantities and placed them in small containers. The mortar of the second container will start to roll out from the point where the previous ended and it continues in this way until the end of a wall, maneuvering the trowel with rotary movements from below to above, from right to left and vice versa, thus obtaining a smooth surface. Regarding the construction types, here this paper is going to analyze the two main ones: the simplest one (*eivan* on front) and the one composed of four parts.

In the first type the spaces are positioned on one side, the rooms separated by doors or windows open to the courtyard, the kitchen instead is placed next to the rooms and close to the water well. The courtyard is characterized by the presence of gardens almost always with a water tank. All the constructions use the ground floor as a cellar to keep food, the bathroom and the services are always placed in this area, which is connected with the upper part through external stairs in the courtyard. The second type provides instead a large central living room with the other spaces arranged around it and the rooms are on the four corners. The building is connected on two sides to the courtyards and in both of them there are gardens and tanks, to refresh the house in summer.

As far as concerns the advantages and disadvantages resulting from the use of this construction technique, it can be said that the brick is made



Figure 4. Adobe process (Hosseini Shirvani).

from a mixture of earth and sand and therefore it must be cleaned with a rag dampened by dust that was collected during the drying process.

With the well-blended mixture is possible to obtain a monolithic skeleton that offers a special resistance even at small earthquakes thanks to the support and snaps of every piece. The presence of raw earth is usually detected in desert and warm areas, where due to the absence of moisture these constructions can resist thousands of years. To create a good resistance to seismic movement tree trunks soaked in tar can be placed (with the skeleton of raw earth positioned above) in the last row of the stone made base with stones arranged vertically.

Finally it can be argued that raw earth construction usually have a greater thickness than the others and so the use of these articles are very common in areas with very hot summers and very cold and dry winter. It is necessary to remember that the new materials have not been able to replace this technique yet and therefore to solve the problem of heat and cold in these geographic areas. Various mixtures can protect the structure for several centuries as you can in fact see in Arg-e-Bam. This method has disadvantage that, the external part of these structures cannot be deprived of protection

because, due to moisture and rain in winter or in other seasons, the structure and the earth granules may swell, destroying the bonds of the various parts and in a short time the city structure itself. To prevent the attack of termites to the earthen structures, it is useful to apply the plugs (called camel plugs) in the mixture, which prevent their proliferation.

Cracks also favor the penetration of rain and snow in some parts, for example in the joints, on the roof and on the external parts that must be filled with very resistant materials. In some cases, the *tamusceh* or clay pipes having the gutter function can be applied in the direction of the cracks. Finally, both the absence of knots in the walls separating the fixtures and the pressure exerted on the crossing of the walls in the vaulted roofs shouldn't be ignored. The absence of a double junction between the latter and the bearing walls ensures more resistance during strong movements. Talking about construction techniques, it cannot be argued that the problems arise from a possible seismic event (as happened in 2003). The action and reaction effect of seismic waves lead to the movement of the frontal walls, moreover the absence of the nodes between the vaults and the fixtures, causes the collapse of the vault and of the arches of the doors (which moved for the tremors).

However using proper techniques you can also protect the structures from these movements. Individual elements, like the vaulted structures, for example, don't have much resistance in case of ground movements because once the walls have undergone a translation they may collapse due to the materials used for the construction. For this reason it is necessary to stabilize the walls through the buttresses. Their presence in the inner and outer walls improves the resistance of the structure, when the walls are larger. You need to build the buttresses along the structure, because if made then by drying with subsequent withdrawal, they can detach from the rest of the structure and losing effectiveness. The earthquake safety in earthen structures follows very precise rules. For the window frames and doors, for example it sticks out of twenty centimeters the socket fixed inside the wall in the width of the wall are then placed three long trunks, one of five-eight centrally, while the other two of a six-three fixed to the column and together with each other through a piece of wood.



Figure 5. Bam: Panoramic view (Hosseini Shirvani).



Figure 6. The main entrance called Narmashir located south of the city, with the bridge on the big ditch (Hosseini Shirvani).

5 CONSERVATION PROJECT

The Bam Cultural Heritage is one of the most important examples of an ancient Islamic city with a almost complete ensemble of all urban elements generators and characteristic such as palaces, houses, mosques, khans, hammams, bazaars, workshops and fortifications. Also it provides a wonderful example of houses entirely built over clay layers that documents the city ancient history. Unfortunately, on December 26, 2003, in the early morning, a violent earthquake measuring 6.5 (Richter scale) devastated a large area of Kirman province with serious loss of human lives.

The epicenter was located about 10 km southwest of Bam, along Kamari fault line that cuts east-west across the region. Half the population of Bam disappeared, the new city was completely destroyed and Arg-e Bam (the ancient city) reduced to just ruins. The international community responded quickly to the rescue of this heavy human tragedy both for the recovery of the city and for the preservation of the exceptional cultural heritage of Arg-e Bam. In fact the citadel as well as being a major tourist destination, a vital resource for the region, was the historic al testimony and cultural identity of the whole country as a symbol of a glorious past.

Organizations such as UNESCO, ICOMOS and ICCROM have planned, together with the Ichto (Iranian Cultural Heritage Organization) the recovery program of the Cultural Heritage hit hardly by the earthquake. In 2004 Bam and its region became part of the World Heritage (UNESCO).

6 INTERVENTION AFTER THE 2003 EARTHQUAKE

After the earthquake, the Italian Government has been involved in the recovery project.

After several examinations, MiBAC has opted to restore and safeguard the no. 1 tower on the southwest wall.

The intervention of seismic restoration (limited to a small sector of the fortification) is experimental and it is the model repeated on a large scale.

The tower can be considered a multilayered system with masonry bodies added in the outside support.

The oldest part has a rectangular shape with a slightly rounded corners and it is built with regular courses of square mudbrick enticed with colloidal sandy-silt mortar.

The restoration works have concerned consolidation phases of the tower, which consist of a system of parallel walls, with a sloping profile.

They rely on pre-existing structures are realized in lots with the function of close and tighten, they contain two elements: the embankment and structures (in new tower elevation process).

The collapse also highlights a vaulted roof on the south side, obliterated in the tower core.

The recovery phase of this part complies with the vault construction technique, perfectly adherent to the Iranian constructive model.

All the interventions have been imposed by specific technical and behavioral characteristics that define the earthen structures.

Finally, other further restoration works are characterized by a different organization and spaces' distribution on higher altitudes, which stood on the pre-quake pavement levels.

7 CONCLUSIONS

This case study wants to emphasize the architectural technique in raw earth, focusing on both the history of the citadel of Arg-e-Bam and on the earthquake that heavily affected this geographic location. The collected data by the writers in situ allowed the full development of the research, arguing in a vertical manner (from general to specific) all the problems found during the research. As mentioned above, the construction system in raw earth is among the most popular in the world, but faces challenges of updating and revisiting the structure to handle the seismic risk, dangerous even for traditional building types.

The citadel was almost entirely destroyed by the earthquake, but the buildings that have succumbed had undergone restoration and remodeling since 1950, while ironically, those who had not been subjected to any modernization suffered less damage or even remained completely unharmed.

The case of Arg-e-Bam is, on this point of view exemplary: although the traditional earthen buildings were those expected to have the lowest resistance and to collapse, the ones which were completely destroyed were the buildings in which steel modern and heavy masonry roofs levied on existing brick walls, rather than the hotels in adobe built with the ancient vaulted systems.

These and other disastrous examples of earthquake-resistant buildings, where ancient technologies combine effortlessly with contemporary ones, must serve as an example for the potential dangers arising from the insertion of works and timely interventions in the traditional construction systems of historical buildings, when this is subjected to some work to improve the seismic resistance.

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Vernacular heritage in Mendoza (Cuyo region, Argentina)

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ABSTRACT: Vernacular architecture in Mendoza is the result of two conditions of the physical environment: the aridity of the climate and the high seismic activity, and due to its authenticity and originality it represents a very valuable part of the region's architectural heritage and the most vulnerable. This paper summarises the results of a series of systematic studies (historical, cataloging, restoration) that our team has been carrying out for several years in these types of buildings. The aim is to provide a brief description of the most significant architectural types and to explain the development of different constructive traditions. Lastly, the imminent dangers to which these buildings were and are subjected, with some at risk of extinction, are pointed out.

1 INTRODUCTION

1.1 *Mendoza, an irrigated oasis*

The Cuyo region, with Mendoza as the main city, has characteristics of its own that bestow the region a particular identity within the Argentine territory. Since the foundation by Spaniards in the middle of the 16th century, Mendoza's development has been strongly conditioned by two factors inherent to the natural physical background: a) the aridity in a desert environment and b) the high seismicity of the region.

Human settlements have been linked, since pre-Spanish times, to the presence of water. The regional economy, based on agriculture and the distribution of the population are highly dependent on artificial irrigation. This has determined the conformation of irrigated oasis ecosystems, using and systematizing hydric nets fed by rivers. In the case of Mendoza, these oases occupy a minimum part (4%) of the province's surface where 97% of the population is concentrated.

Mendoza city is in a high seismicity region, with violent earthquakes recorded along its history.

The hazard zone coincides with the arid and semi-arid diagonal of the country, where both cities are in the most dangerous zone.

These two conditioning factors have affected the architectonic production since the early years to the middle of the 20th century when the traditional solutions gave way to the effects of modernization and technology.

Vernacular architecture adapted adequately to the environment in these bioclimatic aspects as well as in the use of regional materials. Due to their scale and dimension, the settlements did not destabilize the natural ecosystems until the end of the 19th century.

1.2 *Vernacular production*

In the case of Mendoza, this Hispanic city, which was founded in 1561 on an indigenous Huarpe agricultural settlement, had systematized the use of water coming from a branch of the Mendoza River. Water constitutes a structural element in the oasis' organization. The evolution of the city proves a strong subjection to a primary net, organized in the pre-Hispanic times from the use and systematization of the natural watercourses in relation to the topography and the slopes. This hydric matrix conditioned the location of this Spanish city and the structural plotting of the territory: the streets, the roads, the urban and rural cadaster, and the location of buildings and cultivated areas in the flat plains.

The buildings were very low, one-storey with walls of thick adobe or rammed earth (locally called *adobón* or *tapia*), reed and mud roofs over poles or wood tie beams. Descriptions by travelers in the middle of the 19th century coincide in their praising of its gardens and orchards, and also in the flatness and sparseness of the buildings, where only churches outstood. The agricultural activity, together with an intensive use of the soil, determined a territory organization where differences between rural or urban, faded. This means that the city had quite a rural appearance due to the low density, the presence of many orchards, vineyards and cultivations, and the surrounding agricultural land, organized by the irrigation net, had buildings as good as those of the city.

The vernacular architecture has been generally characterized by two factors: one, the prevailing development of unbaked mud architecture, and low buildings. The available materials of an arid environment were mud, reeds, found by rivers and lagoons and very scarce wood.

The lack of wood heavily influenced the building traditions up to the 19th century. In particular, this lack made it impossible to install brick kilns that used wood as fuel. Instead, adobe was used for curious roofing such as the mud domes, with or without the supporting framework.

The consolidation of the agricultural oasis, the availability of wood from the crops (fruit and olive trees) and the introduction of some foreign species that rapidly spread like the poplar tree (*Populus alba, Populus nigra, Populus canadiensis*) gave way to important modifications in 19th century architecture. Buildings became progressively lighter and modulated. Columns and breast summers appeared in traditional galleries (semi-open spaces as extension of inhabited locals), instead of the solid pillars with arcades of previous years. Dome covers and the roofs with a marked pitch disappeared.

The earthquake of 1861, which was very destructive, notably affected the architectonic production of the region. Popular knowledge was then reformulated new and ingenious solutions were sought after, where the technical knowledge of specialists and the building techniques of other seismic regions (Central Valley of Chile and Peru).

After the great earthquake (1861) the buildings were still made with mud systems as they were considered more elastic, needed cheaper resources and it was technology at everyone's reach.

Technological innovations were the adding of resistant wood structures, using adobe, and walls of reeds rendered with mud (locally called *quincha*) in the closing or interior walls. Works produced since then cover a wide range of variants where mud systems, light *quinchas*, and wooden frameworks were combined.

Even though buildings were still low and one-storey, these technological modifications affected the spatial form. Floor plans as well as façades tend to symmetry and to modulate openings and columns. These modifications were fed by a new cultural tradition from the Italian and French immigrants who had been arriving in the region in large numbers since 1880. Vernacular technology and forms are presently maintained in the architecture of rural or urban periphery zones—especially in domestic architecture—where the building replacement has been slower.

2 THE CRIOLLO TRADITION

The criollo cultural tradition has its foundation in the Spanish dominion (middle of the 16th century) and has developed it over three centuries (the Criollo is the Spaniard offspring born in America). The Hispanic influence prevails in the cultural process that incorporates the Huarpe builder's tradition on the management of the region resources, within a situation of isolation. The architecture is a Mediterranean type, low, single level using a system and technology based on adobe or rammed earth.

In the urban zones, the buildings have few openings and are closed to the outside; life develops in the inside around patios and orchards, with a special microclimate created by vegetation and water in contrast with the environment. It is possible to identify the Arab tradition in the network of irrigation ditches used to water patios and gardens. The floor plans are a combination of a single row of rooms with undifferentiated use, and open galleries defined by masonry pillars and arches or wood columns. The colonial' architecture does not manifest an aesthetic intention but a strong subjection to conditions such as the climate, the environment and available resources.

2.1 *Building types*

2.1.1 *Houses*

The agricultural and semi-rural character of Mendoza city means that there is scarcely any difference between urban and rural houses. The floor plans are L, U or T (inverted) shaped, and they spring from the line—above the rooms, which are almost identical and of undifferentiated use. The attached galleries have a freer disposition in the rural areas (double gallery, frontal gallery) than in the city, where these elements appear introverted.

Open and semi-open spaces such as patios, orchards, and galleries have a central role in everyday life.

2.1.2 *Chapels*

Chapels are built in rural locations, for religious worship, sometimes of the missionary type. They are generally part of a group of houses, bell tower, and cemetery. The floor plans are narrow and deep, and there is always a closed area used as an oratory, and an open area (galleries or atria) for catechism or mass celebration for a large Indian or peasant population.

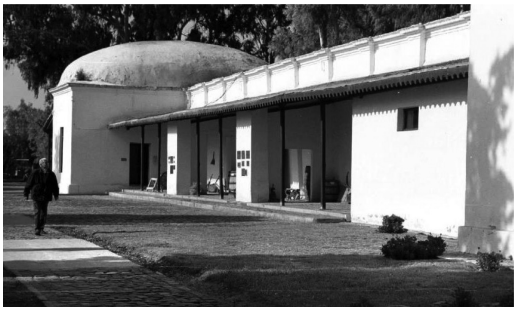


Figure 1. House Bóvedas at San Martín, Mendoza.



Figure 2. Main house in Panquehua at Las Heras, Mendoza.



Figure 3. Rural house in Bermejo at Guaymallén Mendoza.



Figure 4. Chapel of Rosario in Lagunas, Lavalle at Mendoza.

Chapel of Rosario in Lagunas de Guanacache, Lavalle—Mendoza: Built at the end of the 18th century and rebuilt with the same characteristics after the 1861 earthquake. It is a traditional chapel

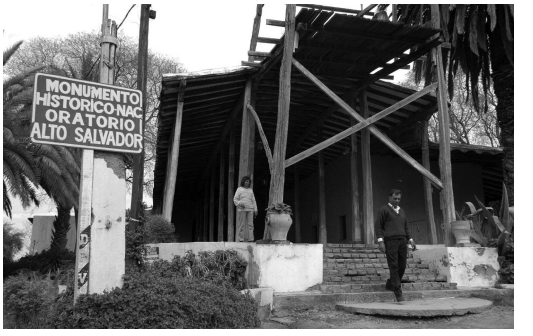


Figure 5. Chapel Alto Salvador at San Martín, Mendoza.

of the aboriginal population of the ancient Lagunas de Guanacache. This chapel was built with adobe walls, has only one nave, very narrow and deep. It has two choirs and a balcony with eaves, from where mass can be celebrated in the open-air atrium. Since the 20th century, the change in ecological conditions of the lagoon oasis determined that these territories, converted into deserts, were only suitable for breeding goats.

The chapel is currently the gathering point of the scattered population of this vast region, and at same time represents a testimony and a symbol of a cultural group that refuses to disappear.

Capilla de Alto Salvador (San Martín, Mendoza): Built in the middle of the 19th century. The group is formed by a closed chapel (oratory) for the private worship of the landlord family, an open chapel (gallery) used to celebrate mass for the peasants and catechism; a house (now museum) and a bell-tower/*mangrullo* (pole lookout used to watch for Indian raids).

The group is an accurate insertion in the surrounding agricultural landscape.

2.1.3 *Mills*

Rural buildings of an agro-industrial type, testimony the cereal stage of the regional economy, before the development of the wine industry. The mills are placed by water-courses as they used hydraulic energy to grind the grain.

3 THE "IMMIGRANT" TRADITION

From the middle of the 19th century, modifications began in the Criollo tradition in relation to spatial forms as well as to technologies. Modifications answered to two concurrent motives: The process of cultural modernization and the arrival of the European immigrants.

In Mendoza, the 1861 earthquake greatly accelerated changes as it meant an abrupt rupture with

the past and allowed for an almost total renovation in architectural production.

Although most of them were dedicated to agriculture, many had trades connected with buildings and brought knowledge and books: handbooks, treatises, and guidebooks from their country. The cultural predominance of the Italians is evident in the rural and urban houses organized on regularity and symmetry, and they typify outlines that have been endlessly repeated for decades.

The Italian presence is noticeable in the modulation of facades and metrics, in the classic proportions of wineries, the use of baked brick, and the numerous ornamental and decorative elements. In contrast, the French presence is less important than the Italian, but is evident in the adding of certain combined technologies of wooden structures, frameworks and mud closings.

3.1 *Building types*

3.1.1 *Urban houses*

The "row house" resulted from a process of synthesis between a Criollo tradition of houses, patios, orchards, with galleries and the cultural contribution of Italian immigration that adapted to the new conditions in narrower urban lots and with a more rigorous spatial array.

The type is very versatile and adapts to different situations. If the land plot is narrow, the patio is rectangular, if it is wide the patio is square as in earlier years, but keeps a strict symmetry and modulation. The galleries are always on the inside, while the 20th Century, ones are closed with glass screens (or glass doors).

The typical immigrant house is structured in three functional sectors: the front with the social or business area; another in a row with an affixed gallery that constitutes the main sector of the house and contains the bedrooms and dining room; and a back sector towards the rear with kitchen and bathroom.

3.1.2 *Rural houses*

The typical housing of the contractor (where Italians prevailed) invaded the farms of the agricultural periphery. The outline of the floor plan is a double-row rectangle with an open hall over the longer side. The rooms form an inverted "U" that can have an affixed gallery at the rear. The hall is

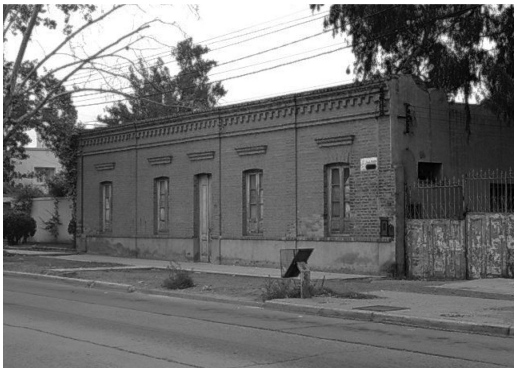


Figure 6. Urban house in Bermejo at Guaymallén Mendoza.



Figure 7. Urban house in Guaymallén Mendoza.



Figure 8. Winery Terrazas, Agrelo, at Luján de Cuyo, Mendoza.



Figure 9. Winery s. XIX—Maipú, Mendoza.

roofed, has two pillars that mark the entrance, and communicates to all rooms. The kitchen can be placed in one of the lateral rooms, while the bathroom is always a latrine outside the house (Cirvini et al. 2009).

3.1.3 *Wineries*

The most typical and representative industrial buildings of the region, the wineries are essentially for storing wine, and were always built at soil level, even though since 1885 buildings of industrial scale started to have cellars with one or more levels.

The wineries from the end of the 19th century, of Italian influence, are the same simple prismatic buildings, but have notably varied proportions, modulation, and the façade treatment. The use of baked brick of Italian tradition, and the appearance of numerous ornamental and decorative elements from the classic repertory: pilasters, cornices, arcs, etc. manifest a clear aesthetic intention. This tradition was widely spread over half of the 20th century.

4 THE VERNACULAR ARCHITECTURE TODAY

In the province of Mendoza, there are two fundamental types of buildings of this vernacular earth heritage:

1. large scale building, such as mills, wineries, chapels and manor houses, usually with declarations of MHN (Historic National Monument), and:
2. A vast array of minor buildings, both of rural and urban domestic architecture, composed of numerous homes and small wineries that are completely lacking in protection and care.

Both groups suffer from the subordination and devaluation of earth buildings. In the case of monuments, they do not have particular treatment, nor do they have periodic maintenance, nor proper management plans and this usually results in premature deterioration in earth constructions. Although they have small maintenance budgets, they are generally the ones in a worse state (Cirvini & Gómez 2005).

On the other hand the assets of so-called "modest heritage" are no better off. They are victims of the mixture of materials and systems and endure frequent, anti-regulation interventions. As any intervention in adobe buildings is prohibited, the reform works are done clandestinely, without the mediation of professionals who understand these systems and technologies and are therefore already forgotten and in disuse. This heritage is vanishing because of the replacement of buildings.

In Mendoza has not prospered the development of new earth constructions due to cultural rather than technical reasons. It is an alternative of a few ecological groups that prefer to save energy and recover symbolic aspects of this type of architecture. But it is not an option to solve the problems of mass popular housing from the State. The common inhabitant, whether rural or urban, is attracted more to bricks which are more accessible, economical and associated with the culture of progress (Guerrero Baca 2007).

In Mendoza, municipal regulations prohibit the use of material and systems of raw earth in new constructions and limit construction work that can be done on existing buildings which have contributed to the progressive increase of their discredit and of the material and systems. The loss of value and of meaning of the vernacular earth heritage is "dragging" the current earth construction into disrepute, resulting in an initial devaluation that hinders its development.

There are also few technical resources specialized in the management of these technologies, both artisan and professional, since neither the training of current architects or engineers, nor artisan labor contemplates training for earth construction and less still the conservation and restoration of earth architecture, neither from the conceptual nor from the practical.

It can therefore concluded that the most valuable and ancient vernacular heritage is in a difficult situation and almost at risk of extinction.

5 CONCLUSIONS

In the region, the earthen building technologies have created real long-lasting traditions, whose origins are traceable to pre-Hispanic times. These technologies developed into varied forms until almost disappearing, due to the influence of modernization. Earthquakes have worked as catalysts of technological innovations in the region. After the destructive 1861 earthquake this search for better buildings solutions was aided and enhanced by the foreigners' presence, as they were carriers of different knowledge, that combined with the local available resources resulted in novel solutions.

The Italians had masons who were outstanding in the use of fired brick for walls, arches and domes; the French had notable carpenters who introduced elaborate wooden structures combined with the ancient *quincha* technology.

The 19th Century brought along significant changes in different fields of the local lifestyle. The socio-cultural process became greatly dynamic and left its footprint in the architecture of that period. On the one hand, the use of adobe gets spread and

wood became much more available in this expanding oasis than in previous years. On the other hand, the commercial activity brought to the area materials, staff, and people from other cultures. This situation was prosperous for many changes, regarding not only construction methods but also cultural guidelines related to the everyday life and the way of living, which represents the preface of the big transformations of the modern age by the late 19th Century.

The big 1861 earthquake was considered a landmark, a turning point for the life of the city and its citizens. The breaking of its physical integrity contributed to the blurring of the past and created the concept of a founding reconstruction.

This was a period where land architecture displayed a wide range of construction systems, with great technological and typological value. Then the 20th Century modernization imposed, in a gradual but relentless way, the use of new materials, such as steel and the innovative reinforced concrete, setting the traditional construction systems aside, especially the use of earth.

Lastly, the current situation of earthen architecture and associated heritage will be summarized.

Most of the oldest heritage buildings that Argentina has are built in adobe or rammed earth. In some regions, such as the Northwest and Cuyo, this heritage reaches between 75% and 90% of the total Historical Monuments declared as such. This heritage, usually from the colonial era, is the most vulnerable to erroneous interventions, the most affected by the barrage of techniques and modern materials which are aggressive and contradictory to the historical message of authenticity.

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Comparative evolution of vernacular mudbrick houses in the Nile Delta and Qurna (Luxor)

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ABSTRACT: Whilst during the 20th century mudbrick architecture developed into a symbol of poverty in the north of Egypt, the specific circumstances of communities such as Qurna (Luxor)—constantly threatened with destruction by the authorities due to its being built on top of ancient Egyptian tombs—meant mudbrick houses turned into a symbol of community life preservation. How did these particular circumstances reflect on earthen buildings and can they throw light into the comparative presence or absence of specific architectural features? Conversely, what part did abandonment and progressive replacement play in northern building characteristics? This paper will aim to answer these questions through a combination of key fieldwork data collected in both areas (2009–2011) and examples from a photographic archive, hitherto unpublished, showcasing Qurnawi architecture throughout the 20th century before its large-scale destruction (2006–2009).

1 INTRODUCTION

Mudbrick had been the vernacular building material in Egypt for millennia. However, several complex factors operating between the 19th century and recent times prompted the beginning of the decline of traditional domestic architecture. Whilst such changes occurred across the country they were more obvious in certain areas, notably in the Nile Delta, where mudbrick houses have become the exception and a mud-based village fabric is no longer visible. Geographical, political and social changes had an influence in house location, distribution, features and building material, as well as in the quantity of mudbrick buildings, which dwindled through time.

An exceptional case within this conjunction was that of Qurna (Luxor, southern Egypt), a community built over ancient Egyptian tombs and whose history is intertwined with that of ancient Egyptian discovery and study. The particular circumstances of this community encouraged, for a large part of the 20th century, the preservation of a number of traditional mudbrick house features which became rare in other areas. Moreover, their adaptation to the Theban hill topography and their quest for preservation against governmental wishes, resulted in a particular number of individual solutions worth studying.

This article seeks to present a body of data previously unrecorded, as well as summarising a series of possible factors resulting in different mudbrick architectural solutions and in the evolution of this architecture in two distinct areas. It also explains briefly the means in which the gathered information is being preserved, processed and ultimately disseminated for public use.

2 THE CASE OF QURNA: A CELEBRATION OF MUD-BRICK ARCHITECTURE

Qurna was the name of a collection of small settlements on the Theban foothills on the west bank of the Nile at Luxor, Egypt. The foothills are a necropolis, a large cemetery used for over 2000 years, with tombs from approximately 2000 BC scattered across the many levels of the hillside. It has been a focus for collectors, excavators and tourists for over two hundred years, but its open tombs also provided temporary refuge to local people for far longer. To take advantage of the work provided by excavators, collectors and tourists, from the late 18th century many families who had lived in northern tombs and a village nearby, then took up permanent residence in the hillside tombs. Living in the City of the Dead gave them homes and a livelihood, but in the long run led to the death and destruction of their community.

Initially they built low walls round a yard outside their tomb, and many mud structures for storage, animals and cooking both in and outdoors. In the early 20th century, realising that the

Antiquities authorities were keen to claim as much land as possible, the Qurnawi enlarged their yards and extended their walls. In 1921 a detailed survey recorded the houses and enclosed spaces so that any further expansion could be prevented (Survey of Egypt 1924). The habitable areas were thus fossilised around the tombs.

The first post-Coptic building on the hillside, built by a European collector, Giovanni D'Athenasi, in the 1820s, was a multi room, two storey building, with a large yard surrounded by a mud-brick wall. In the later 19th century some local people also built one or two storey square cornered houses, but many more built low, simple dwellings with reed roofs in the tomb courtyard while the tomb was still their main residence. These first simple houses usually had walls made with mud and stone mixtures, left to dry and then built up gradually. During the first half of the 20th century the most important, decorated tombs were vacated and became archaeological and tourist sites, but many of the tombs were of no such interest, so occupation continued, and yards were extended when possible. Most families built proper houses outside their tomb-houses, usually leaving the tomb entrance in the back yard, but sometimes as a cellar. In the 1930s and 50s most of the substantial square-cornered mud-brick houses were built. There was major re-use of building materials that were lying around the hillside, such as pieces of limestone (carved or plain) from tomb construction or various earlier stone buildings, and mud-bricks of many sizes from the old Coptic and Pharaonic buildings and the tomb fore-courts; large fragments of broken ceramic water pots were also incorporated into walls, but most new buildings required new locally made mud-bricks.

The pattern of the houses was largely due to the position of open tombs. Some stood alone on the hillside, but they were mostly in randomly shaped family groups which might have been above a group of tombs, or one extended family who had built additional buildings in the courtyard. There were no actual roads on the hillside—no straight lines—only paths for people and animals. The majority of the houses had two storeys, and a family group would have a mixture of one and two storey buildings. Built of mud-brick and usually rendered with mud plaster, they were often painted with Hajj paintings by local artists (Parker & Neal 1995). Many had brick and mud-plaster mouldings decorating the tops of the walls, and around the doors. One or two houses had large curved outer front walls which reflected the shape of the hillside behind. The large square house of the mayor had many rooms distributed over two floors and the huge tomb beneath was the village jail. Some had verandas at the first floor; the first floor of some farmers' houses had big loading doors with hoists to storage lofts.

The workshop of an alabaster vase-maker was in the big tomb at the back of his small house high on Dra Abu'l Naga, the most northerly of the settlements, where he lived with his parents and five children.

The actual shape and plan of the houses was extremely varied. This was partly due to the occupation and relative wealth of the family, but also to the number of live-in sons and expanding families, and again due to the actual position of the original tomb-house. As the family grew, so did the house; additional rooms were built up and out where possible. All the houses had flat roofs, whether above the ground or first floors. Most solid roofs had timber beams, with reed or mid-ribs of date palm leaves above, and then surfaced with mud. Many roofs were accessible by a staircase and used for storage, drying crops and clothes, sleeping on hot nights and more recently for satellite dishes. The simpler houses had roofs made of palm branches or reeds. While stairs to an upper floor were of normal width, staircases which just led to the roof were often very narrow and cantilevered from a wall on timber supports and the steps themselves roughly moulded from mud, straw and stone mixtures (Henein 2001: 46–49).

There were few fixed uses to most rooms, apart from one where the husband and wife slept. *Dekka* (long wooden benches) and cushions could be moved easily, so people could sleep anywhere—inside or out. The *mandara* or main entrance room or a room off it, was where guests were greeted and



Figure 1. Sheikh abd el Qurna c. 1910.



Figure 2. Sheikh abd el Qurna in 1994.

entertained. Often food was eaten laid on the floor here. The *forn* (bread oven) was in the yard, and modern kitchen equipment fixed the kitchen area, usually on the ground floor.

Most households kept some birds and animals for food, looked after by the women and children. Sometimes a room, usually on the first floor if there was one, would be for pigeons, and mud roosting-places were created on interior walls, staircases and tombs. Other birds were in pens in the back yard, or mud bird houses in the yard or tomb. Goats or sheep were also in pens off the yard, or in a room on the lower floor. Some families also had a cow or buffalo—occasionally more than one—again kept in a lower room, stable, or pen off the yard, or sometimes in the tomb. There were some houses where the ground floor was exclusively for animals and farming—crops and machinery.

Water damaged the tombs, and there was no piped water in the hillside houses. In recent times, all water was brought up from the water taps down below the hillside by donkey carts with ex-oil barrels or by women carrying large water-jars. Nearly every dwelling had to have a space, preferably inside the front yard, for the cart and the donkey. Until the late 1970's there was no electric lighting in the houses, and it was very much an outdoor culture, both day and evenings. *Dekka* were often outside in the front yard, in addition to the mud-brick *diwan* or *mastaba*, a bench built off the bottom of the exterior wall.

The shape and form of some living spaces was very much central to the occupation of the male members of the family. One family of Coptic weavers on Sheikh abd el Qurna had a very simple exterior space and when indoors lived mainly in one small room and their tomb. After climbing the hill the visitor was faced with a pale washed wall, the lowest metre or so built of large pieces of limestone, and the rest mud-brick covered in rough mud-plaster at the higher level. The door, with raised mud moulding round it, faced west to the tourists and road below and led to the enclosed, partially shaded little yard which was their day-time space. This space was a workshop filled with the long loom which Rushdy or his older sons worked almost every daylight hour, and the other end of the space had the earthen *forn* for bread making that was exclusively the work of his wife, and daughters. Haniya, his wife, sat on the ground and did the spinning, while the older kids were often out selling trinkets to tourists. There was one small room extending from the workshop. The roughly shaped window and roof were made of re-used timbers, and the window had wooden shutters. The back wall of the workshop was the limestone of the hillside and the tomb entrance.

Many of Rushdy's poor neighbours from the higher occupied levels of the main central settlement of Sheikh abd el Qurna, who had moved off the hillside in the previous fifteen years, also mainly lived in the tombs and had small low-wall enclosed areas outside them with the characteristic mud storage and cooking structures (Borchardt and Ricke 170: 188–192). The 'Nobles Shop' was down near the car park of the much-visited Nobles Tombs area, and the shop-owners made their living from selling to locals and tourists, some farm labouring, and breeding goats and sheep. They had a fairly formless, mud and mud-brick low building with a reed roof covered in heaps of straw, a group of low tombs and the open courtyard between. Often the lack of a second storey indicated a poor family, but not always. Mahmoud abd er Rasul, multi-lingual and well-travelled, was the owner of the popular Ramesseum Resthouse, but had a low, unimposing house with a large outdoor area with many chaotic animal pens and working spaces. Mohamed Lazim was also a richer man, and the village headman's family house had been there since the late 19th century, but it was still a single storey range of buildings with a small open front space, and a large low-walled yard at the back and side. It may be that Al Sadat's Presidential Decree No. 267 of 1981, which forbade any new construction or extensions in the archaeological area, had indeed prevented these two owners from building a second floor.

In Lazim's yard there was a family *zawyeh*, or meeting room. There were many *zawaya* on the hillside, sometimes a single-storey free-standing building, sometimes a special open fronted room on the outside of the main house (Simpson 2001). They were easily accessible, often had verandas, and enough floor space for many benches to hold a large family gathering. They were usually clearly visible on the hillside as they were there to welcome guests, often in the dark.

3 THE DECLINE OF MUDBRICK ARCHITECTURE IN THE DELTA

In contrast to the more widespread preservation of mudbrick architecture in southern governorates, of which Qurna was a prime example until recent times, Delta governorates suffered a dramatic decrease in the presence of vernacular architecture, to the point that nowadays most villages are home to none, or only one or two, mud-brick houses, which have been trapped amongst the many red brick and concrete buildings around them (Fig. 3).

The reasons for the different development of both areas are complex and manifold, as it is the case for all vernacular architecture. Social, cultural



Figure 3. A mudbrick house in Kom en Naggar, Gharbeya.

and political factors amongst others influenced the recurrence and preservation of mudbrick architecture in Egypt. Egypt's most precious resource—despite recent difficulties—also had a direct effect on them; while Qurna's houses were deemed to cause 'sight pollution' by Egyptian officials (Hawass 2008) who saw them as an obstacle for the preservation and touristic appeal of the ancient tombs underneath, it was largely due to tourism that the communities made a living and that the nostalgic view of ancient times conveyed by mudbrick fabric and wandering people and donkeys endured.

The following data was collected between 2009 and 2011 through individual fieldwork, mainly in the Gharbeya and Kafr el Sheikh governorates. As seen in Qurna, a sturdy type of roof built with wooden beams and a weak type made with reeds, could also be found in the Delta area; weaker roofs were usually present in animal and storage areas, although they could be used regardless of room function if the financial situation did not allow for sturdy roof building. The main difference resided in the external finish of the sturdy roofs; whilst in the Nile Delta the majority of roofs were finished with branches and/or hay piled on top of a flat surface, this was a rare occurrence in Qurna, where objects were stored directly on the roof top and the presence of any hay there also pointed at its storage and was not structural. In the Delta, there was a low proportion of unroofed rooms, which in turn could be commonly seen in Qurna. The main explanation given by oral sources for such differences was the fact that precipitation in the Delta was more abundant, hence the presence of a thick roof providing the required protection from the rain. In reality, both areas are subject to flash floods and although rain is more frequent in the north (compare the annual 26 mm of Cairo with the 1 mm of Luxor, www.climatedata.eu), it does not offer a solid enough justification for the differences in roof finishes.

House walls in the Delta are almost ubiquitously built with mudbrick, while the use of wattle and daub for walls is confined to low fenced areas, such as pens, and stone is only used for foundations and only very seldom. Several types of bonding were recorded and brick-on-edge appeared often to be used as structural reinforcement for roofs or openings. Similarly, the colour of the bricks varied both within each area and between areas, being directly related to proximity to water sources, particularly the main body of the river Nile, which determines a higher proportion of muddy earth vs sand, therefore affecting colour and consistency. The manufacturing process was essentially the same in the two areas, the main difference being the exact size; however, this size could also vary between different villages within very little distance and seemed to reflect the masons' preferences. Mud mortar was used to stack bricks together. The proportion of straw in the rendering could vary within the same area, giving walls a different aspect; whilst in the Nile Delta most houses were not painted, whether due to it not being preserved or to the original design, in Qurna the majority of facades were painted over the render, which facilitated the analysis of the render. Where walls were painted, they present similar Hajj pilgrimage designs to those described for Qurna.

Traditional and Western-type doors were present; locks were widespread but their specific features seemed to respond to the amount of security that the owners felt was needed, rather than to regional preferences. For example, within the same area, locks with a pronged key could be found inside or outside the front door. Arches or buttresses around main doorways played a decorative, structural and protective role, ensuring the safeguarding of the house. On the other hand, features such as fan lights revealed practical requirements, for example house ventilation.

Windows were similar to those described for Qurna, though openings could also be covered with grills made from branches, rather than metal.

Additional features, such as mud drainage channels at doorsteps, were characteristic of the Delta, as this area was susceptible to flooding prior to the build of the dam; for the same reason, some examples can be found in specific locations in southern governorates.

Balconies were rare; their presence could have been linked to architectural trends which, it should not be forgotten, would have also occurred in the history of mudbrick houses, and whose presence in rural areas might have been influenced by the same social processes that prompted the appearance of red brick, that is, a desire to show affluence.

Just as was the case for Qurna, animal keeping was essential. Birds could be found roaming

on upper storeys and structures dedicated to the breeding and keeping of pigeons whether external or internal were ubiquitous, reflecting the importance of these birds for food and the production of fertiliser. Other animals such as cows were frequently found in ground floors and in areas immediately off houses. *Mastabas* and *dekka*, such as those described for Qurna, were also present, reflecting Arab traditions regarding the importance of hospitality and of having a socialising space open to the community. The lack of community fabric associated to mudbrick meant the disappearance of *zawaya.* Ovens were present too, indicating the habit of each household of producing their own bread.

Mud containers were also a prominent feature, sometimes with an added structural function, acting as pillars supporting partial roofing in upper storeys.

The most apparent difference between preserved houses in the Nile Delta and those in Qurna was in the roof and number of floors. While Nile Delta houses almost invariably were single-storey high, Qurna houses were no different from most southern Egypt houses in presenting several floors, though, as has been detailed above, single storey extended dwellings were also present. As is well known, maintenance is paramount for mudbrick architecture, and upper floors are particularly vulnerable to it. In the Delta, only solid staircases appeared to have been preserved, while the cantilevered staircases used to access the roof in Qurna were not recorded. Niches featured in them; in addition to the niche practicality for economising space, they also perhaps reflected difficulties for acquiring furniture. When located on the side of staircases they also were an indication of the low natural light level conditions, which meant that traditionally oil lamps were required. In addition, as explained, Nile Delta roofs were often covered by large piles of hay, plastic, etc; while this was infrequent in Qurna, where roofs could be used for storage, but they were normally flat and large amounts of coverage did not feature.

4 SOME REFLECTIONS ON GEOGRAPHICAL, POLITICAL AND SOCIAL CHANGES AFFECTING DOMESTIC ARCHITECTURE THROUGH THE 19TH AND 20TH CENTURY

The damming of the Nile was a fundamental factor affecting Egyptian domestic mudbrick architecture. It was prompted by the cultivation of all-year-round crops, which became necessary in Egypt in the second half of the 19th century due to the need to feed a fast-growing population, as well as the external demand for products such as cotton, amongst other factors (Ibrahim 1982: 63). While cultivation in the Nile valley had relied for millennia on the annual flood (Ibrahim & Ibrahim 2003: 73), these new crops required permanent irrigation, and for this to be possible, it was necessary to raise the groundwater table. To achieve this, several attempts were made to dam the Nile which culminated in the building of the Aswan dam at the end of the 1960s. This affected mudbrick architecture location, distribution, features and material, as well as the overall number of buildings. Location, distribution, and features were affected by these changes in landscape and land cultivation; while the flood forced rural communities to build very dense villages on high ground, the building of the dam allowed the habitat to become more disperse by allowing the possibility to build on flat ground (Demangeon 1926: 173).

In addition, because of the need to be permanently close to the crops, new types of extended habitat appeared, located in the fields, to host all the land workers, 20 or 30 families living in simple accommodation all arranged around the foreman's house (Lozach 1930: 40, Mahgoub 2000: 6).

Lastly, the building of the dam affected individual houses directly because those built before the dam started to collapse when the groundwater rose. This had a particularly dramatic effect further south from Qurna, in Egypt's border with Sudan, where 70000 Nubians lost their homes and had to be resettled elsewhere, in most cases to non-mudbrick houses (Ibrahim & Ibrahim 2003: 90).

Red brick and mud brick production relied on Nile silt. With the loss of Nile silt after the building of the Aswan dam, it became necessary to obtain it from the river banks, or removing the topsoil, therefore affecting the river course and the soil productivity (Ibrahim 1982: 66). This had as an ultimate consequence the banning of these activities by president Mubarak in 1985, as well as the closing of red brick factories which relied on mud for their production.

Other factors, such as lack of land ownership, may also be considered as explicative of the differences in building appearance between areas. For most of the 20th century, most *fellahin* (peasants) did not have any land of their own or had very little (Baer 1962). This meant that any building had to be small and preferably expand upwards; it might be assumed therefore that there was a correlation between the amount of land available and the size and distribution of the house. President Anwar Sadat's open policy in the 1970s meant that Egypt increased the dependence on Western countries and a new consumerist class developed; this reflected not only in the import of new building

materials, but also on a new fashion which identified red brick and concrete with progress and modernity. In addition, many agricultural workers emigrated to oil-producing countries due to the economic difficulties; when they returned, having substantially improved their financial conditions but finding problems re-adapting to agricultural life, they used these buildings as a means of differentiating themselves from the rest of the community (Fakhouri 1972: 19). Although no official data is available to confirm that most migrants hailed from the Delta governorates, northern Egyptians are traditionally, and according to surveys, more prone to migration than their southern fellow countrymen (Farid & El-Batrawy 2015: 32, Zohry, *per.comm.*). Perhaps, this could be one of the main factors explaining the fastest disappearance of mudbrick houses in the Delta governorates. This mudbrick architecture disappearance trend, which started in the 19th century, has done nothing but accelerate ever since.

5 PRESERVATION OF EGYPTIAN VERNACULAR ARCHITECTURE: PHOTO ARCHIVE AND WEB DISSEMINATION

The fieldwork undertaken in the Delta governorates between 2009 and 2011, was the fundamental pillar of a doctoral thesis presented in 2012 to Durham University (Correas-Amador 2013). This represented the first academic recording, surveying and documenting of Egyptian vernacular architecture in the Delta area and allowed for the recording of a rapidly disappearing tradition. It resulted in an abundant corpus of photographs which are in the process of being organized in an online archive. Since the fieldwork took place, most of the houses recorded have been demolished.

In Qurna, realising there was no future for them on the hillside, some families moved voluntarily and others were resettled. Between 2006 and 2008 nearly all the houses on the hillside were bulldozed, and the spoil carried away in large dumper trucks and lorries. This was a World Heritage Site (UNESCO 1979) and this built heritage should have been treated with respect and conserved, but the physical buildings have gone so other ways of preserving the built heritage of the Qurnawi must now be used. Until recently very few Qurnawi had cameras, and no photos except of weddings and major family events. Portraits of local people and their houses were in books in foreign languages and in photo collections of foreigners far away. In 2004, when it was clear that people would be relocated to modern estates some distance away from the hillside, Caroline Simpson made over 100 A4 laminated photos of individual houses in various parts of the hillside and walked the paths with a Qurnawi friend delivering the photos to heads of households so that they would have at least one pictorial record of their Qurna house. Such photos are treasured. In April 2016, a major oral history project was carried out by the Qurna History Project and the American University in Cairo, recording over 75 elders of the relocated communities, and gave each interviewee an A3 laminated photo of their hamlet or group of family houses. A hundred A3 house portraits will also be put on display at a Qurnawi craft centre in one of the new settlements. Caroline Simpson's archive spans over 850 photos of local buildings, mainly houses. With this body of evidence, an online resource is in the process of being set up. The aim is to make it possible for any family who lived there, and the many millions who were not lucky enough to experience how fascinating Qurna was on the hill, to see it on-line. Any Qurnawis will be able to search for their family name in Arabic or English or search by the area the house was in, and photos will be available for the general public to browse through www.qurnainthesky.org.

6 CONCLUSION

It is hoped that this brief summary has offered a general overview of the importance of undertaking work to preserve the rapidly dying Egyptian vernacular architecture in some form. Sadly, the future does not look promising for the preservation of mudbrick buildings; however, by presenting an analysis of the intertwined myriad of factors which these houses are vulnerable to, some clues have been offered as to how this could be achieved through detailed recording. Egyptian vernacular architecture is a rapidly disappearing heritage, and it is our wish that these projects have at least assisted preserving these traditions both for the Egyptians and the rest of the world, before their complete disappearance.

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Tapiabrick: A digital platform on brick-supplemented rammed earth walls

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ABSTRACT: The study conducted on historic buildings with highlighted presence of brick-supplemented rammed earth walls (locally known as *tapia valenciana*) has allowed the discovery of some details of the techniques and it has shed light on their reason for being implemented. Some features of the walls have remained unchanged throughout the passage of time, but others have undergone variations over the centuries. All the results of the study ("Characterization of Brick-Supplemented Rammed Earth Walls: Documentation, Study and Improved Efficiency" UPV/PAID-06-12/SP20120466) are presented in a web resource, *Tapiabrick*, a structured database that explains resources, results and construction steps to have a complete understanding of brick-supplemented rammed earth walls. Maps, tips, links, texts and photos help students and professionals to better understand the technique and to make possible to use this construction option as a contemporary construction resource.

1 BETWEEN *TAPIA* AND BRICK

1.1 *Tapiabrick: Origin and purpose*

The *Tapiabrick* online repository was developed within the framework of the Project "Characterization of Brick-Supplemented Rammed Earth Walls: Documentation, Study and Improved Efficiency" UPV/PAID-06-12/SP20120466 and has been improved and refined after the subsequent funding received within the framework of the project "*Trazabilidad histórica y perspectivas para los materiales sostenibles vinculados a la tradición constructiva de la Comunidad Valenciana*" Ayudas GV 2014/014, Conselleria d'Educació, Cultura i Esport, GVA. (http://tapiabrick.blogs.upv.es/).

Tapiabrick was therefore developed as an active repository of contents connected to the all-encompassing characterisation of the construction technique known locally as *tapia valenciana* (brick-supplemented and lime-crusted rammed earth walls), and is currently one of the few institutional monographic websites connected to a specific construction technique (Cristini & Ruiz 2009a,b,c).

On the page, several sections shed light on different technological facets, insisting on the origins and primitive documentary references of these walls, to then present contemporary experiments and provide operational indications for the development of such technique. *Tapiabrick* is not a blog, nor is it a database, a digital library, or a web platform... We can say it is all of these things together, being an updated resource, constantly maintained by the contribution of members of the university community, professionals and other groups with an interest in these subjects.

2 HOW TO USE THE WEB RESOURCE

The website is made of 5 main parts: an explanation of the contents and framework of the research; a digital repository and a list of links; a series of thematic maps, and finally a photo gallery. The website is constantly maintained up to date, and the various resources can be easily updated. In fact, it is one of the few 'live' and updated digital tools related to a construction technique and the constant monitoring of its state of the art.

2.1 *The digital repository and links*

The digital repository of the *Tapiabrick* web resource is a collection of digital documents, whose objective is to organise, file, present and disseminate via open access the intellectual production resulting from the academic and research activity of the university community interested in this specific construction technology. Since the end of the 1990s the interest in land architecture has been growing in the Iberian Peninsula (Iborra 2012).

Academic efforts have gradually been refining and detailing the construction and typological variants related to the earth as construction material. In the midst of these activities the brick-supplemented rammed earth wall has been gaining prominence, leading to the production of increasingly specific texts, articles and publications. All of them are continuously updated and most are available in PDF format on the website. This section includes references to doctoral theses, scientific articles, presentation papers or conference

talks, electronic journals edited by the institution, teaching materials, different resources developed by professors and researchers from universities or research centres.

2.1.1 *The thematic maps*

One of the main characteristics of the brick-supplemented rammed earth wall is to be frequently found in different construction types, in rural or urban environments; in buildings or in ruins; in fences, perimeter walls, farmyards, as well as in monumental or military ensembles (Galarza 1996).

For these reasons the *Tapiabrick* website features a series of maps with GPS coordinates, to have an accurate geographical reference, to locate the main examples of these constructions in the territory. These are cases located throughout the Iberian Peninsula, especially in the Valencian Region, but there is also a nod to other geographical contexts, where variants of these walls can be appreciated, such as Algeria or Japan. The aim is to provide cartographic tools to show basic, yet useful, visual, at-a-glance information, locating examples of brick-supplemented rammed earth walls across the territory, and ensuring a straightforward interpretation of the maps (Figs. 1–2).



Figure 1. Valencia city: Examples of brick-supplemented rammed earth walls.



Figure 2. Outskirts of Valencia: Examples of brick-supplemented rammed earth walls.

2.2 *The image gallery*

Always within the purpose of facilitating the recognition of this construction technique and understanding its various details, the website features a threefold image gallery. On the one hand, it presents a brief Construction taxonomy of the types of walls that indicate a combination of wall and bricks, using axonometries to outline sections and volumes (Cristini et al. 2012 a, b).

On the other hand, an abacus of more than a dozen frequent problems that affect the walls executed with this technique has been proposed to facilitate the understanding of the main degradation mechanisms related to the brick-supplemented rammed earth walls.

Both the bricks, the earth or the lime used in the constructions present frequent problems mainly due to the meteoric or anthropogenic impact. A series of images showing material damages with detailed photos is a useful tool when carrying out diagnostic work and inspections of brick-supplemented rammed earth constructions, and helps to propose appropriate intervention techniques (Figs. 8, 9, 10).



Figure 3. Applying construction principles: The formwork.



Figure 4. Applying construction principles: Earth and lime.

One of the objectives of the project is also to valorise the possible contemporary use of this technique (Cristini et al. 2014) and to promote it in contemporary constructions, not only by claiming its historical validity and value in heritage buildings, but also by applying its construction principles in new masonry works (Figs. 3,4,5,6,7).

Consequently, the image gallery features a third section outlining the sequential steps to build a wall using the brick-supplemented rammed earth technique, together with instructions regarding the raw material, its dosage and its implementation.

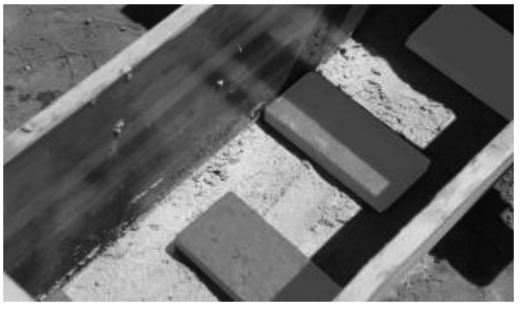


Figure 5. Applying construction principles: Bricks.



Figure 6. Applying construction principles: Ramming.



Figure 7. Applying construction principles: Section.



Figure 8. Decay of a brick-supplemented rammed earth walls: Example of brick cracking.



Figure 9. Decay of a brick-supplemented rammed earth walls: Example of core washing.



Figure 10. Decay of a brick-supplemented rammed earth walls: Loss of connectors.

3 CONCLUSIONS

Tapiabrick is a web resource that gives the international scientific community access to the results of the research carried out, and increases the visibility of the related scientific production, as well as the results achieved.

Research works frequently make use of websites and online resources as a way of publishing and disseminating results. *Tapiabrick*, however, goes beyond these dynamics. It is an active website, which continues to change and expand the information related to the technique and its fundamental purpose.

Problems and variants, details and applications, are constantly updated (Fig. 11).

Being a monographic website about a very particular construction technique makes it an 'ultra specific' reference in the context of digital resources of this type. The use of images provides a more descriptive—and therefore more explanatory—presentation of the website contents (Fig. 12). At the same time, the presence of texts contributes to the preservation of the digital documents deposited therein.

Tapiabrick systemically allows for queries that are entirely focused on the technique of the brick wall (Fig. 12), without external references that can hinder and divert possible studies. The website sees an average of 80–90 accesses per month, and has had more than 4,200 visits in almost 3 years of life. These are interesting facts when taking into account the extreme focus on such a well-defined construction subject.

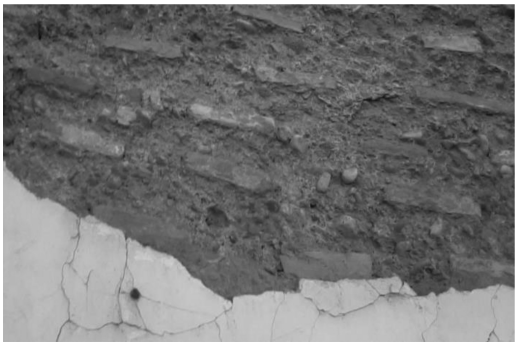


Figure 11. Variations of brickwork in brick-supplemented rammed earth walls.



Figure 12. "Tapiabrick" homepage.

In order to "collect, catalogue, access, manage, disseminate and preserve" information relating to such a specific construction technique, *Tapiabrick* stands out as a website that provides free information and 'training', both in Spanish and English, on the details of the brick-supplemented rammed earth walls, emphasizing its facet of historical as well as contemporary construction technology.

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The credits of all researchers involved in the project are available at http://tapiabrick.blogs.upv.es/credits/. The photos included in the text are from the authors.

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The ancient caves from El Alguacilejo. Vernacular habitat and landscape of Gran Canaria, Spain

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ABSTRACT: El Alguacilejo is a troglodyte site located in the north region of the Gran Canaria Island. The initial dwellings from this site were built at the end of the 19th century and most of them are still in use nowadays. But, what is it known exactly about them? The authors of this paper are currently visiting the inhabitants of this place, most of them aged 70 years or above, to learn about the original local building culture. Working method consists in conducting interview with the native people. In addition, a graphical and descriptive analysis of the building structures and the vernacular landscape is made. Initial results seem to indicate a population with a high collaborative sense. They lived in a three rooms cave, each with a stable. There also remains a water-pond for collective use. All these elements have been excavated on the rock.

1 INTRODUCTION

El Alguacilejo lies over 664 meters above the sea level at the heart of the midlands of the north municipality of Guía. Nowadays, the site is conformed by approximately twelve excavated dwellings. Around eight families live currently in the site, a half of them in a permanent way.

In 19th century, the population was settled in this area, where the ethno-historical tradition continued until the second half of the 20th century. In that moment, an upswing in economic development of the island encouraged the modification of the excavated buildings and, consequently, the landscape.

At the present time, this transition is observed towards the addition of external structures. As a result, the traditional landscape and the building culture have undergone significant changes.

The authors of this paper have recently started an extensive study with the goal of registering the ethnographic history of this region. The characterization and description of the original spatial and morphological distribution of the excavated forms is also an objective.

Until now, the study of the troglodyte habitat from the island of Gran Canaria has mostly focused on the archaeological sites and in some ethnographic goods in a general manner (Aider 2008). Therefore, there are not results in the literature regarding of a comprehensive study of a troglodyte site.

The aim of this research is to perform a widespread investigation about the local and early troglodyte universe, its intangible and tangible values and the transference of the know-how.

2 METHOD

The method followed consists of two phases.

2.1 *Phase 1*

– *Interviews.* Every owner of the selected cave was interviewed. These people over 70 years old, were and are currently the native population. The information received by them helped to detect the shelters subject of study, those that were already excavated at the beginning of the last century.

  Until the writing of this paper, five people have been interviewed.
– *Plans, drawings and sketches*. While the interviews were recorded, excavated dwellings were drawn. The plans registered the original spatial distribution of the troglodyte heritage and their initial uses.
– *Other tools*. Caves were also located with the help of a web satellite imagery service (Grafcan). Subsequently, an unmanned aerial vehicle was used to take aerial photographs. In turn, it was also consulted the geological mapping from the Geological and Mining Institute of Spain.

2.2 *Phase 2*

– *Organization of the information*. Nine caves were subject of a deeper analysis. Consequently, nine sheets will contain all the details concerning every excavated structure.

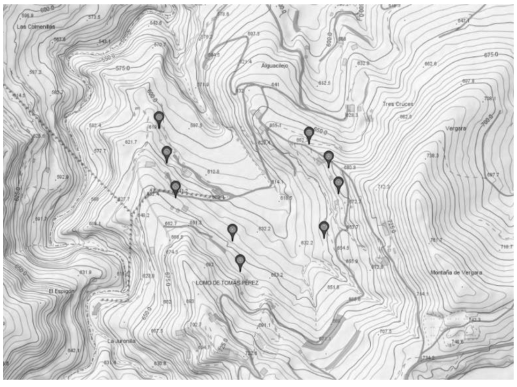


Figure 1. Location of the nine caves subject of study. Author: Grafcan.

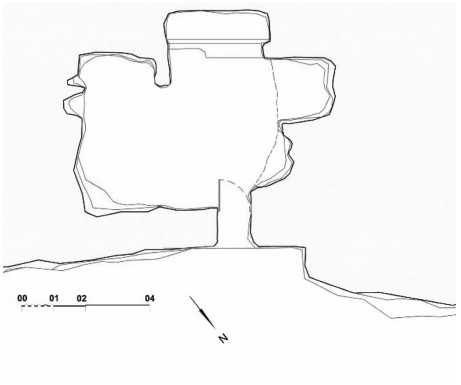


Figure 2. Plan of an ancient stable from El Alguacilejo. Author: Jorge Manzano.

3 THE INITIAL SITE OF EL ALGUACILEJO

The little village of El Alguacilejo is located in a hydrographical basin. Natural limits are two mountain ridges: Tomás Pérez on the south and El Alguacilejo on the north.

During the 18th century, an increase of the inhabitants from the north municipalities of Guía and Gáldar was produced; the population thus moved toward areas over 400 meters above the sea level. Those places had at that moment low land occupancy.

The livelihoods of the local population moved around the cultivation of corns and potatoes, alongside other cereals like wheat and barley. Cow and sheep grazing were also a main activity.

Quintana assures that the definitive establishment from the northeast midland of the island was constituted in the 19th century (Quintana 1995). People were settled deep inside the ravines, which were provided with fertile soils and abundance of water. All these factors encouraged the proliferation of the new settlements (Fig. 1).

4 EARLY BUILT ENVIRONMENT

Ancient caves are the local term used by the natives. This world identifies the dwellings carved during the late 19th and early 20th centuries, thanks to the development of the building techniques (Santana, Pérez & Pérez-Luzardo 2011).

Initially, nine dwellings with their own stables constituted the site (Fig. 2).

These monolithic structures, housing, stables and water-pond, were carved on the cliff following an amphitheatre organization. It is found also a water-pond cave for collective use.

> […] And water-ponds to collect the water were also built with a pick. They were bigger. José lived back there. His trade consisted in building caves.
>
> […] As in winter the water surface transports large amounts of earth, young people helped to remove the earth from ponds every five summers. We did it with the help of bins and baskets. Every five summers, because in this season water-ponds and earth were drier.
>
> Water-ponds were made by digging directly into the rock. They had also a staircase carved on the rock. And we took out the baskets full of earth up there. And then, when we finished, we made a dance night with guitars.
>
> A married couple accompanied the young women. The man walked always ahead of us because the dances took place in caves that were little far away. We previously prepared the cave: we swept the floor; we put then wooden boards to sit down round. And many caves had not floor, they were completely full of holes. [1]
>
> Lucía Ríos

The cultural landscape from El Alguacilejo contains arable fields located on the central nucleus of the ravine basin and a threshing circle to be also used collectively.

Therefore, the described elements of the traditional landscape show the farming vocation of the first inhabitants, where the land limits, not only indoors but also outdoors, were confused.

> In the past, males over 14 or 15 years old used to go to sleep to the haystacks, to the caves, or round there. After mowing, mi father used to sleep on the threshing circle in summer. Formerly, families used to have eight or ten children, and some of them used to go to sleep to the haystacks, other to the caves, round there. [2]
>
> Félix Díaz

5 FIRST HABITAT

> Caves were built with a pick. Some men picked in one side and other men on the other side. I think that everything was built at once. The family never moved into the house until the cave was completely finished. But they needed too little: the cave, the chamber and the kitchen, nothing else […]. [3]
>
> Lucía Ríos

The natural slope of the land, around 40%, benefited the excavation of buildings in the rock.

Earth was removed until obtain the vertical façade that would constitute the housing (Fig. 3).

The courtyard was located once and the removal rubbles had been flattened. Moreover, the patio is the element that connects the rooms (Fig. 4).

> Beds were placed on the cave, and we ate at the chamber […]. The cave is the real home, where we lived and where grooms were together […]. For example, here is the house, like the one that you have currently at Las Palmas. The living room was always ready to receive visits. There, the grooms spent the time: two chairs behind the bed for a couple to sit, other couple could sat there, and another over there. [4]
>
> Lucía Ríos

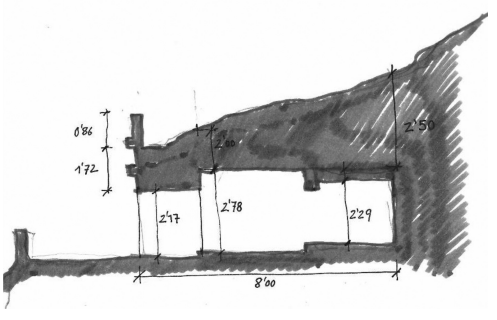


Figure 3. Section of the cave property of Lucía Ríos. Author: Jorge Manzano.



Figure 4. View of the cave property of Lucía Ríos. Author: Alejandro García.



Figure 5. View of the cave property of Angelina Díaz. Author: Alejandro García.

After the excavation of the first room, the rest of the accommodations were extracted. In addition, other interior rooms, used as bedchambers, were placed. Native people call them in the local term *aposentos*.

To date, the spatial and morphologic distribution of the housings has been observed. The living units from El Alguacilejo comprise the house, area that has a living room with two interior bedchambers; the chamber, used frequently as sleeping-room, and the kitchen (Fig. 5).

> We named the different rooms of a cave: the chamber, the house and the kitchen. There were caves everywhere, and we called them the little chamber and the big chamber.
>
> Frequently the caves had two beds into the house. The function of the chamber was to divide male from female. Most of the time female rested indoors, and the males were moved to the chamber when they grew up. [5]
>
> Angelina Díaz

Nevertheless, the property of Lucía Ríos had two chambers. One of them was used as a male sleeping room, and the other one to ageing the cheese.

6 RESULTS AND DISCUSSION

At this stage of the research, it is possible to indicate six keys:

- Interestingly, three rooms mostly constituted original settles from 19th century in El Alguacilejo, the main of them with two cavities inside (Fig. 6).
- Caves were constructed in one time. It means that the family occupied the house when the settle were completely finished (see interview with Lucía Ríos).
- A sense of community was very strong at that time. Community members collaborated in the

cleaning of the water-ponds. At the end of the works, they celebrated a final dance. Farming labors as thresh out the grain in the collective circle, and the exchange of supplies were also very common (Lucía Ríos).
– Absence of limits indoor-outdoor: natural and anthropogenic places were occupied, especially by males (Félix Díaz).
– A cave could have more than one chamber, according to the amount of members of the family. This type of distribution has been observed in the settle of Lucía Ríos, which has two chambers (Fig. 7).

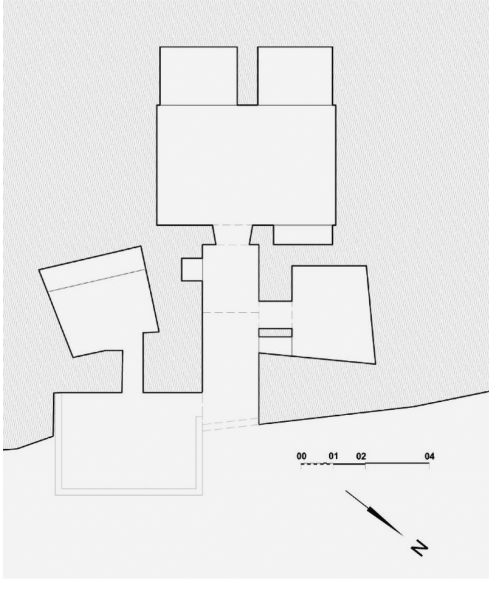


Figure 6. Traditional distribution of a cave. Housing property of Angelina Díaz. Author: Jorge Manzano.

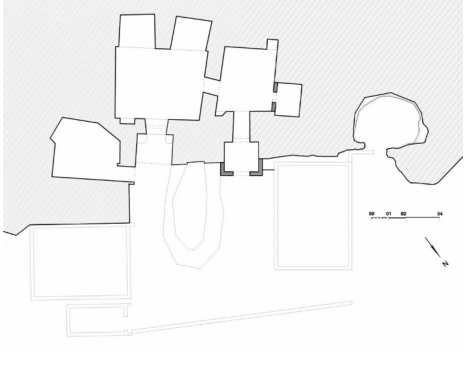


Figure 7. Two chambers cave property of Lucía Ríos. Author: Jorge Manzano.

– Terms as the cave and the house, were used to denominate the real home (Lucía Ríos). However, the chamber could be used as the male/female slipping room (Angelina Díaz) or as a place to accurate the cheese and to store the food (see Fig. 7).

One of the main goals of this research was to enhance and to know in depth the troglodyte building culture from El Alguacilejo.

In general, draws show a three-habitation structure. In 2008, Navarro suggested that in the north of the island it was usual to find in the main room entrance a barrel vault with a semi-circular arch (Navarro 2008). Those elements have been found at El Alguacilejo.

The construction time of this buildings coincide with a third phase in the use of troglodyte habitat in the island of Gran Canaria (Quintana 2008). This phase was held in the beginning of the 19th century. At that time, farmers moved to caves next to the farmlands.

From that moment until the early 20th century, the habitat in caves had a very high average of use in the island, a 25% of the population, mostly in the midlands (López 2007).

However, in the 70s and 80s, the modification of the original habitat started, with the addition of structures that modified completely the original habitat (Figs. 4, 5).

Troglodyte habitat has been a very developed subject of study in the last years. However, the contribution of their inhabitants and their expertise is not fully harnessed, even when it refers to a living heritage. Hence the importance of set them, the troglodyte people, in the centre of the research.

Thus, interviews place a human insight of the troglodyte way of life. Furthermore, the graphical information presented in this paper, contributes to the knowledge of the initial caves capacities.

This work method may be useful for further approaches and researches.

7 CONCLUSIONS

Ethno-historical tradition is inevitably connected to the economic model, which is reflected in the habitat. Settlements are perfectly adapted to the available resources.

The original habitation structure of the ancient caves from El Alguacilejo reveals the basic needs of its inhabitants. Since the majority of the activities were developed outdoor, caves were understood as shelters. Water-ponds and stables were building elements of the landscape that shows the agricultural calling of this area.

Results were a range of information about the traditional habitat. In the light of these findings, the authors believe that this analysis may contribute to implementing field research strategies to the study of the original troglodytes sites. Therefore, a work method that may influence to continuing this work in future researches has been described. In addition, this study could be helpful to difference the original troglodyte forms and sites from the eclectic changes that threatening the vernacular heritage.

ACKNOWLEDGEMENTS

Geographers Javier Estévez and Alejandro García contributed to develop the environmental study. The authors wish to gratefully acknowledge the inva-luable information given by the interviewees: Carlos Díaz, Lucía Ríos, Angelina Díaz, Félix Díaz and Antonio Quintana.

NOTES

[1] *(…] Y después te digo también que las maretas, que pa recoger el agua, también se hacían a pico. Esas eran más grandes. Sí tenía oficio el que picaba las cuevas. José el de Juana, que vivía ahí atrás (sic).*

…] Las maretas cada año, cada a lo mejor cada cinco años, porque después cuando viene el invierno arrastra mucha tierra y la lleva. Y entonces ya en el verano estaban las maretas secas y entonces ya la tierra estaba más seca (sic).

Íbamos toa la juventud a ayudar a sacar la tierra en cubos o en cestas (sic).

Y las maretas en cueva pues tienen escaleras hechas también de la misma pared; y sacábamos por ahí pa arriba las cestas de la tierra, las vaciábamos, y después por la noche un baile, con guitarras y cosas así (sic).

Y después un hombre casado con nosotras y una mujer casada. El hombre adelante, porque el baile era en cuevas un poco más alejadas, y entonces en aquella cueva se hacía un baile: se barría, se preparaba, se ponían unas tablas en redondo pa sentarnos. Y algunas cuevas no tenían ni piso, sino todas llenas de hoyos [sic].

[2] *(Anteriormente los varones desde que tuvieran 14 o 15 años iban a dormir a los pajares, a las cuevas o por ahí. Mi padre se iba a dormir a la era en verano, tras trillar. Antiguamente tenían ocho hijos o diez, y dos se iban a dormir a un pajar, otros a las cuevas, por ahí [sic].*

[3] *(Las cuevas se hacían a pico. A lo mejor unos cuantos hombres picaban, a lo mejor unos hombres por un lao y otros por otro. Yo creo que to se hacía de una vez, que ya después no entraba nadie a vivir hasta que no estaba terminado todo. Pero necesitaban poquito: era la cueva, el cuarto y la cocina, más na […] [sic].*

[4] *(La cueva es donde están las camas, y el cuarto es donde comemos […]. La cueva es la verdadera casa, donde vivíamos y donde se arreglaba pa novios y to eso […]. Esto era la casa, por ejemplo, como la que tienes hoy en Las Palmas, el salón, que lo tienes preparado. Esto es donde venían los novios: allí dos sillas, se sentaba una pareja de novios delante de la cama, ahí otra pareja de novios y aquí otra [sic].*

[5] *(Aquí era, antes le decíamos el cuarto la casa y la cocina. Había cuevas por ahí que le decíamos el cuarto chico y el cuarto grande [sic].*

Normalmente las cuevas tenían lo que era la casa, con las dos camas. El cuarto, su función, era cuando había varones y hembras; casi siempre las hembras se quedaban adentro y los hombres en el cuarto cuando crecían [sic].

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Interpretation of sustainable desert architecture in Ghadames city, Libya

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ABSTRACT: Ghadames is classified as one of the World's heritage city, combining old town (vernacular) and new (modern) city. In Ghadames, the design of houses in old town used the favourable elements and at the same time minimised the unfavourable elements of the local climatic conditions by sustainable design of houses more responsive to the climate in the region. This paper qualitatively highlighted the perfect picture of vernacular architecture, presenting the strategies of the potential of building design to re-think new architecture in the light of understanding the dynamics and the strength of vernacular techniques.

1 INTRODUCTION

1.1 *Background*

Desert architecture is a vocabulary that governed the design concept of the traditional houses while highlighting their distinctive characteristic solutions, which can be traced in many of the existing buildings. It provides a richness of design principles that *"…represented the result of many years or even centuries of optimisation in relation to the resources of materials and labour, the activities carried out within and around the dwelling, the social organisation of the household, and the climate"* (Evans 1980). In hot dry climate zones of Libya, the environmental stresses and climatic hazards in Ghadames City had influenced the architectural design of vernacular building that gradually improved along time in response to the needs of the occupants and the local climate as well as became well-fitted with the surroundings. This setting gives real lessons and significant ideas on how the applications of sustainable design can maintain indoor comfort and how the buildings can be more responsive to the climatic conditions. Moreover, it became a permanent phenomenon that has historical roots accommodating several factors approved through public experience.

1.2 *Climate in Ghadames*

According to the world map of Köppen–Geiger climate classification (2006), Ghadames city is classified as a hot arid climate (BWh) in desert climate, which is also characterized by very hot, dry air temperatures and dry ground conditions. In winter, the maximum average temperature reaches about 20°C during day time and the minimum average temperature is about 3.3°C during night time. The relative humidity average is between 55~19%; increasing in night time and decreasing in day time. However, in summer where direct solar radiation is very intense, and there is no barrier to outgoing radiation from exposed surfaces to the sky, the maximum average temperature could reach about 47°C during day time and the minimum average temperature could be about 26°C during night time. The relative humidity average could increase slightly to 15% in night time and decrease to 11% in day time.

1.3 *Ghadames location*

Ghadames City is an agglomeration of Saharan oasis sited in Libya near the borders of two Arab countries (Fig. 1).

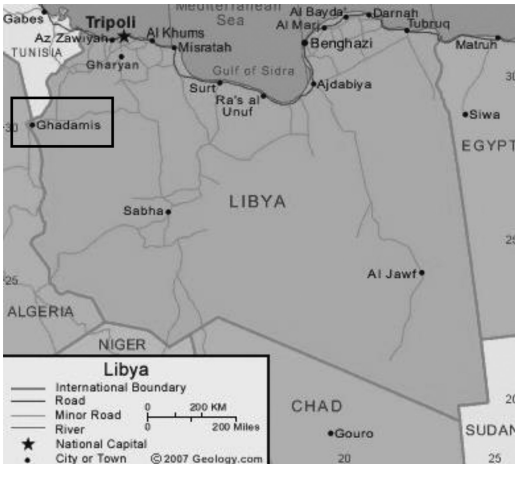


Figure 1. Map of Libya showing Ghadames location and neighbour countries (Geology.com 2017).



Figure 2. Top panorama of the old City showing the integration of buildings with greens (Google Earth 2017).



(Dark) Old town (city) surrounded by oasis
(Light) New town (city)

Figure 3. Arial photo for Ghadames town (Google Earth 2017).

The city is about 340 m above sea level and the site coordinates are 30°08' latitude getting started North and 9°30' longitude East. It is located about 17 km from Tunisia and 14 km from Algeria. Famously, the old town is described as the "Pearl of the Desert" bordered by an oasis that is protected from the drifting sand and from the high air temperature of the surrounding desert by palm trees (Fig. 2).

2 ANALYSIS AND RESULTS

2.1 *Architecture in Ghadames*

Old Ghadames city is an "iconic city" with a scarcity of natural resources in arid desert. It was built by people who were not schooled in any kind of formal architectural design. It is self-conscious to the human eye in buildings' shape, choice of materials, arrangements and the concept of passive techniques.

It also demonstrates the principle of climate oriented architecture, which was a pragmatic remedy to the effects of harsh climate in arid region. It is divided into two parts: (a) the old city with traditional architecture and (b) the modern city with contemporary architecture (Fig. 3).

According to a field study by Ghadames Municipality (1980), the glimpses of urban scenes in Ghadames appeared to represent impressions of segregation, whereas the society itself claims to have unity, integrity and organization that can be patterned by a gradual shift from an urban texture to a building unit. Figure 4 shows the interpretation of the traditional city form that is mainly based on principles of sustainable design approach in old Ghadames town.

2.2 *Sustainable architecture attributes in Ghadames*

1. "Distinctive Design", a compact form of the urban texture, which "… refer to a city that is concentrated and firmly unified with a consolidation of land uses in a close and tight physical relationship with each other and the structures within themselves" (Golany 1996). The urban pattern of the old city is made of irregular blocks divided according to the tribes' distribution and each district has a centrally located communal meeting place and one major mosque, in addition to the local mosques (Fig. 5) (Alund 1987).

The residential units in particular are arranged in a smaller space with un-equivalent size that provides enough suitable land, which has been saved adjacent to the cities for agriculture. In addition, the compactness character of desert architecture is described as "Defensive Architecture", hence, the defensive wall system is formed by the blind rear walls of the houses in the perimeter of the village and the urban design becomes as a big compact fortress with concentric (De Filippi 2006). Cumulatively, this development has been gained through ages, which distinguishes Ghadames itself in its architecture style that has been built in a friendship relation with the nature. Moreover, incredible aesthetics of the city skyline scale has been dominated by mud brick constructions that made a strong relationship between the surrounding landscape and the urban setting. Thus, the traditional buildings have been designed in such a fashion as being constructed entirely of local materials producing an attractive and harmonious architecture within the environment (Aalund 1987). Characteristically, the Ghadamesian houses are shaped according to the internal desires responding to the enclosed activities. The houses' designs have many shapes as the geometry of buildings is different according to land division of the city planning. Therefore, this architectural composition represents a form

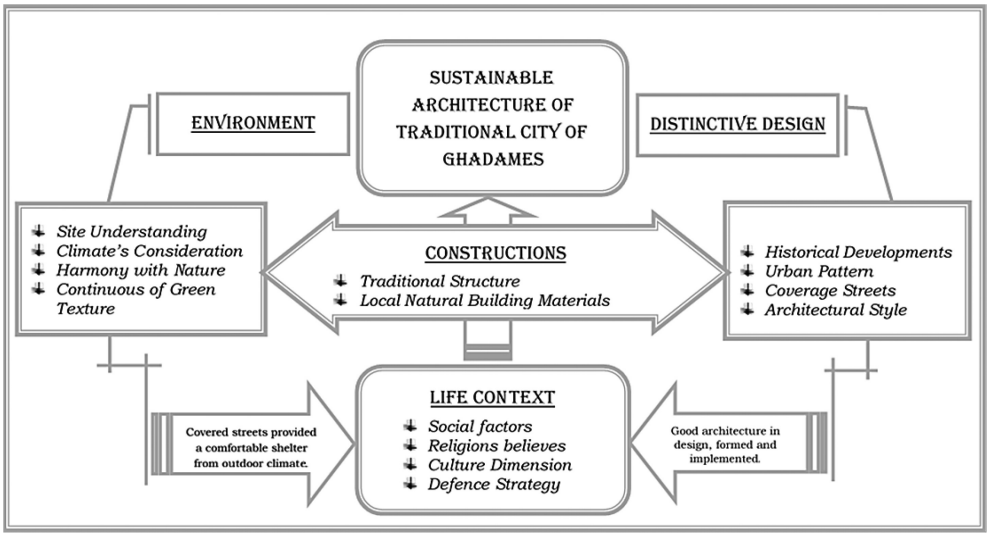


Figure 4. The main principles of sustainable design approach in old Ghadames town.

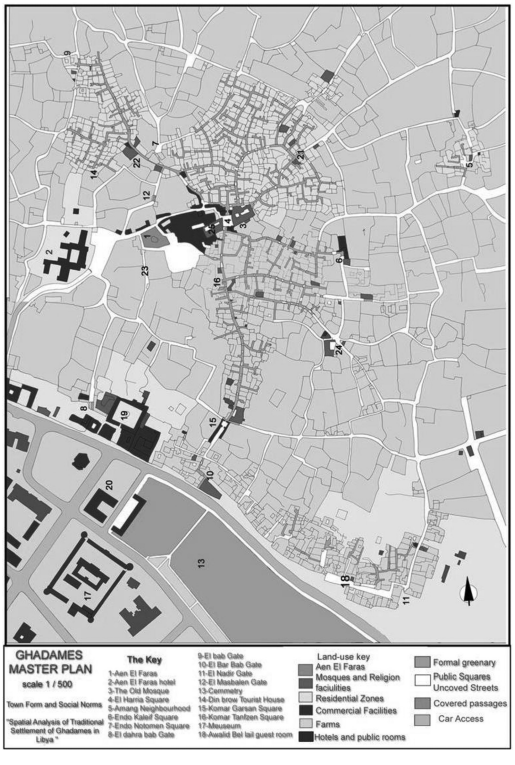


Figure 5. Old Ghadames land use plan (El-Agouri 2004).

that allows only a few visible facades rising in an almost fortifying manner to a height of about 10 m, composed of a number of areas extending on three floors, from the ground floor, through the central hall to the roof floor (Fig. 6).



Figure 6. Tall buildings with less openings protecting the city against the dusty desert winds and providing a defence strategy.

2. "Environment", harmony with nature through understanding the site character and climate considerations. Importantly, the climate is a key factor determining its design parameters, such as distance between buildings, building form, orientation, and building envelope (walls, roof and fenestration). Moreover, the compactness of urban texture in hot dry region *"…contributes to the thermal protection because the narrow winding streets are partially covered; the urban structure is usually a continuous pattern"* (Scudo 1988), therefore, the condensed and compressed urban texture allows the arteries of movement open in the direction of desirable winds and closed in the direction of undesirable winds and sand storms (A'zami et al. 2005) (Fig. 7).



Figure 7. Concentration of urban form decreasing penetration the dusty wind while influencing hot sun radiation on the passageways.

It gives a good choice for residents to change the living space for special hours of the day and night of cold or hot seasons in harmony with the region (Manioglu & Yılmaz 2008). The buildings in hot arid climate are shaped so as to allow natural ventilation in summer *"breezes and induce air movements"* through light-well system in the coverage streets. The construction method has often used as a high mass skin to counter the varying diurnal temperatures, which occur from day to night (Kamel & Ibrahim 2004). Environmentally, the irregular shape of urban structure designed to integrate with the harsh climate and to provide protection against undesirable winds from the south orientation sun radiation. Hence, the structures are made of predominantly local materials, such as the mud that can maintain fairly steady inside temperatures of desert regions in spite of the very high air temperatures and solar radiation. The physical measurements made by the authors between 21st and 26th of June 2014 showed how the high thermal capacity of thick adobe walls and mud roofs can provide pleasant conditions of 24–30ºC with midday external air temperatures of 40ºC.

3. "Construction", using traditional local technique with local natural materials that shaped the identity of Ghadames architecture. Construction system is constituted of load bearing walls built from mixed organic elements, such as mud brick that constructed on a foundation of stones where the thickness is diminishing from bottom to top from 0.75–0.60–0.50 m for structural durability, and also the structure of ceilings and roofs constructed by bisected and smoothed trunks of palm tree as first cover. The second cover, mainly made of ribs of palm leaves are left in water for three months before plating the mat, providing support for the floor slab. Later on, the last cover consists of 10 to 15 cm spongy lime stone and clay with a gypsum mortar. Lastly, about 3 cm gypsum plaster used to cover the walls surface and applied to lime paint in thin layer as a final coating (Al-Zubaidi 2002; Mohamed et al. 2006).
4. "Life context", the social indoor life, culture dimension, religion effects and defence strategy is mainly important in eastern families, especially in harsh climate, where the control is led by the tribe. Historians record that Ghadames was inhabited (4000) years ago. The town was shaped as symbol of *"… regional architecture … represented an idiom that having a distinct identity and being associated with an identifiable group, and having this association used … architectural elements to represent the identity of a group occupying a piece of land"* (Lefaivre & Tzonis 2003). The decisive effect on the sections and the spatial development of Ghadames was built by seven nomad families who came from two tribes: Beni Wazit and Beni Walit. Those families took the land to create numerous habitable buildings in the form of continuous villages (El-Agouri 2004).

2.3 *Lessons from vernacular architecture of Ghadames*

In principle, vernacular architecture is based on knowledge of traditional practices and techniques, and reveals a high regard for craftsmanship and quality (Sundarraja et al. 2009), as well as represented as a composition of climatic adaptation that shows the strength of various settings (religion, culture, building techniques, etc.), where the natural harmony blends between architecture and people. However, this is a meaningful example to contemporary design of homes and much has to be learnt from their great history and development of city planning, building form and construction methods of the past.

According to previous review, indeed, there are many points can be derived from vernacular architecture, especially where extreme climates have stretched human ingenuity and may help to find appropriate concepts, if not models, to address problems. As a result, the performance of vernacular architecture has been providing successful bioclimatic shelter results from a conscious design of microclimates both inside and outside the building, based on climatic responses as follows:

a. The urban texture provides a shelter from the harsh climate because the narrow snake streets provide shades and relatively well-lit areas from regularly spaced light wells each 15 m that let

cool air circulation deposited during the day sweep away partially through the buildings and main gates (Fig. 8).

b. Structurally, the pedestrian network includes an almost unique system of covered lanes with formally arranged squares. It is based on a sophisticated hierarchical system and gradually leading from the more public to the more private areas (Azzouz 2000). This causes air movement from high-pressure zones to low pressure ones, where the hot air is replaced with the cooler and humid air in the shaded passageways, thus regulating the internal temperature (Al-Zubaidi 2002).
c. The first point regarding housing design is that the orientation of the building is the key to achieving thermal comfort. Orienting the openings is also very important, thus the best orientation requires that the building as a whole should receive minimum solar radiation in summer (Nayak & Prajapati 2006).
d. The housing design in harsh climates has shown that the design of an effective envelope is vital. The windows are sized to minimize the penetration of hot air into the housing during the hot hours of the summer and of cold air during the winter, while allowing massive ventilation on cool summer nights (Okba 2005).
e. The thick walls of materials like mud, mud-brick with high thermal capacity and adequate resistance will reduce external temperature so that the temperature variation at the internal surface is only about 15 to 20% of the external air. (Evans 1980).
f. Manipulating the geometry of the housing envelope is the most fundamental way where the ratio of the surface area to the volume of the building (S/V ratio) determines the magnitude of the heat transfer in the building (Nayak & Prajapati 2006).
g. A dense pattern "carpet-planning" layout provides protection from solar radiation, glare and hot temperature by providing mutual shading where groups of buildings are close to each other (Gut & Ackerknecht 1993).



Figure 8. The covered streets content sitting corners also providing shades from harsh climate and are used mainly by men and children.

Finally, a sustainable context between vernacular architecture and local climate in terms of design response to climate is absolutely crucial, particularly in the context of purely passive environmental control. However, it is essential to take the wisdom of the past and evolve a built form, which will be more humanized, more climate-responsive and more environmental friendly for the buildings of tomorrow (Radhakrishnan et al. 2011).

3 CONCLUSIONS

Architecturally, Ghadames is an extraordinary place of aesthetic design with rich and ingenious techniques which present a series of logical solutions for human comfort. The orientation and arrangement of vernacular houses are designed in a way to have appropriate comfort for residents. These vocabularies are not only a symbol for architectural identity, but also successful responses to their social, cultural, climatic features and effectively providing environmental design and sustainable key elements in buildings.

Ultimately, construction materials of the houses that were traditionally used are mud brick, fired brick, white lime plastered walls and fired floor tiles. However, these materials are the important factors in hot-arid regions, where thermal resistance, high heat capacity and absorption of the sun radiation through their external surfaces are the positive characteristics of local materials (A'zami 2005; Salama 2003; Scudo 1988).

Nevertheless, the appreciation of design quality needs developing links between contemporary architecture and vernacular architectural heritage by introducing an identifiable architectural character that would adequately belong to the local environmental conditions and to the behavioural patterns of the population of a locality. Overall, vernacular cities accumulated layers of experience for enhancing thermal performance by designing the part as an essential to the whole, and traditionally developed as compact settlements in practical response to the

environmental stress. In other words, the compact city form reacts positively in its thermal performance to regions of harsh climate.

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Thermal performance and comfort of vernacular earthen buildings in Egypt and Portugal

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ABSTRACT: Despite the far distance between Portugal and Egypt, it was possible to find points of similarity on the influence of Roman and Arab cultures, and on solar passive and construction techniques used in vernacular architecture. Earthen construction techniques are one of these examples, being used in both countries for thousands of years. Through an explanatory qualitative and quantitative analysis, this paper presents an overview of the effects of climate-responsive strategies on thermal performance and indoor comfort of earthen architecture from Northern Egypt and Southern Portugal. To understand the effectiveness of these strategies, measurements of hygrothermal parameters and surveys on occupants' thermal sensation were conducted in two case studies. From the results, it has been found that the case studies have shown a good thermal performance only by passive means and that the occupants expressed as being comfortable. Thus, vernacular passive strategies still can contribute to achieve indoor comfort conditions and reduce the dependency on mechanical systems.

1 INTRODUCTION

The wide area of the Mediterranean, although it is a physical border between countries, it is also a mean of connection and communication between the various countries around it. Through history, the presence of different cultures in these territories has generated a beneficial transference and mix of knowledge. In addition, this sea is a climate regulator in the region.

Despite the distance between Portugal and Egypt and their opposite position in the Mediterranean basin, it was possible to find common approaches regarding passive vernacular strategies used in both countries (Fernandes et al. 2014). They are mainly due to the influence of Mediterranean climate but also a reflection of a common Roman and Arab cultural and architectural influence.

This article is a continuation of a previous work developed by the authors (Fernandes et al. 2014), and the follow-up from a qualitative approach to a quantitative approach. In this study, the authors have chosen two representative residential earth buildings located in Egypt and Portugal. The two buildings were monitored to evaluate their thermal performance during summer peak time and how they managed to reach adequate indoor comfort for their occupants. This study tried to retrieve the main reasoning for thermal behaviour for different and common combined passive solutions used in both the case studies. This paper analyses the thermo-physical properties of earth, as the main building material in the two studied case study buildings in order to understand the effectiveness of vernacular climatic responsive strategies. Results are supported by in-situ monitoring and occupancy surveys.

2 METHODOLOGY

The methodology adopted in this study is based on the analysis of case studies, applying an exploratory approach through quantitative analysis and comparative explanatory synthesis methods for thermal performance and comfort assessment of earthen vernacular buildings.

The main aim of this study is to compare and establish a relation between occupant's perception and expectation regarding their comfort in dwellings built with earthen materials but located in different geographies of the Mediterranean region.

For this purpose, the analysis is based on data from the in-situ monitoring of both indoor thermal performance and perceived comfort conditions of earthen buildings located in the southern part of Portugal and northern part of Egypt. Taking into consideration the climate-responsive strategies adopted in these buildings, the comparative analysis is only focused on the summer season and on the effectiveness of passive cooling strategies.

In the assessment of the indoor environmental quality, the air temperature (ºC) and relative humidity (%) were measured in compliance with ASHRAE standard 55 (2010). In this paper, the analysis of the in-situ monitoring is based on a representative summer week of each specific location. The indoor environment conditions were also evaluated by surveying the occupants. The survey allowed to assess occupants' satisfaction according to ASHRAE thermal sensation scale and was based on the "Thermal Environment Survey" and "Point in Time Survey" from ASHRAE standard 55 (2010). The surveys were carried for the rooms that occupants considered more comfortable and/or where they spend more time.

In the analysis of thermal comfort conditions, the relation between indoor comfort temperature and the outdoor temperature was evaluated considering an adaptive model of thermal comfort. The reasoning for this is that this is the adequate model for naturally conditioned buildings. This procedure is in compliance with the ASHRAE standard 55 (2010). The adaptive comfort charts were performed using the CBE Thermal Comfort Tool (Hoyt et al. 2013). The results obtained were then compared to conclude if they converged or diverged.

3 VERNACULAR ARCHITECTURE AND CLIMATE

The close relation between architectonic form and the geographical context is widely recognized as one of the main features of vernacular architecture. Among all the geographic conditions, the climate stands out as one aspect that most affects the building's performance. Buildings, in their primary function of shelter and protection, are aimed to mitigate the effects of climate. Thus, the need to develop specific mitigation strategies has shaped vernacular buildings differently from region to region.

3.1 *Southern Portugal and Northern Egypt climate and architecture*

The inland Southern part of Portugal and Northern part of Egypt have a Mediterranean climate, subtype Csa, temperate and BWh respectively, with hot and dry summer (AEMET & IM 2011, Fathy 1986). In the Portuguese case, summer is the most demanding season in that part of the country with an average mean temperature of 22.5/25ºC. The average maximum air temperature varies between 30 and 35°C (AEMET & IM 2011), reaching maximum temperatures of 40°C or 45°C. In summer, the inland southern part of Portugal has more than 80 days with a maximum temperature above or equal to 25ºC, being July and August the hottest months (AEMET & IM 2011). The annual average rainfall is below 500 mm, and July is the driest month (AEMET & IM 2011). In the case of Egypt, the warmest months are July and August, the mean maximum temperature is around 38° and the peak around 45°C. In January, the mean minimum temperature is as low as 8°C. The average relative humidity (RH) varies between 34% in May and 57% in December. The mean daily wind speed varies between 1.7 m/s in December and 2.8 m/s in June. The yearly average rainfall is as low as 2 mm (Meteotest 2014).

In both Southern Portugal and Northern Egypt, the range and combination of strategies used to deal with a harsh summer season are varied and resilient. To suit these climatic conditions, the strategies developed are in general more focused on passive cooling (Fernandes et al. 2016; Fernandes, Mateus, et al. 2015; Dabaieh & Eybye 2016; Fathy 1986), such as: i) minimising the size and number of windows and doors facing the outdoor environment, to reduce solar gains; ii) proper orientation of openings, normally facing north for summer cool breeze and south for direct sun needed for winter cold days. The window to wall ratio ranges from 1:20 to 1:25 iii) high thermal inertia building systems (rammed-earth walls, adobe, and vaulted ceilings); iv) the use of light colours for the building envelope, mainly whitewashed surfaces, to reflect the incident solar radiation (Oliveira & Galhano 1992; Koch-Nielsen 2002); iv) ventilation openings to promote overnight cooling and remove diurnal thermal loads. In some cases, these ventilation openings are similar to the Arab *mashrabiya* (Fernandes et al. 2014; Fathy 1986); v) patios (courtyards), usually containing vegetation and/or water, useful to generate a cool microclimate through evapotranspiration and water evaporation, respectively; and vi) the compact building layout, to reduce the surface area exposed to the sun and to generate shade.

The combination of all these strategies is a great asset to achieve indoor thermal comfort during summer season only by passive means, as demonstrated in recent studies (Fernandes, Pimenta, et al. 2015; Fernandes, Mateus, et al. 2015).

3.2 *Description of the case studies*

3.2.1 *Case study 1 – Southern Portugal*

The case study is in a small village from Moura's municipality, located in inland Southern Portugal. This territory has an ancient occupation with a

long dominion of the Romans (3rd century BC to 5th century AD) and the Arabs (8th to 13th century AD). The building is probably from the 19th century and was renovated in 1983. It has main and rear facades facing southeast (street) and northwest (*patio*) (Fig. 1), respectively. The gross floor area is of approximate 200 m^2 divided into two storeys, although the upper storey is just a small attic area. In the ground floor, at the southeast are the living areas and the bedrooms, and in the northern part are the kitchen and the bathroom (Fig. 2).

The building envelope consists of whitewashed rammed-earth walls (average thickness of 60 cm) with a pitched roof, wooden doors, and wooden framed single glazed windows. Indoors, the partitions walls are in rammed-earth; several indoor spaces are vaulted; the floor is in *baldosa*—a sun-dried clay tile. Regarding the windows, it is relevant to highlight the existence of small ventilation shutters above the glazed window to promote controlled natural ventilation, which is particularly useful for overnight cooling without compromising the security level. The heat transfer coefficient (U-value) of the building envelope is presented in Table 1.



Figure 1. External view (northwest façade).

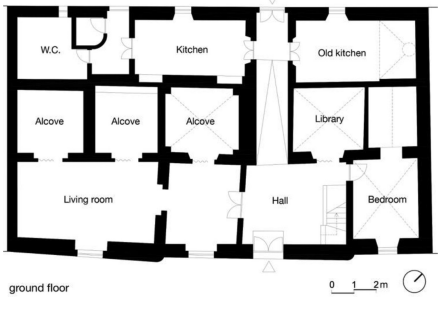


Figure 2. Case study 1 – Ground floor plan.

Table 1. CS1 – Building envelope characteristics.

Envelope element	Heat transfer coefficient U-value (W/(m^2.°C))
External walls	1.30
Roof	0.49
Doors	2.15
Windows	3.40*

Sources: (Pina dos Santos & Matias 2006; Pina dos Santos & Rodrigues 2009).
Note: *Uwdn—mean day–night heat transfer coefficient, including the contribution of shading systems.

3.2.2 *Case study 2 – Northern Egypt*

The case study is located in the Western Desert of Egypt in New Valley governorate. It is a dwelling and the office of the city mayor (Fig. 3). The building is constructed from locally available traditional materials, which are primarily adobe, acacia and palm tree wood. The dwelling is built around the late 18th



Figure 3. External view (west façade).

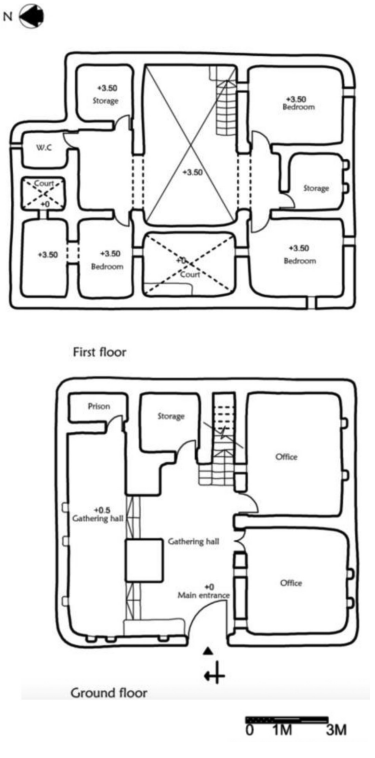


Figure 4. Case study 2 – Building plans.

Table 2. CS2 – Building envelope characteristics.

Envelope element	Heat transfer coefficient U-value (W/(m².ºC))
External walls	0.47
Roof	1.30
Doors	2.40
Windows	1.30

Note: Calculations made based on material lab tests.

century. The house consists of two floors (Fig. 4). It has a main courtyard in the centre used in the morning for official purposes and the evening for family gatherings. The kitchen and meals areas for socialization are shared with the neighbouring extended family house. The two houses are connected from the roof top where the bread oven and chicken coop with grain storage are located. Small and controlled openings are located on the north façade for ventilation and the west and south façade are mostly in shade to reduce heat gain. The building is plastered with whitewash lime. The characteristics of the building envelope are presented in Table 2.

4 THERMAL PERFORMANCE AND COMFORT ASSESSMENTS

The vernacular buildings discussed in this study showed a variety of passive low-tech approaches in the design and construction to achieve indoor human thermal comfort. Such passive approaches have been devised to suit the local Mediterranean climatic conditions.

4.1 *Case study 1 – Southern Portugal*

The data and results presented were collected during a monitoring conducted in the summer of 2015. From the analysis of the results, it is possible to verify that during the representative week, the outdoor mean air temperature was about 27°C (Fig. 5). During the day, the maximum air temperature was often higher than 35°C, reaching and exceeding 40ºC on some days (Fig. 5). Although the daily outdoor temperature amplitude is high, it was found that indoor temperature remained very stable over the monitoring period, with temperature values around 26°C (Fig. 5).

In what relative humidity is concerned, there is a high outdoor day/night variation, with maximum values of 93% and minimum lower than 20% (Fig. 5). In comparison, indoor spaces have more stable relative humidity profiles with mean values around 50%—the most appropriate for human health and comfort (Morton 2008).

Regarding the thermal comfort assessment, in-situ assessments were conducted in the living room. The results show that the living room has thermal comfort conditions within the defined limits, with an operative temperature almost in the centre of the comfort range (Fig. 6). In the "thermal environment survey", all the three occupants answered as being "neutral" (comfortable), confirming the objective measurements.

4.2 *Case study 2 – Northern Egypt*

The data and results presented were collected during a monitoring conducted in the summer of 2014. Figure 7 shows the monitoring results for a bedroom and office space during July 2014. The two rooms studied behaved similarly, however, the average temperature of the office was almost 1.5°C higher than the bedroom. According to the ASHRAE, the average upper limit for thermal comfort is 30.9°C. The bedroom average temperature during the monitoring time was 29°C, while the office was outside the

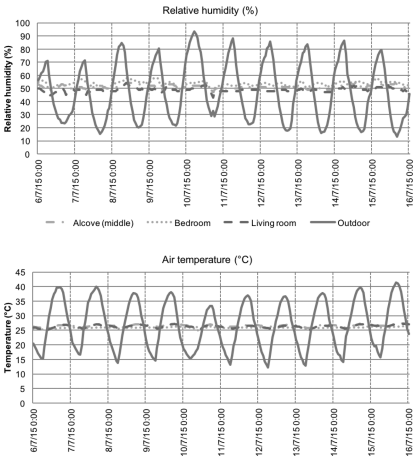


Figure 5. Case study 1 – Indoor and outdoor air temperature and relative humidity profiles.

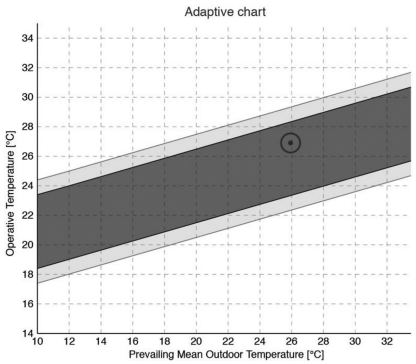


Figure 6. Case study 1 – Adaptive comfort chart. Thermal comfort temperature (operative temperature) in the living room during one representative day in summer.

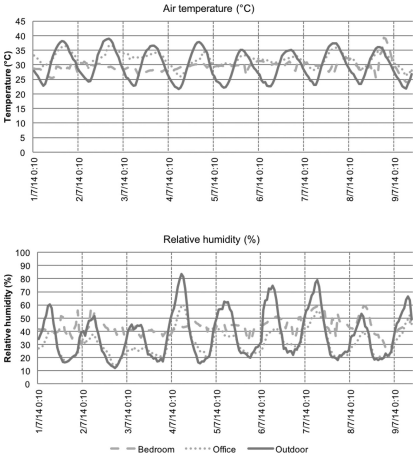


Figure 7. Case study 2 – Indoor and outdoor air temperature and relative humidity profiles.

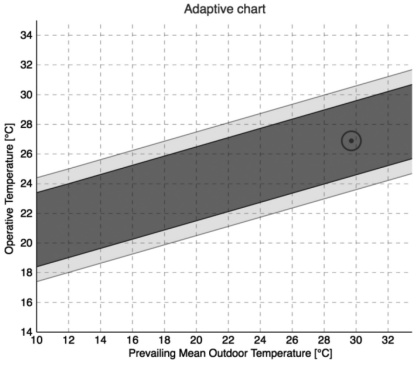


Figure 8. Case study 2 – Adaptive comfort chart. Thermal comfort temperature (operative temperature) in the bedroom during one representative day in summer.

comfort range with an average of 32°C. The average relative humidity was 40% and 29% for the bedroom and office space, respectively.

From the application of the thermal environment satisfaction survey, it was possible to conclude that the occupants were comfortable in the bedroom and slightly warm in the office room. Occupants' answers confirm the objective measurements. The survey was conducted in a representative day where the in-situ measurements were carried out. In Figure 8 is possible to verify that the bedroom has good thermal comfort conditions, with an operative temperature almost in the centre of the comfort range.

5 DISCUSSION

Vernacular earthen buildings, as the ones used as case studies, are seen by many people as low-income households. Nevertheless, these buildings can achieve good comfort conditions only by passive means and the materials used to build them have a low potential environmental impact.

The stability in indoor temperature is due to the high thermal inertia of the building envelope (e.g., thick earthen walls and vaulted ceilings), which provides a high capacity to store heat and to delay the progress of the heat flux (with an average time-lag from 7 to at least 12 hours (Koch-Nielsen 2002). This feature is particularly useful to minimise the effect of high diurnal temperature and the daily thermal range. In addition, the light colours used in façades and the narrow streets reduce direct heat gains by the envelope.

Regarding relative humidity, the difference between indoor (more stable) and outdoor relative humidity values is due to the hygroscopic inertia of the building systems, namely the rammed-earth or adobe walls and the lime plaster, among others, that have the capacity to regulate air humidity (Berge 2009), i.e., absorbing humidity when moisture is excessive and releasing it when the air is too dry. This property of the materials allows a natural regulation of humidity levels, without requiring any equipment, providing a healthy and comfortable indoor environment.

In the Egyptian case study, although the heavy thermal mass walls have a major contribution to indoor thermal comfort, in the case of the office, the room was slightly outside the comfort range. That is due to higher indoor thermal loads (e.g. from the office equipment), to the heat accumulated in the walls during the day and released into the indoor environment at night, and inadequate ventilation during the night time. Normally occupants tend to use the night flush effect by opening the windows for night ventilation. This allows cooling the spaces during night-time, but normally this is not done in the office room. This aspect shows that the effectiveness of some passive solutions to achieve comfort depend on the occupants' behaviour. Additionally, occupants that voted as feeling slightly warm have indicated the possibility of controlling the operable windows as an aspect to enhance cross ventilation and therefore the thermal comfort.

Natural ventilation, as mentioned above, is an essential strategy to promote passive cooling through the stack effect, and also by cross ventilation through the openings (doors and windows) and courtyards. The presence of courtyards in the two projects enhances air circulation inside the building by creating a difference in air pressure between indoor and outdoor. This is an asset to foster air flow inside the building, contributing to increasing users' satisfaction during hot summer days.

In the two case studies, the active behaviour of the occupants to improve their comfort conditions should be noted. It is very common in the two regions to promote passive cooling by natural ventilation of

the indoor spaces during the night and early morning and to shut windows and doors during the periods of direct solar radiation in order to avoid unwanted heat gains.

Since the two case studies use a different earth building technique it is also possible to analyse the different thermal behaviour between rammed earth walls in the Portuguese building and adobe walls in the Egyptian one. For example, the time lag for the adobe walls ranges from 10 to 12 hours while in the rammed earth is higher than 10 hours (Koch-Nielsen 2002). Regarding the U-value, the adobe construction performs better than the rammed earth one. That is due to the air bubbles inside these type of adobe bricks, while rammed earth is more compressed and compact (Berge 2009). These different characteristics show which building system suits best to the specific micro-climate.

6 CONCLUSIONS

The study showed the correlation between the thermal performance of earth vernacular buildings and human comfort perception in two different case studies located in the Mediterranean climate. It shows the common passive strategies and climate responsive practice in both cases despite the location in two different contexts. The culture, human adaptation and interaction with passive solutions affect the overall building performance. The study is still considered as a pilot and should be followed by more in-depth work using a full year monitoring to test the building performance during different seasons. Nevertheless, the results obtained show the effectiveness of a set of passive cooling strategies to achieve thermal comfort conditions. The results obtained both in objective and subjective measurements reveal that the case studies had good thermal conditions and that occupant's expectations were satisfied. Thus, the passive strategies used have potential to reduce energy consumption for cooling.

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Earthen construction in Ourense, Galicia (Spain)

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ABSTRACT: The city of Ourense (with more of 100.000 inhabitants), in the Miño river basin, is placed in a sedimentary basin in the south of Galicia. The most widespread technique in this city until the 19th century was called in Galician language *pallabarro*: a half timber with earth used as structural frame, as enclosure or patitions walls. Currently, they could be observed only in the old town of the city of Ourense and in many hamlets in the surroundings. The origin of this construction system dates back to Middle Age. Nevertheless, it is nowadays at risk of disappearing because of the lack of appreciation by population and the ignorance of their constructive technique by building professionals. The aim of this study is to disseminate the existence of this technique which is not included in Galician vernacular architecture monographs.

1 INTRODUCTION

1.1 *Methodology*

This study began three years ago. Its aim was, firstly, to identify the geographic area and extension of the use of this technique and to find out about the characteristics and dimensions of preserved constructions. The field work was accompanied by a mapping survey of the buildings, with research literature and interviews with Ourense City Council technical experts.

1.2 *About this research*

The strategy to design appropiate and sustainable contemporaneous constructions starts with the identification of richness and variety of vernacular architecture. In this way, this research aims to contribute to disseminate and make known vernacular earthen techniques almost extinct in Galicia. The knowledge of these techniques may contribute to define applicable principles in sustainable contemporary architecture and allow to bridge the current gap of references about earthen construction in Galician vernacular architecture monographs.

1.3 *Geographic context of Ourense*

The current city area of Ourense is located at the bottom of a not so deeply depression formed by the confluence of three river valleys, Barbaña, Loña and Miño, flanked by mountains reaching almost 500 m of altitude (Montealegre, San Mamede, Corvaceiras, Alto do Couso). It is an area of natural corridors with very good conditions for agriculture.

The area is formed by granite materials (granodiorite and two micas granite), with quarries near the centre of town; alluvial deposits along the river basins occupied today by the city; and schists in the western zone (IGME 1974).

The climate has continental traits, with annual average temperatures ranging between 8.3°C and 20.6ºC but reaching 3°C in the coldest months and 22°C in the warmest. Precipitations are not excessively high (818 mm annually) with a summer season with little rains. It also has a high relative humidity (66% average annual) due to its geographic situation.

The most common soils are lithosols on granite materials with a very weak organic horizon, and brown soils with pine forests (IGME 1974).

1.4 *Historical context of Ourense*

The area was already inhabited in pre-Roman times in the settlements of Castro Beiro, Madrosende, Santomé, Valdegola and As Burgas, with hot springs. Around them the first Roman settlement would be established in the first century AD (Chamoso Lamas 1956), as a transit between two of the main roads of secondary Roman network (Rodríguez Colmenero 1976).

The establishment of the Episcopal See in the 7th century, its declaration as free land in 1122, and the celebration of a monthly market consolidated the town (Durany Castrillo 1996). The city will grow until the 13th century, when it reaches a perimeter that will not change significantly until the second half of the 19th century. After a series of demographic crises in the 14th century, the city will live a time of strong economic and demographic growth in the



Figure 1. Fragment of a map of Ourense drawed by F. Coello. 1859 (Gallego Domínguez 2001).

first half of the 15th century linked to wine export. At this time, the power struggles among the bourgeoisie, the nobility and the clergy, which the bourgeois lose. The result will be a de-urbanization of the city (López Carreira 1986) due to the exodus of the most dynamic population (Somoza Medina 2001).

From the 16th to the 17th century, the city will slow down its growth as a result of an extractive political power (Castro Pérez 1996). The 17th century will have an economic and demographic situation very similar to that experienced during the 15th century (Somoza Medina 2001).

During the 19th century, trade and crafts rise again. The new roads, the designation as provincial capital in 1833, and the arrival of a large group of foreign businessmen will allow the city to evolve from a semi-feudal regime and rural town to an urban and capitalist town (Somoza Medina 2001). Thus, from the 19th century will begin a significant demographic growth. It will be the beginning of an urban sprawl that continues today.

2 HISTORIC EVOLUTION OF EARTHEN CONSTRUCTIONS AROUND OURENSE

2.1 *Earthen constructions in pre-roman settlements*

Earthen constructions were common in the oldest settlements during the second and third centuries BC of the Castrexa Culture. They were characterized by circular floors with stone foundations, a central wooden pillar, and walls formed by half timbers with earth and straw (Fernández Palicio 2016). However, from the first century BC began the sole use of stone for the lifting of the walls, a feature that Romans consolidated. The lack of extensive excavations in the surrounding settlements, hinder our knowledge of these constructions in this area.

2.2 *The town of Ourense during the middle age*

From the Medieval period at least from the 12th century to well into the 19th century, the vast majority of buildings in the city of Ourense, were held in *pallabarro* (Otero Pedrayo 2001), a building technique, with different denominations in Spain, that can be observed throughout the north of the Iberian peninsula, between the Basque Country and Galicia (Flores López 1979), and also in Western Europe (López Carreira 1986). In the early years of the 19th century it was still predominantly in the streets of Ourense a landscape of white (of the whitewashed stone walls and *pallabarros*), ocher (clay) and red colours (chimney bricks and tiles), combined with the gray stone (Otero Pedrayo 1996). A description that matches the description of the houses in other Galician cities such as Compostela or Lugo (López Carreira 1999).

2.3 *Changes in town in the 19th century*

The big changes that occurred in the city during the 19th century modified the entire city. During

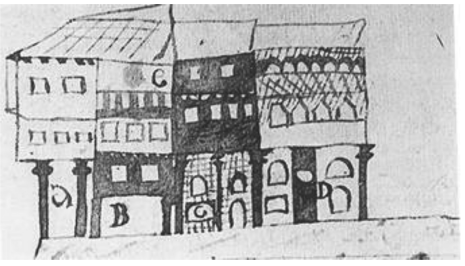


Figure 2. Medieval housing in Praza Maior Square, Ourense (López Carreira 1986).



Figure 3. Housing with medieval tipology in Irmáns Vilar Street at the beginning of the 20th century (Gallego Domínguez 2001).

the middle years of this century, the new class of foreign businessmen chose, to differ from the rest, to build constructions in stone, at least in the first stages, or performing new masonry facades with glazed galleries that hid the old buildings made of *pallabarro*. Thus, a slow, but continual, destruction of old constructions with half timbers with earths continued during the rest of the 19th and 20th centuries, partly by ruin, partly by reform and partly by new municipal ordinances requiring to demolish the projections and the passages streets that were considered unhealthy.

The process uniformed facades and streets in a kind of *crystallizatio*n (Otero Pedrayo 1996) of the city:

> *"The* pallabarro *walls were vaguer, had forms of belly, had forms of hill, had forms projected over the whole street; there was no geometry, there was not an organization. That* pallabarro *walls are dirty when are abandoned and very ugly; but when they are clean, when they are well whitewashed, are very nice and gave, then in Ourense, with fewer people than today, with women sitting at the door of the houses, with children playing in the streets, it could had (…) the whole southern city feel. Seemed Algeria and Morocco, these visions that romantics enjoyed watching (…) because the bright sun of the tremendous heat of Ourense lighted the white of* pallabarro *walls and lighted the boulders and lighted the large chimneys..."* (Otero Pedrayo 2001).



Figure 4. Housing with a new façade with stone blocks built during the 19th century where we can see the old rooftop built with *pallabarro* (author).



Figure 5. Housing with half timbers with earth in the confluence of Liberdade and Padilla streets (author).

2.4 *The hidden heritage: Survival of* pallabarro *constructions in the 20th and 21st century*

A look at urban cadastral plot allows us to observe the survival of this medieval type. Nowadays it is still possible to find in the old town of Ourense lots of buildings erected with half timbers with earth and straw. However most of this heritage is hidden by the already mentioned stone facades raised in the 19th and 20th centuries which are protected by law. It is difficult to appreciate and know *pallabarro* buildings which are not protected. So in this way, this constructive typology is slowly vanishing.

3 EARTHEN CONSTRUCTION TECHNIQUES PRESENT IN AND AROUND THE TOWN

Pallabarro was a construction system used in Ourense since the Middle Ages until the early 20th, when was displaced by the use of stone, when used as structural frame, or by the use of bricks walls and *barrotiño* technique when used as enclosure or partitions walls. These not so different construction systems, as structural frame, enclosure, or partition wall are called with the same word *pallabarro* in Galician language.

3.1 *Pallabarro as structural frame*

Pallabarro as structural frame is a continuous wooden framework between the first floor and the



Figure 6. Detail of *pallabarro* wooden structure in the old town of Ourense (author).

roof formed with 3 m-high vertical wooden pillars (the height of a normal building story) and numerous diagonals for bracing the structure assembled in 7 cm wide by 7 thick wooden sleepers. Diagonal and vertical timber cross-sections from 7×8 cm to 12×10 cm spaced form 15 to 25 cm. Log beams are perpendicular to this frame.

The space within this structure was completed by narrower and thinner wooden planks called *bitoques* assembled obliquely with slots made with chisels and hatchets. All the empty space was filled with a twisted of straw kneaded with mud called *lamprea* interlaced with the *bitoques*. The two faces of the framework are rendered with lime and sand, facilitating their union with the wood through incisions, or chopped, in the tables of the frame. Finally a whitewashed is rendered.



Figure 7. Housing with *pallabarro* structure in Praza da Trinidade Square (author).



Figure 8. Detail of *pallabarro* wooden structure (author).



Figure 9. Detail of *pallabarro* wooden structure (author).

In later times, many of these frameworks were completed with sawn wooden strips placed horizontally as described in paragraph 3.3.

3.2 *Pallabarro as non-structural enclosure*

Pallabarro as non-structural enclosure or partition wall was constructed with vertical wooden planks called *fitoiras* from 10 to 20 cm wide by 3 to 4 cm thick. The *fitoiras* were joined together by narrower and thinner wooden planks called *bitoques*, assembled obliquely with slots that are made with a chisel and with a hatchet. On the other side of this frame were applied new *fitoiras* united by their corresponding *bitoques*. The space between *fitoiras* was filled with a twisted of straw kneaded with mud called *lamprea* interlaced with the *bitoques*. The two faces of the framework are rendering with lime and sand, facilitating their union with the wood through incisions, or chopped, in the tables of the frame. Finally a whitewashed is applied (Lorenzo Fernández 1936).

Many times this enclosure were wicker partitions made with willow, hazel or other flexible wood twigs which were intertwined with the *fitoiras*.

3.3 *The barrote or barrotiño technique*

The *barrotiño* technique was the successor to the not structural *pallabarro* technique in the early 20th century. Strips of wood form the sawmilling factories were used. Ones were placed vertically, the *fitoiras*, and the others horizontally, the *barrotes*. Next

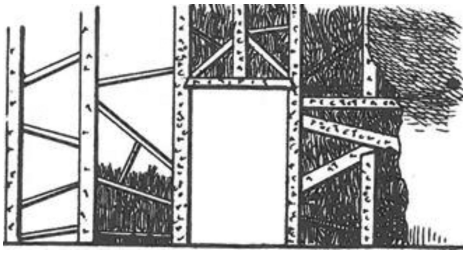


Figure 10. Building process of *pallabarro* non-structural partition. (Lorenzo Fernández 1936).



Figure 11. Detail of a wall made with *barrotiño* technique in Canella Cega Street (author).

to this frame came another identical one and the space was filled with wooden chips, pine needles, or other items. This frame was chopped and rendered like the *pallabarro* (Lorenzo Fernández 1936).

4 HOUSING CONSTRUCTIONS TYPOLOGIES WITH *PALLABARRO* AND *BARROTIÑO*

There are significant differences between urban houses and buildings that originally had a rural character and that can be found in the surroundings of Ourense.

4.1 *Types of urban housing with medieval origin*

Ordinary urban houses of medieval origin typology in Ourense were usually built in row plots (4 m wide) that occupied the entire surface area except sometimes the back areas used for gardens. They are similar to other urban medieval houses studied in Galicia like the village of Verin (Fernández Palicio 2016), Monforte de Lemos (Fernández Palicio 2012), Ribadeo, Mondoñedo and Viveiro (López Alsina 1976) or anothers referenced like Ribadavia or Celanova (Otero Pedrayo 1927).

They were small family houses with a ground floor or even three or four floors, sometimes with attics, with small openings to the street, and often with a balcony with heavy wooden parapets. The interior was divided into several chambers.

The main type of houses was characterized by a ground floor made of stone, with arcades with rounded arcs or doors with lintels, and with the next floors projected over the street made with half timbers with earth and straw which advanced the body of the houses over the street (López Carreira, 1986) leaving narrow and poorly lighted streets. Often even the houses on both sides touched each other (Otero Pedrayo, 1927).

Bricks were used in chimneys, and tiles from local ovens were also used on the wooden roof. The *pallabarro* walls were rendering with local lime.

There are also some medieval houses belonging to nobility, a similar type to that described, but with stone facades with different arcs, shields and other ornaments to externalize the differences in class. An example of this is preserved in the current Casa dos Cadórniga which has a stone facade with an ogee arch and a family shield, originally from the late fifteenth century or early sixteenth century. The rest of the house was made with *pallabarro* walls.

4.2 *Types of rural housing in the surroundings of Ourense*

Rural buildings in the parishes of Ourense surroundings used the same materials as those described for urban housing even though the typology varied. This typology is similar to the meridional type described in the main monographs about vernacular construction in Galicia (De Llano 1996, Caamaño 2003). However we emphasize the significant presence of numerous walls built with *pallabarro* in the oldest constructions that was used to lift the entire first floor of the house leaving only the stone for the ground floor with the pens and stables (Lorenzo Fernández 1936). This type was already studied in other regions of Galicia, like in old constructions in Alto Arnoia river valley (Fernández Palicio 2014).



Figure 12. Housing in Praza do Ferro Square (Ruth Matilde Anderson 1923).



Figure 13. House dos Cadórniga in Hernán Cortes Street (author).



Figure 14. Rural house with first floor made with *pallabarro* in Parada de Sil (author).

5 *PALLABARRO*, REGARDED AS THE TECHNIQUE OF POOR

As we can note, the *pallabarro* technique was perceived from the Middle Ages as a building material for the poor contrary to the stone, which had a more noble character. This negative perception will remain in Galicia during the centuries and will be assumed by the new bourgeois of the 19th century, who replaced or hid the half timbers with earth and straw when they built new homes. This poor perception of *pallabarro* walls will continue in the 20th and 21st centuries among the majority of the population in Galicia due to of the lack of references to building with half timbers with earth and straw.

6 CONCLUSIONS

Although currently the old town of Ourense is considered essentially built in stone, there is a hidden heritage erected with half timbers with earth and straw unknown to the majority of people and technicians. This technique is generally not valued or despised as not appropriated for Galicia, being systematically separated and unprotected in the rehabilitation of the heritage of the town, which is slowly declining.

Earth buildings still survive in the majority of the constructions of Ourense, even though the stone buildings are the only respected traditional constructions. However, it has not always been that way. In the Castrexa culture, the use of materials was evolving. At different times wooden and clay frames or stone walls were more or less used. Also, during the Middle and Modern Ages wooden frames and clay were largely used in many areas of Galicia, being the stone reserved for foundations and ground floors. As a result, the existing imaginary about vernacular constructions, which gives the stone a role of unique or fundamental material in Galicia, can be questioned. This leaves a door open to new approaches, where the study of traditional construction goes beyond the fixed picture inherited from the popular imagination and the monographs studies about vernacular construction.

We need to know different and numerous historical adaptive processes present in every place and consider vernacular constructions as an adaptive process in constant evolution.

The vernacular construction is rich and varied, the same as the materials used in its construction and the adaption processes. Thus, the history of vernacular building in Galicia can be enriched.

Sustainable contemporary construction, which looks to vernacular architecture as a source of learning and inspiration, needs an approach that considers traditional construction as an evolving process, allowing it to escape from its beautification or simple reproduction of traditional forms. It should enable the emergence of a new sustainable contemporary architecture which can plan its own environmental adaptive processes at the current historical moment.

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Earthen vernacular architecture in Cuneo's territories (Piedmont, Italy)

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ABSTRACT: Piedmont is characterized by the presence of numerous earthen buildings mainly concentrated in the province of Alessandria. Studies conducted over the last decade, however, have shown the presence of interesting examples of these buildings also in the provinces of Asti, Torino, Biella and Cuneo. They are generally two-storied rural constructions, built with both fired bricks (for the bearing structures) and earthen bricks (for internal and external walls). These buildings are evidence of the close relationships between man and his territory. Although there are only few examples, they do, however, represent the interesting evidence of know-how and old-aged construction techniques. They are *fragile* architectures, a little or not at all known, which may be irretrievably lost if not properly safeguarded. This paper intends to present the results of a research conducted by people belonging to different fields, in order to study the testimonies of earthen constructions in the Cuneo's territory (Tanaro valley).

1 INTRODUCTION

Piedmont is characterized by the presence of numerous earthen buildings mainly concentrated in the province of Alessandria. Studies conducted over the last decade, however, have shown the presence of interesting examples of these buildings also in the provinces of Asti, Torino, Biella and Cuneo.

Primarily designed only for utilitarian purposes, they are the expression of cultural and architectural values representing a significant testimony of the relationships between a community and its territory.

Although only few examples are still surviving, they do, however, represent the interesting evidence of know-how and old-aged construction techniques. They are *fragile* architectures, a little or not at all known, which may be irretrievably lost if not properly safeguarded. Their preservation is in fact «threatened world-wide by the forces of economic, cultural and architectural homogenization» (ICOMOS Charter 1999), as well as by the lack of recognition of its true historical and cultural value. Its identification, but also a good knowledge of the typologies, construction techniques and materials are needed, in order to facilitate the implementation of appropriate restoration and reuse interventions.

This paper intends to present the results of a study conducted by researchers belonging to different fields, on the testimonies of earthen constructions in the Cuneo's territory.

The research aims to deepen the knowledge of the earthen buildings present in different areas of the province of Cuneo, examining types, construction techniques and analyzing the characteristics and performance of the constitutive materials through in situ tests (rebound test, capillary absorption), characterization of the earth (XRD, calcimetry, particle size distribution) and identification of possible additives.

This type of research will be useful to promote again the use in Piedmont of these construction techniques, evidence of skills and abilities of people to take advantage of the local environmental resources.

2 EARTHEN ARCHITECTURES IN CUNEO'S TERRITORIES: TYPOLOGIES AND CONSTRUCTIVE TECHNIQUES

Piedmont has one of the richest collections of historical and architectural earthen heritage in the whole of Italy, whose characteristics change from one area to another.

Earthen constructions in the province of Cuneo (Tanaro valley) are mostly rural buildings. The most common typology is the *cassina* which is usually both for residential (Figs. 1–2) and agricultural use (Figs. 3–4). The buildings have little wings so that they are suitable to be erected on the hills without the need of huge earth moving. Earthen buildings can be found both in the towns and in the countryside.

They are generally two-storied rural constructions, built with both fired bricks (for the bearing structures) and earthen bricks (for internal and external curtain walls) (Palmucci 1988, Bosia 2009). The kitchen, the dining room, the cellar and/or the storage are located on the ground floor. The bedrooms and the barn can be found on the first floor and they can be reached by a wooden staircase or, sometimes, made of bricks or stones.

The buildings have generally stone/bricks foundations 40–50 cm high in order to protect earthen walls from the water capillary rise. In many cases, a fired brick basement reaching the first floor can be found. The wall thickness is about 40–60 cm. The openings are small and have vaulted lintels and brick frames.

The horizontal elements are mostly made of wooden beams (placed at a distance of about 80 cm) which support wooden boards or, more often, brick vaults. The balconies stand on wooden beams which are the extension of the internal ones.



Figure 1. Residential building in Govone (Cuneo) (credit Manuela Mattone).



Figure 2. Residential building in Priocca (Cuneo) (credit Manuela Mattone).



Figure 3. Rural building in Priocca (Cuneo) (credit Manuela Mattone).



Figure 4. *Cassina* in Magliano Alfieri (Cuneo), back side of the storage (credit Manuela Mattone).

The roofs are double pitched and mainly have wooden structures, whose beams lay on earthen or fired bricks. The roof covering uses tiles and, when there isn't the eaves gutter, the overhang of the roof is greater in order to allow adequate removal of rainwater and ensure more protection to vertical surfaces.

3 MATERIALS AND METHODS

The following materials, coming from the three earthen building located in Govone, Magliano Alfieri and Priocca villages (Tanaro valley, Cuneo province), were analyzed: earthen bricks and earthen bedding mortars.

3.1 *Mineralogical composition*

The mineralogical composition of the earthen bricks and earthen bedding mortars was determined through X ray diffraction (XRD) (X'Pert PRO diffractometer by PANalytical equipped with X'Celerator detector and HighScore software for acquisition and interpretation of data according to the following operative conditions: CuK $\alpha 1 = 1.545$Å radiation, 40 KV, 30 mA, $2Q = 3–70°$).

The analysis of the clay minerals was determined on the fraction <4 µm extracted through sedimentation according to the Stokes' law (Cipriani, 1958; Cipriani & Malesani, 1972) utilizing a Philips PW 1729 diffractometer, according to the following operative conditions: CuK $\alpha 1 = 1.545$Å radiation, 40 KV, 20 mA, $2Q = 3–20°$).

3.2 *Calcimetry*

The amount of calcium carbonate was determined through the Gasometric technique by using the Dietrich Früling calcimeter (Leone et al. 1988).

3.3 *Grain size distribution*

The grain size distribution of earthen bricks and earthen bedding mortar has been carried out through sieving in order to separate the following fractions: sand ($Ø > 63$ µm), silt (4 µm $< Ø < 63$ µm) and clay ($Ø < 4$ µm).

3.4 *On site test*

3.4.1 *Rebound test*

An analysis by the hammer sclerometer (rebound test) was carried out on a wall of the three different buildings under investigation in order to determine the compressive strength of the earthen bricks.

The determined values are indicative values, because the rebound test is an indirect test, which correlates the surface hardness to compressive strength.

The employed hammer sclerometer was the Proceq pendulum hammer type PM (range 0.2–5 N/mm^2), suitable for a wide range of materials with low compressive strength and where small impact is required.

It consists in measuring the rebound R, which is in relationship with the hardness and strength of the material.

For each wall, the average rebound was determined and the average compressive strength was determined from the corresponding conversion curves/equation.

A total of 12 measures for each wall were carried out.

3.4.2 *Water absorption test*

The water absorption tests have been carried out using Karsten pipe (Kartsten 1983) and by measuring, for a maximum of 15 minutes and at regular intervals of time (one minute), the rate of water absorbed from the graduated pipe (Fig. 5).



Figure 5. Water absorption test and Rebound test in Magliano Alfieri (Cuneo) (credit Manuela Mattone).

4 RESULTS AND DISCUSSION

4.1 *Earthen bricks and earthen bedding mortars characterization*

The results of XRD and grain size analysis are reported in Tables 1–3.

Concerning the comparison between the mineralogical composition of bricks and mortars it is possible to observe that in the case of Govone an earth rich in carbonates (marl) was used for bricks while for the bedding mortar an earth without carbonates was selected. Also in the case of Priocca the mineralogical composition points out that different earths were used for brick and mortars while in the case of Magliano Alfieri the same earth was used.

As for the grain size distribution, it seems that, for all the three buildings, an earth richer in clay was used to realize the bricks.

The comparison with the data from other Piedmont sites where adobe building have been studied (Rivasecca, Borgo Cornalese, Magnano) (Fratini et al. 2014, Fratini et al. 2016) show that in the Cuneo province (Tanaro valley) the used earth is more fat. While, concerning the difference between mortars and bricks, the same trend is present i.e the grain size of mortars is coarser than that of bricks.

With regard to a comparison with the optimal granulometric curve reported by CRATerre for earthen bricks (Houben & Guillaud 1989), it is observed that the granulometry of Priocca bricks falls within the zone of acceptability while Govone and Magliano Alfieri bricks are too rich in clay.

Table 1. Principal mineralogic composition.

	Qz	F	C	D	Clay + Acc.	*CO_3^{2-}
Govone (bricks)	XXX	XX	XXX	X	XX	30
Govone (mortars)	XXX	XX	tr	–	X	tr
Magliano-Alfieri (bricks)	XXX	XX	X	–	XX	8
Magliano-Alfieri (mortars)	XXX	XX	X	–	XX	8
Priocca (bricks)	XXX	XX	X	tr	XX	6
Priocca (mortars)	XXX	XX	XX	tr	XX	10

XXX = abundant; XX = medium; X = scarce; tr = traces. Qz = quartz; F = feldspars; C = calcite; D = dolomite; Clay + Acc = clay minerals + accessory minerals. *CO_3^{2-} = carbonates relative amount % by gasometric method.

Table 2. Clay mineral composition*.

	K	I	IS	S	Cl
Govone (bricks)	30	45	–	10	15
Govone (mortars)	15	45	20	15	–
Magliano-Alfieri (bricks)	20	55	–	25	–
Magliano-Alfieri (mortars)	15	65	–	20	–
Priocca (bricks)	15	40	–	30	15
Priocca (mortars)	20	45	–	35	–

*relative amount %; K = kaolinite; I = illite; IS = illite–smectite; S = smectite; Cl = chlorite.

Table 3. Grain size distribution.

	Sand	Silt	Clay
	f > 63 µm	4 µm < f < 63 µm	f < 4 µm
Govone (bricks)	18	26	56
Govone (mortars)	11	50	39
Magliano-Alfieri (bricks)	10	46	44
Magliano-Alfieri (mortars)	21	44	35
Priocca (bricks)	18	48	34
Priocca (mortars)	24	45	31

4.2 *On site test*

4.2.1 *Rebound test*

The following compressive strength were determined on earthen bricks: 5.1 MPa (coeff. of variation = 1.0) for Govone, 3.6 MPa (coeff. of variation = 0.7) for Magliano-Alfieri, and 2.3 MPa for Priocca (coeff. of variation = 0.6).

A comparison with the compressive strength of other earthen bricks (Baglioni et al. 2010, Briccoli Bati et al. 2011, Fratini et al. 2011, Fratini et al. 2012, Fratini et al. 2014, Fratini et al. 2016, Gamrani et al. 2012, Rovero & Tonietti 2012, Rovero et al. 2009) shows that for Magliano-Alfieri and Priocca the values are similar.

As for Govone the compressive strength is particularly high. This could be explained by the different composition of the used earth, definitely more marly, with possible phenomena of dissolution and precipitation of calcite within the brick, resulting in a consolidating effect.

4.2.2 *Water absorption test*

As can be seen in the diagram of Figure 7, the values obtained from the tests show that the absorption capacity of the bricks is quite different. In particular, the walls of Govone show a higher absorption capacity, comparable to the one of Priocca. It should be taken into account that in Govone and in Magliano Alfieri internal walls were tested while in Priocca the tests were carried out on an external wall exposed to sunlight.

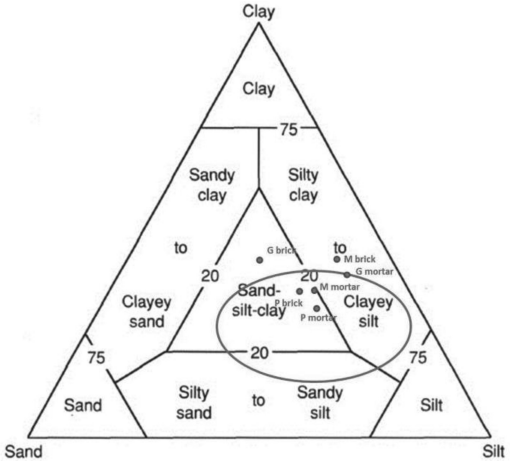


Figure 6. Ternary diagram sand-silt-clay: the red ellipse represents the zone of acceptability for earthen bricks as reported by CRATerre, the dots are the average values for the earthen bricks and mortars (G = Govone; M = Magliano-Alfieri; P = Priocca) (modify after Shepard 1954).

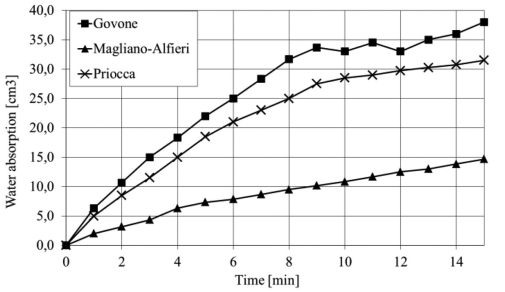


Figure 7. Diagram illustrating the results of capillary absorption tests (credit Manuela Mattone).

5 CONCLUSION

Earthen architecture in the province of Cuneo is an interesting, even if sporadic, testimony of vernacular architecture, expression of the traditional and natural way by which communities used to house themselves. The detailed study of these architectures, their construction characteristics and materials is an essential prerequisite to safeguard them and might also contribute to the rediscovery of the earth as a construction material.

The results of compositional, granulometric and mechanical investigations give useful information in order to understand characteristics of the material and technologies used in earthen building construction near Cuneo.

The mineralogical composition of Govone bricks show that the used earth is particularly rich in carbonates (marl) and this characteristic could explain their good mechanical properties. On the contrary for the bedding mortar an earth without carbonates was selected.

Also in the case of Priocca the mineralogical composition points out that different earths were used for brick and mortars while in the case of Magliano Alfieri the same earth was used.

As for the grain size distribution, it seems that, for all the three buildings, an earth richer in clay was used to realize the bricks.

Concerning the water absorption test, the data are strongly affected by the thermo-hygrometric conditions of the sites which are extremely variable also during the day (not to say for the different seasons). Therefore, these data are able to characterize the different bricks only in case the tests are performed in laboratory controlled conditions.

Aware of the need to conduct further tests and analyzes aimed at assessing the performance characteristics of the earthen buildings near Cuneo, it is believed, however, that the research conducted so far can be a first useful step to promote the knowledge and the safeguard of this heritage. Moreover, it could also foster the rediscovery of these construction techniques, evidence of skills and abilities of people to take advantage of the local environmental resources.

NOTE

To be noted that all the authors should be considered as principal authors.

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Vernacular earthen architecture and its restoration in the region of La Manchuela in Albacete (Spain)

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ABSTRACT: Earthen construction is widespread in the traditional architecture of most of the Spanish mainland. This study focused on the region of La Manchuela in the province of Albacete, where traditional earthen construction was predominant until the early twentieth century, when with the introduction of new materials these traditional constructions began to progressively disappear. The main aim of this research was the cataloguing of earthen buildings still conserved in the region, in order to collect data for subsequent analysis of the different earthen constructive techniques used for buildings as well as the interventions for restoration and maintenance carried out on them over time, finally cross-referencing the case studies to extract a series of overall conclusions.

1 INTRODUCTION

This research is part of a wider project, "SOStierra. La restauración y rehabilitación de arquitectura tradicional de tierra en la Península Ibérica. Líneas guía y herramientas para una intervención sostenible", which aims to research the possibilities of a compatible and sustainable restoration and rehabilitation which respects non-monumental traditional earthen architecture built on the Spanish mainland. These actions should avoid standard alien solutions but favour options that respect the technical and cultural diversity of this type of architecture and its lessons in sustainability for the future. The value of earthen architecture as part of the culture of construction materials on the Spanish mainland is undeniable both in terms of origin and the degree of conservation of these structures, and of their perfect adaptation to the environment (AA.VV. 2011).

This is a general proposition, but the research is being carried out by region, and the work presented in this paper is more defined and located in a specific geographical region in the Autonomous Community of Castilla La Mancha, La Manchuela, in the province of Albacete.

1.1 *Research frame*

The region of La Manchuela, in the northeast of the province of Albacete (Castilla La Mancha, Spain) borders to the north with the Manchuela Conquense and Plana de Utiel, to the east with Valle de Cofrentes, to the south with Monte Ibérico-Corredor de Almansa and Llanos de Albacete, and to the west with the region of Mancha del Júcar. The region is divided by the river Júcar, which crosses it from east to west creating the contrasting landscapes of the valley and the plain.

There are 25 municipalities in the region, nuclei of population, which have been covered in this research and case studies have been selected from these (Fig. 1).



Figure 1. Geographical map of the community of Castilla La Mancha and the region of La Manchuela in the province of Albacete.

2 RESEARCH OBJECTIVES

The main aim of this research is to contribute to knowledge of traditional earthen architecture in the region of La Manchuela in the province of Albacete (Spain) as a type of architecture suited to the contemporary world, with cultural, technical, bioclimatic and environmental values.

In addition, this study aims to encourage sustainable conservation and restoration compatible with the built traditional architecture heritage in La Manchuela. The types of interventions carried out in this architecture were analysed to learn from their strengths and weaknesses, assessing the results of these interventions, as well as the pathologies identified in the case studied, both those prior to the intervention, and those to some extent caused by the intervention.

Finally, taking into account the localised nature of this study, attempts were made to contribute to the valorisation of traditional materials and techniques to encourage their use in the restoration of traditional heritage. Traditional earthen architecture uses local materials and is the technique best suited to local environmental conditions and makes frequent use of local workers.

3 METHODOLOGY

In general, the use of earthen constructive techniques and traditional techniques has been developed through experience, always using the nearest and most plentiful prime material and making the best possible use of geographical conditions (Noguerón, Giménez, Barrelles 2011). In order to assess the solutions proposed this research has analysed the current situation and the restoration and rehabilitation interventions in earthen architecture carried out to date in the area.

The methodology used in the analysis and assessment of the interventions carried out was developed in different phases. In order to carry out a joint analysis initial comprehensive data collection was carried out for the different case studies of buildings constructed with earthen techniques which had undergone interventions. For the data collection process a database was created recording each case study in fiche format. This cataloguing system allowed the subsequent analysis and cross-referencing of the individual and global interventions carried out. Solutions and guidelines for action on this heritage could later be proposed based on this practical knowledge of interventions.

For the purposes of this study, visits were made to 16 municipalities in the region (Fig. 2), selecting a total of 61 case studies that have been entered in the database from each of these.

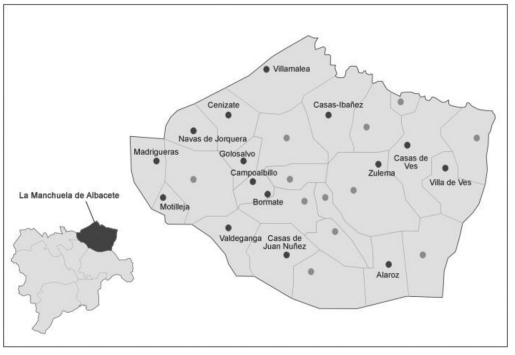


Figure 2. Plano de situación geográfica de la comarca de La Manchuela en la provincia de Albacete, con la distribución geográfica de las poblaciones visitadas.

Cases were selected by identifying earthen buildings which may have experienced interventions, even partial ones. This database aimed to compile all the information relating to the materials and constructive techniques used in the earthen architecture in the area, including its insertion into the landscape (mechanisms of adaptation to local bioclimatic characteristics) and restoration-rehabilitation.

The cataloguing methodology developed is common to all the research being carried out within the framework of this project. The use of a single methodology for all studies will therefore enable the subsequent global analysis of the interventions carried out on earthen vernacular heritage throughout the Iberian Peninsula, thus drawing global conclusions on the situation of this heritage and its conservation.

4 INITIAL PROGRESS OF THE RESEARCH

The development of these data collection tasks and production of fiches make it possible to carry out a global analysis, extracting some preliminary conclusions on the constructive techniques used and interventions carried out.

4.1 *Earthen constructive techniques*

Following analysis of the case studies it was established that rammed earth was the predominant earthen constructive technique in the region. In some parts of the province of Albacete this technique was used for most buildings until the mid-twentieth century (Temes 1933). Some authors have established that the last rammed earth buildings in the area are 50 or 60 years old, although a few more recent individual cases have been found (Castilla Pascual 2010).

Most of the vernacular architecture in this region is rammed earth but some examples of adobe architecture have also been found, mainly in the northwest of the region, on the border with the province of Cuenca, specifically in the municipalities of Villamalea and Navas de Jorquera, where some examples of adobe dwellings have been catalogued (Fig. 3).

Within the predominant earthen construction technique of rammed earth the most frequent constructive variants are the simple rammed earth walls on the perimeter of plots and farmland; the rammed earth walls with reinforcements, mostly rammed earth walls with reinforced joints, and rammed earth walls joined with gypsum *brencas* and *rafas*, in the construction of dwellings. Generally, in any of these constructive variants reinforcements are also incorporated on corners and other individual points such as jambs for door and window openings (Fig. 4).

Although limewash is the usual rendering and coating for these walls, there is another type of traditional rendering in the area, featuring the use of frames or lime mortar studs which act as guides when rendering smaller areas or panels (Fig. 5). These studs generally frame a space of similar measurements (40 or 50 cm), although this can sometimes be increased to adapt and frame openings.



Figure 3. Adobe dwelling in Villamalea (L. García-Soriano).

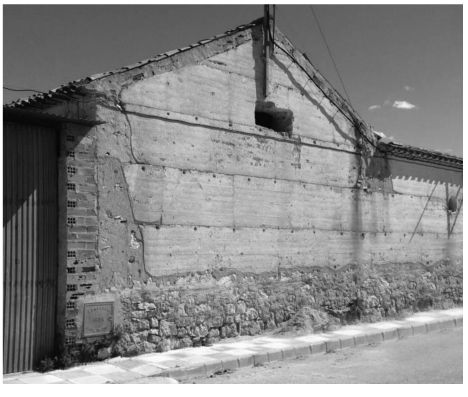


Figure 4. Rammed earth wall with *rafas* on the corners in Casas de Juan Nuñez (L. García-Soriano).



Figure 5. Above: Traditional rendering using lime mortar studs in Campoalbillo, rendered in cement mortar below. Below: Rendering detail (L. García-Soriano).

4.2 *Interventions carried out*

Interventions for the repair and rehabilitation of these earthen structures (dwellings, storerooms, auxiliary work constructions…) were analysed based on the part of the wall intervened (foundation, wall, plinths, rendering, openings, floors and roof). This individual analysis aimed to ascertain the general action dynamics in the area, which are generally attempts to resolve specific problems with varying degrees of success.

4.2.1 *Interventions on the base of the walls*

Although the plinths and foundations of the walls of these earthen constructions are usually masonry, but sometimes there are none and the rammed earth walls are in direct contact with the ground. The main problem in this part of the wall is water rising through capillary action which causes progressive loss of material. In these cases, cement mortars tend to be used for the proposed repairs,

progressively affecting the wall as they produce salt efflorescence when the capillary water comes into contact with the salt in the cement mortar. Masonry plinths are often rendered with cement mortar, but given that these renderings are superficial the water which eventually rises by capillarity is unable to reach the surface. Instead it comes into contact with the earthen wall, potentially causing major loss of material at the exact point where the cement plinth ends. In some cases the material incompatibility of masonry and cement goes so far as to cause the progressive detachment of this new coating (Fig. 6).

4.2.2 *Interventions in walls and surfaces*

Usually there are different types of interventions on the walls depending on the sort of deterioration they attempt to resolve.

Generally, when repairing gaps on walls or surfaces cement mortar is chosen for the localised repair of the points affected. In these cases the repairs are spontaneous and do not seek any aesthetic or decorative purpose (Fig. 9). In contrast, in other cases, generally dwellings, the most frequent solution for main façade walls is to render them completely using modern single-layer mortars. It is difficult to establish whether these dwellings are built with earthen materials or not and on occasion it is the partition walls, rarely intervened, which reflect the original constructive system of the walls (Fig. 7).

Other pathologies requiring interventions in walls are those due to structural causes, generally cracks in the walls resulting from differential settlement or occasional excessive stress, usually on the weakest points, where there are changes in material or width, or near corners and reinforcements (Aymat Escalada 2000). The most frequent interventions for resolving these pathologies are the filling of cracks using mortar, usually cement. In addition, in specific case studies the use of braces (generally metal with wood dowels) is proposed to prevent the wall from moving (Fig. 8). In these interventions it is important to take into consideration potential material incompatibility between the wall and the new materials added, as this can cause future pathologies (García-Soriano 2015).



Figure 6. Construction in Casas de Juan Nuñez with a plinth rendered in cement mortar, detached at some points (L. García-Soriano).



Figure 7. Rammed earth dwelling in Casas de Juan Nuñez with a completely new façade (L. García-Soriano).



Figure 8. Rammed earth construction in Motilleja with repairs of a crack and a structural brace (L. García-Soriano).

4.2.3 *Interventions on the crowning and roofs*

Generally in the case of crownings two types of solutions are employed.

The consolidation of the crowning following the wall profile is generally proposed, usually employing cement mortar, in the case of walls which are not enclosed and have no roof protection.



Figure 9. Rammed earth construction in Golosalvo where part of the roof has been replaced with a corrugated metal sheet resting on several brick courses on the crowning of the rammed earth wall (L. García-Soriano).

In cases where there is a roof, the solution employed is usually the adaptation of the profile of the crowning to support a new roof. These repairs are frequently carried out with brick courses resting directly on the rammed earth walls and supporting the roof.

Although interventions on roofs usually consist in proposing solutions for the lack of watertightness some unfortunate interventions have easily and quickly ensured watertightness but cannot be recommended as they affect the overall material and do not contribute to material conservation. This is the case of overhanging anti-drip solutions used for roofs, as in many cases these affect both the fabric of the roof (as the roof tiles can no longer be recovered) and that of the wall in the area of the crowning. In cases where the roof is eliminated and rebuilt there are usually two types of actions: either the roof is rebuilt using contemporary materials and finished off with roof tiles or the roof is built using corrugated metal sheet (Fig. 9). In the case of the latter the exterior image of the building and its character are severely affected, so that this sort of solution should be avoided wherever possible.

Other frequent actions are the complete replacement of roofs, generally in order to incorporate new insulation and waterproofing sheets to improve the interior conditioning. However, these conditioning actions on the roofs can be carried out using compatible materials, recovering original elements in good condition while contributing to the preservation of the general character of the building.

5 CONCLUSIONS

This study has analysed the constructive techniques and interventions used in the earthen vernacular architecture of the region of La Manchuela in Albacete. Studying and assessing these makes it possible to propose solutions and tools which can be applied in a modern and efficient recovery that is compatible with heritage, constructive, environmental and sociocultural values.

The evaluation procedure used to date for case studies has contributed to the establishment of an analysis methodology as homogeneous and objective as possible. As this work will continue to be expanded, compiling information from other regions in the province of Albacete, this methodology will have to be applied to all the cases identified during the project, but may be subject to variations or adaptations in order to include new aspects for analysis. However, the results of this first study phase have provided a clear identification of the dynamics for rehabilitation and maintenance currently being applied to this type of traditional earthen architecture.

It can be concluded that many of the interventions carried out are sporadic and spontaneous, with no prior planning or thought, and that these are mainly quick small one-off interventions carried out as cheaply as possible without consciously considering important values that ought to be taken into account, such as material compatibility, respect for existing architecture, the conservation of the constructive character of vernacular architecture…

In most cases, these interventions seek a response in the new modern materials, trusting that these (generally involving cement) are the solution to a wide range of issues. However, it should be noted that in time the use of these materials causes major issues in earthen walls (damp, salt efflorescence…) usually caused by material incompatibilities which trigger off a whole series of related pathologies which could seriously affect these constructions. Therefore, proposals for action should analyse these aspects, suggesting more compatible actions using other materials closer to the original ones which will integrate better into the original construction.

The main threat to this vernacular architecture is perhaps the lack of valorisation, giving rise to the loss of many of these constructions. New technologies, such as Google Street View, can even serve as witness to the past and the slow disappearance of this architecture. Examples of this were detected during the fieldwork, including that of a building in Golosalvo (Fig. 10) which was still standing in Street View images from 2014 but had since been torn down, only preserving the ground floor façade wall to establish the perimeter of the plot. This was completely rendered in cement mortar, so that the only remaining recognizable part of the original building was the brick from the jambs



Figure 10. Above: Traditional rammed earth dwelling in 2014 in Golosalvo (Google Street View). Below: Image of the same building in 2017 (L. García-Soriano).

of the main door, which had been blocked off. This is the real situation of earthen vernacular architecture when it is not valued as part of the cultural and historic heritage of a territory, and if it is not fully understood that it deserves to be conserved, rehabilitated and adapted to contemporary needs.

Although this research is limited to a specific geographical area it has contributed to the study of interventions being carried out in the region of La Manchuela de Albacete and their dynamics, pleading the case for the need for global learning. This knowledge should be based on the different experiences carried out to find out the results of the different actions, and in turn should make it possible to establish guidelines for the rehabilitation and adaptation of this architecture to current standards.

NOTE

This work is part of the research project "Restoration and rehabilitation of traditional earthen architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention", funded by the Spanish Ministry of Science and Innovation (Ref.: BIA2014-55924-R; main researchers: Camilla Mileto and Fernando Vegas López-Manzanares).

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Earthen elements in the Iberian Peninsula: Cataloging and preliminary study

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ABSTRACT: Earthen elements, especially adobe, are frequently found in the traditional architecture of many parts of the Iberian Peninsula. The geography and climate of this vast territory, the specific properties of the elements and the constructive variants in which they are used are very disparate. This text presents a catalog of samples collected from different points of the Iberian Peninsula and a preliminary visual analysis, aided by a study fiche and uniform criteria. A comparison of the properties of these elements allows correlations to be established between the constructive typologies they are used in, the properties of the walls, and the characteristics of the individual elements (bond, size, color, measurements, stabilizers…).

1 INTRODUCTION

This proposal for cataloging and studying earthen elements (adobe, cut earthen blocks or *terrones*, and) is part of the study of traditional techniques in earthen construction in the Iberian Peninsula within the project "SOStierra. Restoration and rehabilitation of traditional earthen architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention".

Construction with earthen elements is found in the constructive tradition of large parts of the Iberian Peninsula, especially constructions in adobe, although it is possible to find examples of traditional architecture using sods and cut earthen blocks. These construction variants are considered part of a large family of earthen constructive techniques which used elements—usually parallelepiped—that are gradually bonded. These elements are characteristically made up of earth, occasionally supplemented by other locally accessible materials to improve their properties. The variety of materials in each region and the local constructive know-how have given rise to many different shapes and materials in these elements in different parts of the Iberian Peninsula, even in different towns in the same area or region (VVAA 2011). The characteristics of these elements always adapt to the resources and needs of each location, maintaining a close relationship with their surroundings.

Adobe is undoubtedly the most common constructive technique with earthen elements of the three analyzed in this study, and is found all over the Iberian Peninsula. In addition, sods and cut earthen blocks are less frequent techniques and to date have only been identified in the most western part of the Peninsula. Cases of construction with sods have been recorded in the north (Galicia and Zamora), while constructions with cut earthen blocks are found mostly in central Portugal (Fig. 1).

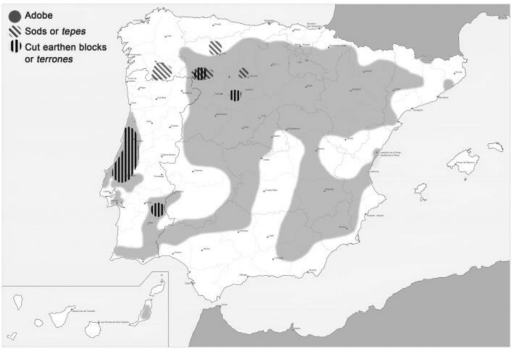


Figure 1. Location plan for construction techniques using earthen elements, and drawn up for the SOStierra project.

2 OBJECTIVES

The earthen elements studied are highly heterogeneous (shape, size, composition, color, texture and added materials or stabilizers) and their properties vary depending on the place or region they occur in (VVAA 2008). This study aims to create a methodology for preliminary analysis and cataloging in order to ascertain the characteristics of the earthen elements collected throughout the Iberian Peninsula using detailed individual analyses, as well as an analysis of their characteristics in relation to the characteristics of the walls and buildings they are found in.

The main aim of this study is to record the different types of earthen elements and their main constructive characteristics and variants in traditional architecture in the Iberian Peninsula. In many cases, the analysis of these elements already existed in an isolated or localized form. The final aim of this study is to provide an overview of the Iberian Peninsula establishing comparisons and cross-references between the different regions studied.

3 METHODOLOGY

The systematic study of the different elements was based on a catalog of samples, resulting in a database that will continue to expand in the course of the study. The analysis process applied includes the following tasks:

a. Firstly, an overview of the areas of the Iberian Peninsula where construction techniques using earthen elements are found. Work was mainly carried out using the specialist bibliography (indirect sources) and scientific projects (direct sources), to identify the regions or areas where this type of construction is frequent and extract samples. The samples of the different elements were not evenly collected throughout the Iberian Peninsula (Fig. 2), and took into account the original typology of the walls they were found in (half-timber, interior walls, loadbearing walls and enclosing walls). This ensured the study of the greatest variety and most diverse characteristics possible. Data collection on the elements and on the buildings or walls from which they were extracted has been equally important in the extraction process. Measurement tasks, analysis of the building and wall, and extensive photographic documentation have been key in ensuring there is sufficient information for subsequent analysis.
b. Secondly, all the information collected was summarized and transferred to the study fiches created for this catalog process. Thus, the main data or characteristics for each case study can be compiled and studied objectively, clearly, and quickly. These sets of fiches make up a database which allows information to be accessed simply and accurately, extracting tables and graphs as necessary. Preliminary study of the samples consisted of a complete visual analysis and was recorded in the fiche. The data compiled in the fiches can be grouped as follows: a first part with general sample data (location, photographs of place of extraction and of the element in detail); a second part with the measurements of the wall they were found in; and a third part with a visual analysis of color, composition, and stabilizers of the elements, a record of the degradation found in the sample, as well as other observations considered relevant or of interest to future analysis of the sample (Fig. 3).

This inductive analysis, based on the specific premises of each of the samples and case studies, aims to establish a series of general data which will ultimately make it possible to draw general conclusions on these elements (similarities



Figure 2. Location plan for sample distribution in the territory.

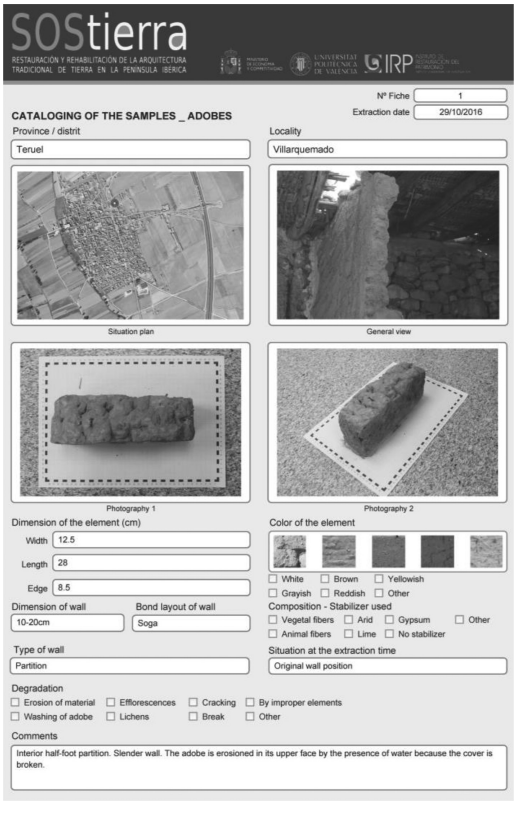


Figure 3. Example of a catalog fiche.

and differences) in the different parts of the Iberian Peninsula where they are used in traditional construction.

c. Thirdly, there was an initial examination of data collected, establishing relationships and comparisons between the different characteristics of the samples in order to obtain data of interest. For instance, an important relationship to be observed is the size of the sample in relation to the type and thickness of wall it was found in. Visual observation of the sample requires rigorous data collection in the field, based on the criteria established for all the cases to ensure results that are reliable, comparable, and as objective as possible.

4 PRELIMINARY STUDY OF SAMPLES

The study was carried out on a total of twenty samples from throughout the Iberian Peninsula, in order to represent their diversity. The study fiches collected sample data for comparison and cross-referencing.

Firstly, the relationship of the element size was compared with the type and it was found in. These were divided based on the structural characteristics of the wall: structural walls (80% of total), which can be loadbearing or enclosing walls, and non-structural walls, which include partition walls and half-timber (20% of total).

In the case of structural walls there is a very varied range of solutions, but walls are always at least 25 cm thick, and most are 30 cm or more. In the cases analyzed all the loadbearing walls are one foot thick with header bond, and occasionally with stretcher and header bond. In the enclosing walls the solutions are more varied and depend mostly on the height of the wall and the size of the elements. Large elements such as samples 10 and 11 are header bonds found in walls of an average height between 1 and 2 m. However, sample 4 is very large but is from a stretcher and header bond stabilizing the wall, which is over 2 m high. Samples 14, 15, and 16 are notable for their size within this group and are cut earth blocks used to build thick walls in single story buildings in all three cases.

In the case of non-loadbearing walls all the adobe bricks are in stretcher bonds, and the walls are not nearly as thick as those described previously, between 12 and 16 cm, with the exception of sample 9 which is from a 6.5 cm thick shiner bond.

The relation between the size of elements and the type of wall is an example of the optimization of material resources, showing a thorough knowledge of the resistance of materials and the structural logic already displayed in these constructions (Fernandes & Conceição Lopes 2011), as well as the need to handle these elements efficiently for ease of construction (VVAA 2008).

Visual analysis also included the color of samples and their composition or stabilizers used. The color of the elements depends on the composition of the soil it is found in and the most common is earthy brown in different shades (70% approx.), although elements with whitish tones are also often found (30%). This could be due both to the color of the earth used in its production or sometimes to the use of lime as a stabilizer.

In terms of composition, according to CRA-terre (Houben & Guillaud 1989) the ideal proportions for producing adobe are: sand 55–75%, lime 10–28% and clay 15–18%. When the properties of the mix do not fall within these ranges, other materials must be used to stabilize the mix. The most commonly used stabilizer in the elements studied is vegetable fiber which appears in almost 50% of cases. The percentage of fiber in adobe pieces varies greatly between the samples studied. These fibers were generally added when the ratio of clay in the mix was above 18%, due to retraction in the drying process (VVAA 2008). Experts consulted determined that these fibers were mostly wheat or rye although as they were cut, crushed or threshed it is very difficult to establish their exact composition visually. When the mix used is very sandy with little clay (between 4% and 10%), it is stabilized with lime to ensure greater resistance of the element (VVAA 2008). The characteristics of some of the elements, samples 4 (Hermedes de Cerrato, Palencia), 10, and 11 (Aveiro, Portugal) suggest that they might have been stabilized with lime, as they have a sandy texture, are harder than other samples, and also have a very whitish color (Fig. 4). However, samples should be analyzed in a laboratory in order to confirm this hypothesis.

In addition, the visible degradation in the elements varies greatly and almost all present considerable material erosion, mostly due to exposure to weather, including wind and rain. Lichen and smaller vegetation are mostly found in samples from Portugal, as their growth was possibly encouraged by humid, rainy or marine environments.

When the crowning of the wall is unprotected, either from origin, as in the case of enclosing walls, or due to the degradation of the building itself, the surface of the samples has been washed away revealing different degrees of loss of volume depending on the individual sample properties. In these cases it is essential to know whether it is the upper (adobe) element which forms a barrier and crowning for the rest or whether it is a lower element, in which case it is only partly eroded at the sides (stretchers or headers). It is worth noting sample 4, from Hermedes de Cerrato in Palencia,

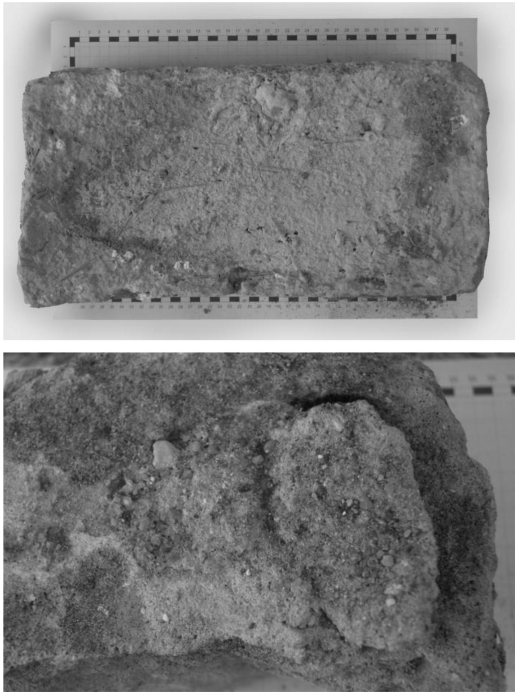


Figure 4. Samples of adobe elements stabilized with lime. Above: Hermedes de Cerrato, Palencia; Below: Murtosa, Aveiro.

mentioned above. Despite the adobe being exposed to the weather it shows minimal signs of erosion. These adobe bricks also display characteristics which make them more resistant to wear than the other samples analyzed, possibly due to the lime assumed to be in the sample.

5 CONCLUSION

The work of collecting samples and preliminary analysis and visual examination of the elements collected in different parts of the Iberian Peninsula have allowed several correlations to be established between the aspects analyzed, thus obtaining preliminary data for the whole Peninsula. However, this work is in its initial phase and further research will be needed to obtain overall guidelines as to what the earthen elements traditionally used in Iberian vernacular earthen architecture are like.

NOTE

This work is part of the research project "Restoration and rehabilitation of traditional earthen architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention", funded by the Spanish Ministry of Science and Innovation (Ref.: BIA2014-55924-R; main researchers: Camilla Mileto and Fernando Vegas López-Manzanares).

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Vernacular architecture in El Khorbat, Morocco. Evolution of the Igrems

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ABSTRACT: After the research carried out in the frame of the Arqui-Hábitat project, in this communication we present the results of the analysis of the two traditional urban areas in the El Khorbat locality. Constructed with earthen architecture, and in two different periods, the use of the rammed earth constructive technique has remained almost invariably until the second half of the 20th century. Not so its morphology, which has been adapting and evolving over time. Through the formal and constructive analysis of both urban models, we will draw conclusions regarding the factors that influenced their construction and development.

1 THE *KSAR*, AN URBAN TYPOLOGY

One of the elements that better characterize the landscape of South Morocco is its earthen architecture. The constructive tradition imported centuries ago from other latitudes, today has become a resource directly linked to the identity of the Berber culture.

Here the *ksar* has its own entity as an urban structure, and although there are several typologies varying from one valley to another, there are a series of patterns or elements that are always repeated. In all of them, the village border is limited by its wall, giving origin to a closed defensive system in which their towers and monumental entrances stand out. Within, a number of families, united by consanguinity or identity, live communally under the rules established by the clans' leaders. And lastly, its urban network is composed of a series of narrow streets following a more or less regular layout, on which the dwellings proliferate covering its layout, opening only to the exterior at the crossroads, creating light wells that allow the ventilation of the *ksar*. Unfortunately, the state of abandonment and vulnerability they present today is also common, which threatens the existence of this vernacular architecture, transforming at a time its cultural landscape.

The work that we present here has been carried out in El Khorbat, a village belonging to the city of Tinejdad, located on the road linking Er-Rachidia with Ouarzazate. In this village we find two *ksour* (*ksar*, sing.): the first of them, known as Igrem Akedim or ancient settlement, dates from the 16th century, while the other, known as Igrem Jdid, dates from the 19th century. Despite being from different periods, they were both built under constant social upheaval as a consequence of the repeated clashes between the different tribes and, consequently, they have the same defensive character. Evidently, today, there are no tribal struggles, which makes it unnecessary to seek refuge in these constructions, but aside from that there are many other factors that have contributed to the transformation of this traditional habitat.

Through the project "Arquitectura y Hábitat: investigación para la mejora global de espacios habitacionales en la región del Tafilalt - ARQui-HÁBitat, ADSIDEO 15/16, código AD1409" to the Universitat Politècnica de València, our research has continued to deepen in the objective of previous research (Rodríguez-Navarro & Gil Piqueras, 2015). The objetive is to advance the knowledge of this habitat, documenting it both at the formal and constructive levels in order to contribute to the enhancement of traditional systems and autochthonous models, preserving the constructive tradition of the region.

The research presented here originates from the reading of the material remains of the two Igrem, a term designating the *ksar* in some regions of Berber tradition, and which in the case of the Igrem Jdid are preserved in a relatively good state. The methodology followed has been based on a thorough data collection supported by exhaustive field work, which has allowed us to represent the exact morphology and urban layout of the two *ksour*, as well as their main urban elements. That is why architectural drawing is presented here as a fundamental analytical tool, allowing us to compare the results.

The work begins with the urban reading of the ancient *ksar*. Wandering its streets and outer limits, and relying on satellite images, we defined its external morphology and its internal plot, limiting its dimensions and arriving at the level of detail as far as possible. Throughout our routes we were able to identify common use facilities and the current

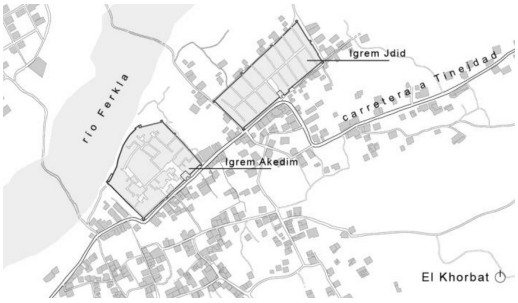


Figure 1. Situation of the two *ksour* and expansion area in El Khorbat (A. Pérez Vila & T. Gil Piqueras & P. Rodríguez Navarro).

installations of the *ksar*. Likewise, we proceeded with the Igrem Jdid. With respect to the urban area surrounding the two *ksour*, which we have called the emerging area, the study area was divided into quadrants located on the base geography. We identified all the existing houses in the immediate surroundings of the *ksar*, noting the number of ground plans, streets, urban infrastructures, etc. In short, all those elements that could provide us with information to later draw some conclusions regarding the urban evolution of El Khorbat.

Starting from the analysis of urban structures and their invariants, we have been able to compare the typological and formal characteristics of each one of its parts, as well as the constructive systems used. As a result, the graphic survey of the common used elements, as well as of the most representative typology of housing of both *ksour*, has been performed.

2 FORMAL ANALYSIS

Today, in the El Khorbat village we find up to three different urban areas, occupying a total surface area that reaches 2.77 ha. The three zones correspond to different periods, being their current demographic occupancy very unequal. In this research we deal with the first two, being the vernacular ones.

The ancient *ksar*, known as Igrem Akedim, was the first urban nucleus to be built in El Khorbat. Its antiquity goes back to the 16th century, a time in which the attacks and clashes between tribes were the order of the day. The outer morphology of the *ksar* is quite regular, almost square shaped (150 m of maximum length in the Northwest-Southeast direction and 130 m in the Northeast-Southwest direction), its wall defining a straight border on all faces, except for the side looking out over the river where we see that it adapts to the layout of its course. After covering its entire outer perimeter we observe that the wall, of 571 m of length, still preserves at present a total of seven towers, in addition to the two that flank the entrance door, resembling



Figure 2. Igrem Akedim plant, with urban network and main equipment: 1) entrance, 2) square, 3) *fondac*, 4) well, 5) stables, 6) mosque (A. Pérez Vila & T. Gil Piqueras & P. Rodríguez Navarro).

the typical monumental entrance characteristic of the great Tafilalt *ksour*. Although originally it was the only entrance, nowadays we can access the interior of the *ksar* at additional sites as a result of the opening holes in the wall. Once we access the interior, the urban plot branches in different directions following a branched layout. Near the entrance, two narrow streets, approximately 1.80 m wide, lead us towards opposite ends. Their rides are parallel to the one of the wall, to which they are attached in both directions occupying three of its four sides.

At the end of the plaza, a third terminal street, or cul-de-sac, appears to the right, with a width of 2 m, giving access to a residential area where we find a small number of houses. Finally, the fourth street, which we can consider as the main artery of the *ksar*, is found at the opposite end of the entrance. This street follows a ring route traversing most of the *ksar*. Its width varies between 3 m at the beginning, and 2 m at the innermost part of the *ksar* (4–5 cubits). From there, other secondary streets emerge giving rise, in some cases, to small plazas from which even narrower streets come out, generating private spaces, restricted in some cases to the family or even tribal context. Several tribes lived together here (Mimó 1996) among which would be the Ikabliîn, Negro race inhabitants considered to be the *ksar* founders; The Ait Merghad, Caucasian Berbers arriving later from the Northeast of the country; and the Irbiben, a warrior tribe that occupied the area around the small plaza in the southern part of the *ksar*, which was separated from the rest by a door. In the main artery, and strangely just at the opposite end of the entrance, is the mosque, which leads us to assume that the *ksar* would originally have its front door in another place closer to this.

Below we show in Table 1 the built surfaces, which we have obtained after our work at Igrem Akedim:

The second urban area is the Igrem Jdid or new ksar. Its construction is a consequence of the demographic increase of the Ait Merghad tribe, which forced them to generate this space. The Igrem Jdid dates from the 19th century, just before the cessation of tribal struggles as a result of the arrival of the French protectorate that came into force starting in 1912. The urban structure of this ksar is different from the previous one, remaining much more orderly.

The exterior morphology is rectangular, being approximately 206 m long by 83 m wide and limited by a wall 635 m long covering a total area of almost 16,500 m^2, a little smaller than that of Igrem Akedim. The plaza is accessed from the entrance located in the middle of one of the longest walls, the one looking over to the farmable area, at the opposite side of the river. This entrance is very similar to the Igrem Akedim's one, although at the present it has lost a third of its surface as a consequence of the mosque expansion works, in this case located next to it and originally having access from the plaza.

From the square it is also possible to access the main street of the *ksar*, which runs along its center, parallel to the longest side of the wall. The interior street layout is kept very orderly throughout the *ksar*, generating the secondary streets from the main artery. In them, the doors of the houses are located maintaining the same social hierarchy between all of them, except for the entrance to the house of the *qaid*, maximum representative of the *ksar*, which is the only one that opens to the main street. In this case it is remarkable how the same approach is followed by other important *ksour*, such as the Taourirt kasbah belonging to the Glaoui family, whose main stay is also found looking out to the plaza, facing the entrance, so that the monarch could control who entered and left the *ksar*. In Table 2 we show the surfaces of the Igrem Jdid spaces:

As for the capacity of both *ksour*, Foucauld gives us an estimate of 400 families between the two (Foucauld 1888), not distinguishing between one and the other.

Today, we see how the façades of both *ksour* face the road that connects all the urban areas of the valley and guarantees its accessibility. This road represents the axis that promotes the growth of the ex-*ksour* (outside the *ksour*) expanded areas. From them, the new constructions, despite their chaotic order appearance due to their disaggregated origin and without apparent relation, are generating a comb-shaped urban growth system connected by that axis at its Southern part, thus invading the palm grove's farmable area. From this system's extensions arise other transverse connections

Table 1. Igrem Akedim area.

General area (a)	m^2
Total area	17,768
Urban area: streets and squares	3,063
Residential area: housing	13,549
Partial area (b)	**m^2**
Equipments of community use: entry, mosque, stable, *fondac*	1,156
Front door	168
Principal square	452
Mosque	363
Housing type: Floor area	60

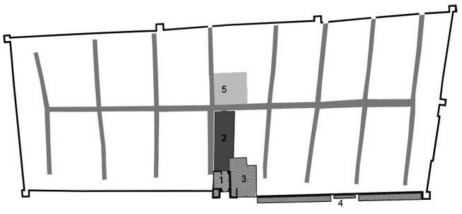


Figure 3. Igrem Jdid plant, with urban network and main equipment: 1) entrance, 2) square, 3) mosque, 4) stables, 5) *qaid* dwelling (A. Pérez Vila & T. Gil Piqueras & P. Rodríguez Navarro).

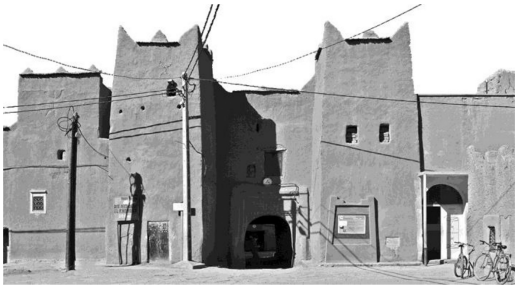


Figure 4. Front door Igrem Jdid (T. Gil Piqueras).

Table 2. Igrem Jdid 6 area.

General area (a)	m^2
Total area	16,500
Urban area: streets and squares	1,933
Residential area: housing	13,651
Partial area (b)	**m^2**
Equipments of community use: entry, mosque, stable, *fondac*	515
Front door	104
Principal square	254
Mosque	223
Housing type: Floor area	60



Figure 5. Igrem Jdid square (T. Gil Piqueras).

providing a greater cohesion to the ensemble and, in turn, a chaotic aspect.

As for services, the two *ksour* originally had water supplied by wells located inside or next to the *ksar*, existing in the case of Igrem Akedim, where a well, located in its plaza, still serves the entire community. We observed that, as a consequence of population relocation outside the *ksar*, this situation changed due to the fact that the wells became of a more private nature, since the majority of those that we could locate were inside the houses' courtyards. Today, the two *ksour* have a public electricity supply. For crops, an extensive network of ditches reaching all the fertile zones is maintained. This ditch irrigation system originates in the river and is channelled to the farthest point of the palm grove.

3 MATERIALS AND CONSTRUCTION SYSTEM

3.1 *Materials*

In general, the vernacular architecture of the South of Morocco adapts its constructive system to the natural resources found in its surroundings. Thus, the construction materials employed in both *ksour* are limited to the use of water, earth, stone and vegetable matter.

The water, needed to moisten the earth before being used, is extracted from the river or from underground wells near the work area. In this sense, we have been able to verify the presence of water, as a large number of wells are excavated around both *ksour*.

Both for the construction of the foundation and the wall's footings, stone are used as the base material. Usually, the stone is taken from the riverbank, since they are boulders.

Another fundamental material is earth that is used both for the wall's execution and to elaborate the adobes that are manufactured in a place next to the *ksar* construction site. When selecting the earth, it is sought to previously eliminate the vegetal layer and the possible thick gravel in order to attain a more consistent mass.



Figure 6. Intervention carried out in 2015 on the wall of Igrem Akedim, which shows the use of mixed structure: concrete, rammed earth and blocks (P. Rodríguez-Navarro).

Of all available vegetable matter, palm wood obtained from the Ferkla palm grove is used for the execution of slabs, stair stringers, and as tying material in the corners of the walls. We also observe the use of straw mixed with earth forming a paste that once fermented is used, depending on the proportion, as wall coating or for the construction of adobes. In some houses, especially in repair works or in the upper floors, we have also observed the use of reeds in the slabs, forming a board that lays on the beams and palm logs on top of which rests the slab's earth layer.

Finally, and as a symbol of "progress" the use of concrete has been introduced in structures and enclosures in substitution or in combination with earth. In both the old and new *ksar*, interventions have been made in this regard, altering the height of the wall at some points. In the case of the structures, reinforced concrete placed in situ is used mainly for the execution of foundations and pillars, to which the wall is attached closing the openings. Concerning the slabs, we find concrete in bidirectional slabs lightened by the placement of prefabricated hollow bricks and footings. Prefabricated concrete blocks, both solid and hollow, have started to be used in the last decade within the *ksar*, mainly for the construction of partitions. Despite the use of concrete in some places of both *ksour*, its presence goes unnoticed by being hidden behind the lining of the walls, which maintain the same earth and straw coating as the original ones.

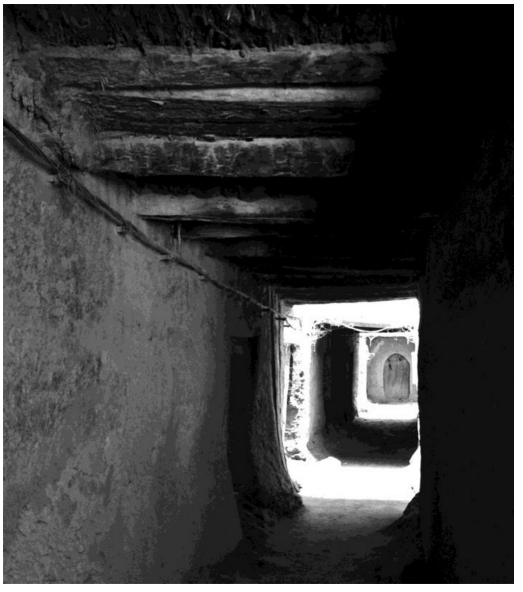


Figure 7. Street. Igrem Akedim (P. Rodríguez-Navarro).

3.2 *Constructive analysis*

Similarly as in the case of the materials used, the two *ksour* maintain the same construction system.

The foundation of the rammed earth walls used in the construction of the *ksar* is not very deep, reaching a maximum that oscillates between 0.50 and 0.80 m. It is constructed with stones of different sizes, perfectly embedded and glued by a mass of moistened earth that gives them coherence, on top of which the first row of rammed earth is built directly. In the interior, one can appreciate how the foundation is wider than the wall, forming a screed that extends above ground level, as a socket, in order to protect its base from runoff water and moisture by capillarity, which would favour its erosion and reduce its loading capacity.

For the execution of the walls, the two earth building techniques used are the rammed earth and the adobe ones, transmitted from generation to generation by the Maâlem (master builders). Usually, the earth comes from the vicinity of the *ksar*, which expedites its transport and guarantees its availability.

Rammed earth walls have variable dimensions, ranging from 0.45 to 0.90 m of thickness, depending on where they are located, and their height is around 0.82 m. The rammed earth system is used in the *ksar*'s first two or three stories, usually closing the top floor with adobe. We also find adobe work in the high part of the towers, which facilitates the decoration of their facades. In the interior, the adobe is also used in the construction of the stairs, and in the execution of both square and hexagonal base pillars.

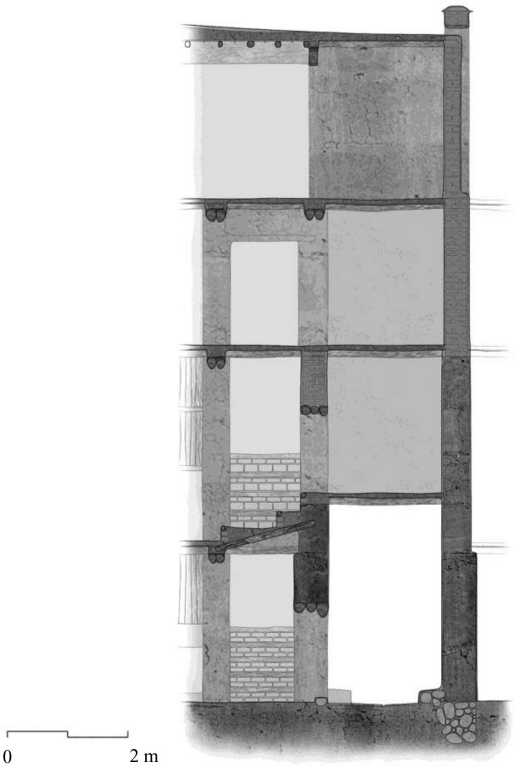


Figure 8. Constructive system. Igrem Jdid (A. Pérez Vila & T. Gil Piqueras & P. Rodríguez Navarro).

The walls are protected at the upper part by a layer formed by reed pieces arranged parallel to the direction of the wall, topped with a layer of earth that supports and fixes them. These walls are covered with a layer of sieved earth mixed with vegetable fibres, a coating that allows them to achieve a more uniform surface and better water insulation, while concealing the joints and covering the perforations of the rammed earth wall needles.

The slabs and rooftops of the two *ksour* are composed of palm wood beams, sometimes arranged in pairs. Joists of the same material, cut out longitudinally and arranged with an approximate spacing of 40 cm between axes, are laid on top of them. Over this structure, a board made up of longitudinally cut wood pieces of variable dimensions is placed. The slab is finished with a compression layer made of compressed earth. In the case of the slabs covering the street area, the board rests directly on the beams due to the dim light that these spaces have. On the rooftops there is also a last layer of sieved earth mixed with vegetable fibres, which gives them greater sealing and allows the formation of slopes for rainwater evacuation.

Stairs can only be seen inside the houses and in the Igrem Akedim mosque minaret, since the

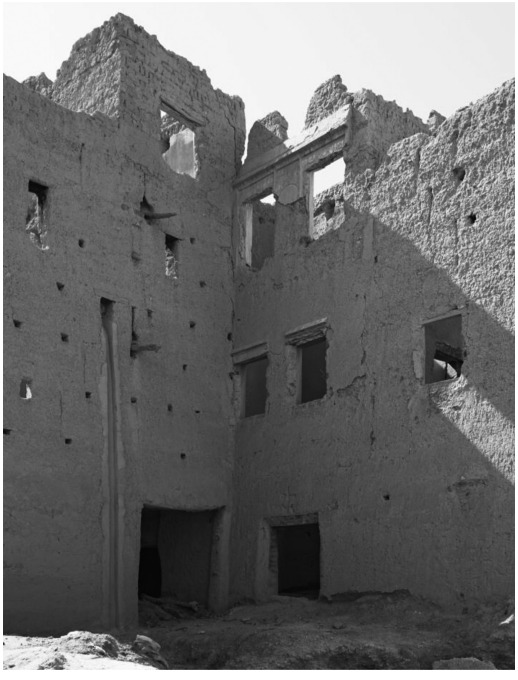


Figure 9. Intersection of streets. Igrem Akedim (T. Gil Piqueras).

Igrem Jdid mosque is newly built. In general, we observe that they are executed on a main structure supported by the perimetric walls of the house and by a second isolated wall located in the centre of the stairs, which dimension depends on the length of the same. In this way, they build stair stringers made out of logs sustained in the rammed earth walls and in other beams sustained in turn in these, which allows reducing the distances.

4 CONCLUSIONS

From the analysis of the data, we were able to obtain the following conclusions.

Although both *ksour* were constructed at different times, they follow the same constructive system and use the same materials, contributing to perpetuate the constructive tradition in spite of the years that separate them. In addition, the fact that they originally belonged to different tribes has not changed this, although it affects their internal organization, which in the case of Igrem Jdid is much more orderly and maintains a unanimous hierarchy. Externally, the morphology of the two *ksour* is also different, observing that in the case of Igrem Akedim its proximity to the riverbank has influenced its back layout. This could have also been the cause of the change in the location of the original front door, which we thought should be located next to the mosque. In addition, the fact that it is very similar to that of the Igrem Jdid also suggests that this change could have been made during the 19th century when the second *ksar* was built.

Data in Tables 1 and 2 shows that although the area of Igrem Akedim is larger than that of Igrem Jdid, the area designated for residential use and the dwelling surface are practically the same. Thus, we may conclude that both *ksour* would have a similar capacity, which would be close to 225 dwellings, data that nearly resemble Foucauld's estimation of 400 families.

Regarding the introduction of new construction habits, it is presumed that they are caused by the unavoidable maintenance needs that the original systems require. If a *ksar* dwelling is abandoned, that is, it is not maintained, it undergoes a quick degradation process due to its materials composition, causing unavoidable damages to its adjoining houses as they are part of the same structure. This fact caused the departure of many *ksar* inhabitants, who now, thanks to the support of foreign foundations and the initiative of the local associations, is re-inhabiting the Igdd Jdid, thus recovering this traditional habitat.

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Examination of structural decay processes in adobe vernacular architecture in Spain

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ABSTRACT: Although adobe is a material widely used in traditional Spanish architecture, over the last century it has been progressively replaced by industrialized construction materials. At present, limited information on this technique contrasts with the abundant surviving heritage, progressively abandoned, demolished, or repaired using unsuitable techniques which threaten its survival. The current lack of understanding of adobe architecture becomes even more obvious when assessing its structural behavior. In response to this situation, this article aims to provide an overview of the mechanisms of structural decay affecting this type of construction, determining the way in which these are manifested and establishing an initial classification approach to facilitate their identification.

1 INTRODUCTION

Spain has an extremely rich constructive culture of earthen architecture, both in terms of the abundant heritage and the vast amount of techniques and variants which can be found. However, these systems have progressively been abandoned over the last century, replaced by new industrially produced materials.

As a result, much of the vernacular earthen heritage has been abandoned, demolished, or repaired using modern materials that do not suit its behavior or composition. At present, many constructions in adobe, rammed earth, or other earthen construction techniques display a wide range of material and structural decay phenomena which need to be known and identified in order to propose interventions to stop or reverse them and guarantee the survival of this type of architecture.

However, in the case of the structural behavior of earthen architecture, it is uncommon to find texts which provide a cross-sectional account of the subject, and it is necessary to alternate between writings taking a more general approach to earthen architecture and others examining the structural behavior of buildings without specifically taking the materials into account.

The lack of directly applicable literature makes it essential to carry out intense fieldwork in order to acquire information on the subject, allowing the structural concepts extracted from the study of the bibliography to be applied to the techniques studied.

The aim of this article is to identify and study the most frequent pathological processes associated with the structural degradation of adobe through detailed analysis of case studies all over the country. Results of the analysis will establish families of easily identifiable lesions, determining how these are manifested and specifying the main possible causes.

2 METHODOLOGY

During the fieldwork on which this work is based, investigators from the research group "Investigación, Restauración y Difusión del Patrimonio" of the Instituto de Restauración del Patrimonio of the Universitat Politècnica de València have compiled photographs of 553 adobe constructions found in 183 locations in twelve Spanish regions.

From this database all the images showing structural lesions in adobe buildings were identified and extracted for analysis and classification.

In order to record and organize these photographs, three families of decay mechanisms were established which categorized the causes of structural instability:

- Mistakes in the building design
- Alterations in the structure during its useful life
- The effect of the natural environment on the building.

Simultaneously, each of these large groups was subdivided according to the specific causes and appearance of the lesions. Thus, 33 variants of 12 different types of structural damages were identified.

3 EXAMINATION OF MATERIAL DEGRADATION MECHANISMS

When examining pathology processes in earthen architecture it is common to assess the different mechanisms which can lead to progressive degradation

of the material based on the agent causing it (Gómez-Patrocinio et al. 2016).

In order to understand and carry out an intervention on these lesions, visible damage in an element should be considered as the visible effect of more complex processes. This is why as long as no action is taken on the causes of these mechanisms, deterioration will continue and lesions will worsen. Therefore, degradation observed in buildings is the manifestation at a given time of a transformation mechanism which will develop into more serious lesions whose causes are still active (Mileto et al. 2014).

These material transformation mechanisms generate two types of pathologies: alteration and degradation. The former modifies the characteristics of elements without worsening their physical, chemical, and mechanical properties. However, degradation does reduce these properties.

Given that most forms of alteration are aesthetic interventions they do not require immediate intervention on the building. However, the presence of degradation processes makes it necessary to develop actions to stop or reverse their causes, preventing them from advancing to threaten the survival of the building.

4 TOWARD A CLASSIFICATION OF STRUCTURAL LESIONS

The term structural lesions covers the effects of all the decay which is not detected through the material degradation of the affected elements, but through the overall deformation of the structure affected. Alterations in shape modify the load distribution scheme of buildings, generating second-order effects due to deformation and progressive fissure leading to eventual collapse (Gómez-Patrocinio et al. 2016).

Due to the fact that modifications in the geometry of the structure generate distortion stresses, frequently mere intervention on the causes triggering the mechanisms does not suffice to prevent damage from progressing. Unless action is also taken to neutralize second order effects, the structure continues to deform due to its own eccentricity, and any fissures displayed will worsen until they cause the construction to collapse.

This article proposes a classification of this type of lesion into three major groups according to the origin of the failure in the structural scheme of the building.

4.1 *Structural lesions due to misconceptions in the building*

Misconceptions in the design and definition of the loadbearing diagrams for a building can prompt a wide range of structural failure mechanisms. These processes are manifested through the appearance of fissures and considerable deformations which can worsen to the point of endangering the overall stability of adobe constructions.

Occasionally, walls which are too small or poor design of the meeting of elements introduce heightened stress in the constructions which could cause them to break. These excessive loads are highly likely to appear in multi-story adobe buildings. In these cases, the load accumulation generated by the wall itself and the subsequent floors and ceilings added can cause weakening in a portion of its base, with parallel vertical fissures appearing from the cross-wise tension effort produced by the flattening.

Although less frequent, damage can appear under very heavy roofs with beams resting on sleepers and generate intense homogeneous stress on the supporting walls. In contrast, when floor and roof beams do not have these distribution elements they tend to introduce intense concentrated loads on the point of the wall that supports them, encouraging the appearance of punching stress problems (Fig. 1).

This type of damage is more likely to appear when the floors and ceilings transmit their load unequally due to weight concentrated on a given sector or to the absence of efficient boards or sleepers distributing the loads between beams. These occasional stresses materialize as large vertical fissures starting at the support of the beams and descending in the direction of load transmission, often deviating toward weaker points in the structure such as the upper corners of openings or gaps between elements.

In addition to the problems linked to excessive loads in walls, the configuration and design of openings can entail major problems for the structural response in adobe constructions (VV.AA. 2008).

The incorporation of openings always modifies stress distribution in walls, relieving pressure from some areas while adding to it in others. The position of doors and windows near important loads, for example beam supports, generates a concentrated effort that can favor the appearance of upward fissures from the upper corners of the openings (Fig. 2).



Figure 1. Fissure from punching stress at the base of a beam. San Pedro de la Viña, Zamora (F. Vegas and C. Mileto).

In buildings where openings have been built too close together it is common for small fragments of wall to become detached from areas that have to withstand the strain placed on the openings flanking them. In these areas, the concentrated loads and thinner wall also favor the appearance of signs of fatigue in adobe constructions.

As well as the location of doors and windows, size and configuration are also critical for the stability of the construction. Wide openings, often designed for livestock or vehicles, can cause the panels above them to deform. These deformations worsen when the lintel above them is not rigid or is insufficiently set in to withstand possible flexural stress.

In the case of door openings with poorly configured jambs, in addition to the possible appearance of problems stemming from excessive flexure of the lintel, there is an added risk of collapse in the adjoining walls (Fig. 3). As these elements are eroded by use and atmospheric conditions, they tend to rotate inwards into the opening, potentially triggering significant collapse in the building.

Structural damage caused by rotating elements is especially obvious given the considerable deformation it generates. On occasion, unstable rafters generate horizontal thrust on the crowning of walls which could cause them to lean. When this thrust is homogeneous throughout the eaves, the deformation appears as vertical fissures where the rotating wall and the perpendicular elements meet (Fig. 4). In contrast, if the building sidewalls are able to support the ends of the roof and stress is only felt in its center, deformation concentrates there, with vertical fissures appearing at points of maximum distortion (Vargas 2014).

On occasion, the walls' tendency to rotate does not occur because of the thrust towards its crowning, but because of a shifting base. This type of mechanism is mostly due to shallow foundations in steeply sloping ground or to the construction of cellars and dug-out spaces below the foundation level of the surrounding walls (Fig. 5).

As with roof thrust, undermining tends to appear in the form of cracks appearing at the meeting point with transversal walls. However, while in the latter cracks first appear at the top part of the meeting point, in cases of shifting cracks start at the base.

4.2 *Structural lesions due to alterations in the loadbearing diagram of the building*

The introduction of modifications to building elements and surroundings inevitably alters the load transmission scheme of structures, which undergo

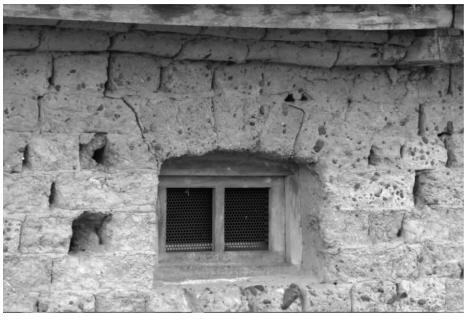


Figure 2. Structural lesions caused by openings around major loads. Lagunilla de la Vega, Palencia (F. Vegas and C. Mileto).



Figure 3. Structural lesions caused by instability in jambs. Lagunilla de la Vega, Palencia (F. Vegas and C. Mileto).



Figure 4. Rotation mechanisms linked to roof thrust. Santiago de la Puebla, Salamanca (F.J. Gómez-Patrocinio).



Figure 5. Rotation mechanisms linked to the undermining of a wall. Monreal de Ariza, Zaragoza (F. Vegas and C. Mileto).

small movements and deformation in areas where stress is increased or reduced. When carried out without taking into account possible consequences, actions such as raising the height, replacing construction elements, or excavating around the construction can cause fissures and even endanger stability.

Due to the long useful life of many vernacular residential or production constructions it is common to find building extensions resulting from changes in the users' needs. When these extensions take the form of building upwards there is a considerable increase in the load that the base walls have to withstand. The passing of time and the exposure to the elements often lessen the initial resistance of these elements, which display the excessive stress they are subjected to by developing fissures due to flattening similar to those described in the previous section.

The elimination of loadbearing elements such as columns or wall sections causes stress transmission schemes to readjust, potentially generating excessive stress in the preserved structure (Fig. 6). This excess load is manifested mostly through the appearance of flattening in the case of walls and buckling in the case of adobe columns.

The creation and modification of openings is a common type of intervention when adapting vernacular architecture to the functional demands of changes of use or current comfort standards. However, these operations should be executed with caution given the wide range of structural problems they could trigger off.

The definition of new openings in sections of wall under heavy stress can seriously increase accumulated tension in weakened areas of the walls, speeding up the appearance of fissures which could lead to mechanisms which could provoke the collapse of part of the structure.

While in sections under heavy stress the addition of openings could speed up the fissures appearing in sections of the construction, the progressive concentration of perforations in walls which display no problems may gradually accumulate load transmission to the increasingly reduced loadbearing sectors. The concentration of loads increases the stress on these panels, so that they show signs of weakening. In cases like these, excessive load is combined with a loss of rigidity in the perforated section, and may cause the appearance of deformation in the blind panels above it.

A frequent action is the expansion of existing openings to allow vehicle access or improve interior lighting (Fig. 7). This type of intervention introduces flexure stress above the openings, and the lintels found there are not always able to absorb these completely. At the same time, the loads transmitted through the upper panels are concentrated in the blind sectors flanking the openings, increasing working stress. These situations of stress mostly appear as diagonal cracks in the upper corners of the openings or as convex fissures above the opening, similar to the creation of a discharge arch and a lowered panel below.

As stated in the section on structural problems due to design misconceptions in buildings, the fissures associated with the rotation of elements are often clearly visible. The damage listed above, linked to the sliding of the wall base and the thrust of the roof at the crowning can also be triggered by alterations in the structure during its useful life.

The construction of new rooms under the foundation level of the walls or the excavation of adjoining plots to construct new buildings can cause the foundations to slide. Lesions generated by these movements can vary from the appearance of vertical fissures at the meeting point of the rotating element and transversal walls to partial structural collapse. Moving surrounding earth to add collective installations or to build elements in the streets can have similar consequences (Fig. 8).

Alteration in the thrust of the sloping roof at the head of the supporting walls tends to be linked to the degradation of the meeting point with the ridge beam due to poor maintenance of the roof.



Figure 6. Structural failure mechanism due to the dismantling of an adobe column. Toro, Zamora (I. Oliver).



Figure 7. Structural failure mechanism linked to the extension of an opening. Villanueva del Arzobispo, Jaén (S. Tomás).

In addition to these mechanisms, large building extensions or building up and modifying structures in the building can cause considerable increases in the load transmitted by the foundations at some points (Keefe 2005). These alterations cause differential settlement in the form of diagonal fissures in the corners of the construction (Vargas 2014) or the formation of discharging arches due to the lowering of central elements.

Finally, when treating structural lesions caused by alterations in the loadbearing schemes of the building, the damage caused by the differential behavior of the original elements and the added material should be taken into account.

The use of rigid materials or those which react to temperature change can cause fissures to appear in meeting points linked to movements of dilation or differential deformation (Fig. 9). These problems tend to become apparent especially quickly in the case of interventions which introduce modern materials such as cement or metal into adobe panels.

For this reason it is vital for the materials used in the interventions to be compatible in terms of behavior with preexisting elements and are suitably integrated with them.



Figure 8. Undermining of a building due to the construction of a road. Monreal de Ariza, Zaragoza (F. Vegas and C. Mileto).



Figure 9. Fissuring linked to gaps between materials. Roscales de la Peña, Palencia (F. Vegas and C. Mileto).

4.3 *Structural lesions due to environmental effects on the building*

As well as human interventions, the passing of time or environmental factors can give rise to decay in a building which can lead to fissures and deformation.

Fatigue and the inevitable degradation of materials during the useful life of a building reduce resistance in constructive elements, forcing the building to deform in order to adjust its structure to schemes for more stable load transmission. These processes clearly affect the elements under tension, causing secondary deformations or even failure (Fig. 10).

Equally, the constant pressure of the building on the soil progressively compacts it, causing gradual settlement. When constructions transmit their loads to the soil unequally or when there are different thicknesses of soft strata, settlement can occur differentially. In these cases, the distortion of the soil itself can introduce major stresses to the building structure causing severe fracture and deformation.

In addition to the problems derived from material fatigue, this section should consider that the degradation suffered by the building because of the action of biological and climate elements can affect the overall stability of a structure if not stopped in time.

The instability of adobe walls whose base is greatly eroded by rising damp and stress introduced by roots in the earthen fabric are clear examples of this type of damage (Fig. 11) (AA. VV. 2006).

Finally, in this section seismic action should be mentioned as one of the most intense natural agents introducing traction into earthen constructions, causing the appearance of large scale structural damage (Vargas 2010a, 2010b). However, the seismic risk in Spain is very limited and concentrated in the regions of Murcia and Eastern Andalusia, where there are very few examples of adobe architecture.



Figure 10. Failure of elements due to aging material. Roscales de la Peña, Palencia. Valderas, León. (F. Vegas and C. Mileto).



Figure 11. Failure of elements due to the effect of surrounding damp. Valderas, León (M. Diodato).

5 CONCLUSIONS

Given the severe degradation of much of the adobe architecture in Spain, it is easy to find examples of advanced structural degradation. Observation and analysis of the fissures in these buildings can provide a better understanding of the behavior of earth as a construction material.

In the overview provided in this article it can be observed that there is a variety of cases of structural degradation processes and that the failure mechanisms can occur at any point in a building's lifespan: due to design errors during construction, due to unsuitable interventions during its useful life, or due to aging and loss of properties of its material after years of use and exposure.

This text has also stressed the importance of intervening on the origin of mechanisms to prevent their effects from worsening. Merely repairing fissures will not stop the degradation of a building unless the causes have been eliminated. As the different phenomena identified produce different types of fissures, observation and the careful study of each case form a vital step prior to the design of effective interventions.

Finally, it should be noted that this study presents an organized catalog of the main structural lesions to be found in adobe architecture in Spain. In addition, the combination of this qualitative information and a statistical analysis of the frequency with which the pathologies identified appear in the case studies completes the work with highly relevant information on the degree of incidence of the different types of damage on these heritage buildings. Therefore, these results should be completed with further research.

NOTE

The analysis of earthen construction techniques presented in this article is part of the research project "Restoration and rehabilitation of traditional earthen architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention", funded by the Spanish Ministry of Science and Innovation (Ref.: BIA2014-55924-R; main researchers: Camilla Mileto and Fernando Vegas López-Manzanares).

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Mid-century earthen architecture in Aotearoa New Zealand—a new vernacular?

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ABSTRACT: Earth was once widely used as a building material in Aotearoa New Zealand; it was an integral part of the vernacular architecture. Indigenous Māori developed their own earthen techniques, and European settlers adapted those from their countries of origin. During the twentieth century, earth construction fell out of favour, and by 1930 it was all but non-existent. After the Second World War, however, a new interest emerged, motivated not by nostalgia, but by pragmatism and a desire to find modern techniques for utilising earth to build everyday houses. The mid-century builders looked to modern technology and current research in soil engineering, in particular the work of Christchurch engineer, P.J. ('Pip') Alley. Three groups of earth buildings, built between 1947 and 1965, are the enduring legacy of this era, and they provide evidence of a mid-century movement towards a new earthen vernacular in Aotearoa New Zealand.

1 INTRODUCTION

By the 1930s, vernacular earthen traditions in Aotearoa New Zealand had all but faded away. When a new interest emerged after the Second World War, its proponents were starting afresh. They were motivated, not by nostalgia, but by pragmatism and a desire to find modern techniques for utilising earth to build everyday houses. Three groups of earth buildings, in Nelson, Christchurch and Wellington, are the main legacy of a distinct period of earth-building activity between 1947 and 1965, and they provide evidence of a mid-century movement towards a new earthen vernacular in Aotearoa.

2 METHODOLOGY

This paper is part of a larger research project investigating the history of earth building in Aotearoa New Zealand. It builds on prior research carried out by the author, including the compilation of a database of earth and straw bale houses built since 1945 in the Nelson Tasman region (Hall 2012c). This database, together with Heritage New Zealand's register of historic buildings, and an unpublished but exhaustive national survey of earth buildings conducted by Miles Allen between 1990 and 1991 (Allen 1991), provided the raw data for investigating the historical incidence of earth buildings and locating them. To this was added information from archival photographs, construction drawings, journal and newspaper articles, academic papers, and published books and pamphlets found in national and regional libraries and museums, university collections, and local body records.

The author visited all the houses discussed in the paper and analysed the structure and performance-in-use of seventy percent of them. Informal interviews were held with current house owners and, in the case of Riverside Community, some of the original owners or builders and this yielded additional information, archival photographs, plans and documentation.

The information gathered was then analysed and critically examined with reference to the framework proposed by Carter & Cromley in "Invitation to Vernacular Architecture" (Carter 2005).

3 BACKGROUND

The history of earth building in Aotearoa begins with Māori, who arrived seven hundred years ago (King 2003). They used predominantly bio-based materials for construction, but also incorporated earth for floors, as protective mounds against partially buried buildings, and as a binder for wattle and daub type systems (Phillips 1952). When Europeans arrived in the eighteenth and nineteenth centuries, they brought with them vernacular earthen traditions from their countries of origin: cob, wattle and daub, adobe, and pisé de terre (Salmond 1986). These were easily adapted to suit the local soil types, and during the nineteenth century building with earth was relatively commonplace. However, its use steadily declined as the twentieth century progressed, and timber framed

construction, with a variety of cladding materials, became the norm for house building.

Vernacular architecture can be described simply as "the common building of a given place and time" (Mercer 1975). In mid-century Aotearoa, the vernacular was changing. The dominant construction method was still timber framing, but the earlier villa and bungalow styles were being replaced by something more modern, driven by the government's response to a chronic housing shortage. From 1936, successive governments built state rental houses in towns and cities all over the country, and the characteristics of the ubiquitous state house, an "icon of New Zealand architecture" (Gatley 2008), provide a useful illustration of the vernacular of the day.

Carter & Cromley propose a framework for the study of vernacular architecture in which recognisable patterns are analysed in terms of time, space, form, function and technology (Carter 2005). Using this framework, the emerging national vernacular of mid-century Aotearoa can be described as follows: standalone houses on individual lots arranged within orthogonal street layouts; simple rectangular forms with hip, gable or mono-pitched roofs; plans suited to modern nuclear families, including combined kitchen and dining areas and two to four bedrooms; and timber framed construction with a variety of cladding materials. This was the evolving built environment in which a new generation of earth builders began working.

4 AN EARTH BUILDING RENAISSANCE

Immediately after the Second World War, earth building began, almost simultaneously, in two locations in the South Island: at Riverside Community in Lower Moutere, some forty kilometres west of Nelson, and in Christchurch, four hundred kilometres further south. These instances were soon followed by another in the North Island, at Wainuiomata near Wellington. The choice of technique makes it clear that this movement was based on a rational, analytical approach, in keeping with the modernist thinking of the times. Rather than reverting to nineteenth-century techniques, these mid-century builders looked to modern technology and current research in soil engineering, in particular the work of Christchurch engineer, P.J. ('Pip') Alley.

Alley lectured in soil mechanics at the School of Engineering at Canterbury University College in Christchurch and had become interested in using soil cement for building houses after using it for road construction while working as a local body engineer. In 1948 he began testing the readily available loess, finding it to be eminently suitable. The test results, "Loess in Soil Cement Mixtures," were published that same year (Alley 1948). Alley was well versed in overseas developments in the field, and his research in Christchurch closely paralleled the work being done by Australian architect and engineer G.F. Middleton at the Commonwealth Experimental Building Station in New South Wales (Allen 1997). Middleton's work was published in bulletins as it progressed, the first appearing in 1947 (Middleton 1947). The three groups of houses built in New Zealand between 1947 and 1965 embody much of this ongoing Australasian research, particularly that carried out by Alley.

4.1 *Riverside community*

New Zealand's first earth building in the mid-century period was built in rammed earth by the men of the Riverside Community in 1947. It was the first permanent house built at Riverside, taking shape amidst the sheds, huts and tents which then served as homes for the families. The community's second house, built in 1950, was also in rammed earth, but soil cement was used for the remaining earth buildings completed during this period – three further houses, a large workshop, and a substantial hall (Fig. 1).

Riverside, founded in 1941 by Christian Pacifists, is New Zealand's oldest intentional community (Jones 2011). During the Second World War most of the Riverside men were conscientious objectors and as a consequence they spent the war years in prison. Upon their release they were not entitled to any of the benefits, including access to cheap loans, that were available to returned servicemen, and it was this lack of money that made the option of building with earth, so freely available, particularly attractive. The labour-intensive nature of earth building was not an obstacle; what the Riverside builders lacked in finance was more than made up for by their strong work ethic, fuelled by a vision of a new community-based way of life (Rain 1991).



Figure 1. Riverside Hall from the road c.1970. Unknown photographer. Cole Family collection.

Alley's influence is not evident in the first two Riverside houses, but it is probable that the builders were informed by Middleton's 1947 bulletin, a copy of which is still in the community's possession. In her history of the first fifty years of Riverside, Lynn Rain writes that one of the builders "read up" about rammed earth in "an Australian book" (Rain 1991).

The bulletin, which includes detailed drawings of the formwork and wall construction, as well as a specification based on work carried out in South Africa and the United States, would have been extremely useful (Middleton 1947).

Although he was not initially consulted, Alley was certainly interested in the community (Hall 2012a), and he eventually tested the Riverside material. The test results shown in the 1952 article "Soil Cement House Construction" include some from Moutere with 25% clay content, 30% silt and 45% sand (Alley 1952). Alley concluded that more than 10% cement was required, and from this point on cement was added to the Riverside mix, with a corresponding reduction in wall thickness from 300 mm to 200 mm (Hall 2012b). When comparing photographs of the construction of the 1947 house and the 1965 workshop (Rain 1991), it is clear that methods became more sophisticated as time went on: pneumatic rammers replaced hand rammers and the boxing became more lightweight.

The Riverside houses were individually designed by the men who built them and the families who were to occupy them, while the community's most ambitious project, the large hall, was designed by architect Robert Burton (Rain 1991). There is no strongly articulated 'Riverside' style, but rather an overall sense of simplicity and a shared aesthetic of plain forms and surfaces. Like all the rammed earth and soil cement buildings of the time, those at Riverside were finished with cement plaster to the exterior and subsequently painted, and all the Riverside houses, whether constructed in timber or earth, are straightforward in both plan and form.

Riverside's 'cultural landscape,' how it fits within the wider environment, is also a strong defining element. The community evolved as a village surrounded by farmland and developed its own unique characteristics. In 1950 an overall master plan was developed with the assistance of émigré Wellington architect Helmut Einhorn, and David Driver, an architectural student in his employ (Rain 1991). Spatially, the Riverside plan differed from the orthogonal layout of most New Zealand towns and suburbs. The houses were arranged on an elevated plateau around an oval-shaped green, with the hall in a prominent position at one end. Everything was focused inward except for the hall, which also functioned as the church, its tall western window looking outwards towards the mountains. This western elevation was highly visible from the road, and because the building took three years to complete, its distinctive earthen construction was well known locally. When it opened in 1961, the hall became not only the physical heart of the community, but also its highly visible signature building. To the outside world, Riverside was defined by what is arguably still New Zealand's largest soil cement building.

4.2 *Christchurch*

Meanwhile, in Christchurch, Alley's first test results had piqued the interest of local architect E.C.R. Anderson. In Alley's words, "Judge of the writer's surprise when, after having written a paper on soil cement mixtures, a real life architect stepped out of the blue and asked for information which would enable him to construct, at his own expense, a house in soil cement" (Alley 1949).

This is how New Zealand's first soil cement house came to be constructed in Makora Street, Christchurch, in 1948. The design was simple, the eaves were generous, and the 200 mm thick walls were tied together with a reinforced concrete bond beam. Now 70 years old, the house is one of the best examples of soil cement construction in the country, and survived the Canterbury earthquakes of 2010 and 2011 with only superficial damage (Morris 2011).

Both Alley and Anderson worked hard to promote and advance the use of soil cement construction. Alley disseminated his knowledge via professional journals and local newspapers; he attended trade fairs, and also assisted prospective house builders by assessing the suitability of their soils and advising them how to proceed. Engineer and architect alike objected to "our native forests being turned into making weatherboards and studs for thousands of 'boxes'," and argued for the use of soil cement as a viable and longer-lasting alternative (Alley 1952). As a result, the interest in soil cement continued to grow, and during the 1950s and 1960s eleven soil cement houses were built around Christchurch.

Alley was keen to enable people to build for themselves: "In these times of high costs, many people are desperate for a house, and there is no reason why a young married couple should not be able to build a house in their spare time, provided occasional help is forthcoming from friends and relatives" (Alley 1952). Indeed, most of the Christchurch houses were built by their owners, including the Stephens house in Beckenham and the Tothill house in Halswell. Both couples engaged Anderson as architect and Alley as engineer, and they also shared a set of Hypsicon shuttering, a mobile wall-building system. A photograph of this is included in the Stephens' lively memoir, "Mud in Our Eyes" (Stephens 1981). The Stephens described how they acquired the necessary building skills, and

wrote enthusiastically of the spirit of camaraderie amongst the soil cement owner-builders.

Alley was also excited by the possibility of using soil cement on a commercial scale – a development that could put earth building back into the mainstream, and make it a part of New Zealand's vernacular architecture once more. By the late 1950s, this possibility looked like becoming a reality, as a commercial building firm pursued the use of soil cement for constructing new government-approved houses in the fast-growing suburb of Wainuiomata (Alley 1955).

4.3 *Wainuiomata*

Wainuiomata is a large suburb in the Wellington region of the North Island. During the 1950s and 1960s it underwent a period of sustained growth, driven by the availability of new affordable housing (Maclean 2012) in the form of state rental houses built under the auspices of the Department of Housing Construction, and also private houses financed by cheap loans available from the State Advances Corporation (SAC). The resulting housing stock, the epitome of New Zealand's mid-century vernacular architecture, has defined Wainuiomata ever since.

It was here that a family of builders, the Anker brothers, built fifteen soil cement houses between 1952 and 1960, in a conscious attempt to introduce soil cement as a modern mainstream building method. John Anker, a builder and returned serviceman, was one of those who consulted Alley and had him test samples of the locally available soil (Alley 1952). John and his brothers Chris and Peter were eager to explore the potential of the new method, and began by building houses for their own families. These house designs were relatively adventurous; John's, for instance, included a curved sunroom and a modernist low-pitched roof. More importantly, building their own houses gave them the opportunity to develop a construction method suitable for building soil cement houses on a commercial scale. They formed a company, Terracrete Constructions Limited, designed and patented machinery for wall placement, and devised a method that they believed could compete with the prevailing timber framed construction (Evening Post 1954).

The overall Terracrete system comprised reinforced concrete columns, 200 mm infill walls of soil cement on concrete foundations, and a reinforced concrete bond beam. The floors were concrete with a variety of coverings, and the joinery was timber, as was the roof structure. Unlike other soil cement systems, where window and door frames were built in as the wall building progressed, Terracrete walls were rammed to their full height, with openings cut out later by chainsaw once the concrete bond beam had cured enough and before the walls set too hard. Sand cement plaster with a paint finish completed the exterior, and internal walls were battened out and lined with plasterboard. Roofing consisted of corrugated steel, or concrete roof tiles.

Despite the dominance of timber framing in the construction industry, the government was prepared to look at other options for building state rentals: "Anyone interested is invited to submit prices for houses involving any type of construction at all" (Firth 1949). The SAC was also prepared to consider alternative construction methods, providing finance for Chris Anker's house and then working with Alley to develop a "Specification for Soil Cement Construction" which was approved for new houses. However, the SAC would not approve Alley's lime plaster interior wall treatment, demanding instead the plasterboard linings that were subsequently adopted by Terracrete (Alley 1955).

In 1958 Terracrete successfully took part in the Wainuiomata Parade of Homes, a project in which a number of builders constructed show homes in the same street for public inspection. All eighteen houses were pre-approved for SAC loans to first-home buyers, and apart from Terracrete's soil cement house, all were timber framed. Visitors to the Parade of Homes would also have been able to view the six state rental houses which Terracrete were building nearby, under contract to the SAC. Photographs of the houses, which were in the early stages of construction, were included in a newspaper article which coincided with opening of the Parade of Homes (Evening Post 1958). The six three-bedroom houses were built in a row to very similar floor plans, all with hip roofs covered in grey concrete tiles. Like their timber framed neighbours, they occupied their quarter-acre lots on either side of Wainuiomata Road in a distinctive pattern: a smaller, more formal front yard and a larger private back yard with room for a washing line and vegetable garden, and space for children to play. They fitted seamlessly into the burgeoning Wainuiomata vernacular.

The Ankers' foray into soil cement was, however, short-lived. According to Miles Allen, "Although Terracrete successfully built houses slightly cheaper than their competitors, their contract [with SAC] was not renewed" (Allen 1997). He suggests that the government was more interested in promoting the use of timber from its own forests than supporting the commercialisation of soil cement. The government was also influenced by a powerful construction industry lobby led by Fletcher Construction, New Zealand's largest building firm (Schrader 2005). Fletchers not only built with timber, they were also involved in timber processing, using logs purchased from the state-owned forests. The dominance of timber construction was further strengthened by the successful development of timber-treatment

processes during the 1950s (Wolfe 1999) which seemingly resolved the durability issues cited by both the Ankers and Alley as good reasons to look to earth as a preferable method of construction. The odds appear to have been stacked against them; in any case, demand fell away, and after 1960 the Anker brothers resumed conventional building practices.

5 A NEW EARTHEN VERNACULAR?

How far did these developments succeed in establishing a mid-century earthen vernacular in Aotearoa New Zealand? Carter & Cromley maintain that "In vernacular architecture there is a strong community content that is manifest in distinctive qualities and results in recognised patterns of everyday building." These patterns or communities of buildings may exist on a local, regional or national scale depending on the number of buildings involved (Carter 2005).

By 1965 more than half the permanent buildings at Riverside Community, including the highly visible hall, were constructed in earth. Within the wider rural region, Riverside sat apart, both physically and socially, which meant that its buildings' distinctive earthen quality became a significant feature of its identity. The use of contemporary earthen technology combined with the community's unique cultural landscape provided a clearly identifiable vernacular architecture. Only one earth house has been constructed after the mid-century era, in 1978, and the proportion of earth buildings to timber framed buildings is now close to one in five, but earth building nevertheless remains an integral part of the local Riverside vernacular.

In Christchurch, the soil cement houses sat within the prevailing mid-century vernacular; except for their wall construction, they were nothing out of the ordinary. Unlike the Riverside buildings, they have never existed in such a significant concentration that they could be considered a local or regional vernacular in their own right. Their significance lies more in their role as a proving ground for Alley's research, which in turn informed the Anker brothers. The high incidence amongst the Christchurch group of owner-built houses, eight out of eleven, also set the scene for a pattern that has continued in earth building in Aotearoa ever since. The writer's 2010 survey of post-Second World War earth and straw bale houses in the Nelson region showed that seventy-five percent of them were built by their owners (Hall 2012c).

If a distinct mid-century earthen vernacular were to have developed anywhere at a national scale, it would have been in Wainuiomata. Terracrete built fifteen soil cement houses over an eight-year period, and made considerable efforts to introduce the new earthen technology into mainstream construction. In a full-page Terracrete advertisement in the official guide to the Parade of Homes (Fig. 2), the Ankers emphasised the unique advantages of building in soil cement: its longevity, its fire-resistant properties, and its thermal qualities. They extolled the quality of the interior environment customers could expect, and made much of the financial advantages: low building and heating costs as well as investment security. Yet, apart from the three houses built for their own families, the Terracrete houses were designed to look anything but unique, and none of the exceptional qualities mentioned in the Parade of Homes advertisement were obvious to the passer-by.

Perhaps this was a deliberate move on the Ankers' part to not appear too unconventional, or perhaps the SAC insisted on conservative designs that were virtually the same as those produced by the Department of Housing Construction. Either way, if government support had continued and customers were forthcoming, Terracrete's designs might have evolved into something more expressive of their materiality, something that would have been distinctly earthen. As it was, the six soil cement state rental houses in Wainuiomata simply merged into the national mid-century timber framed vernacular.

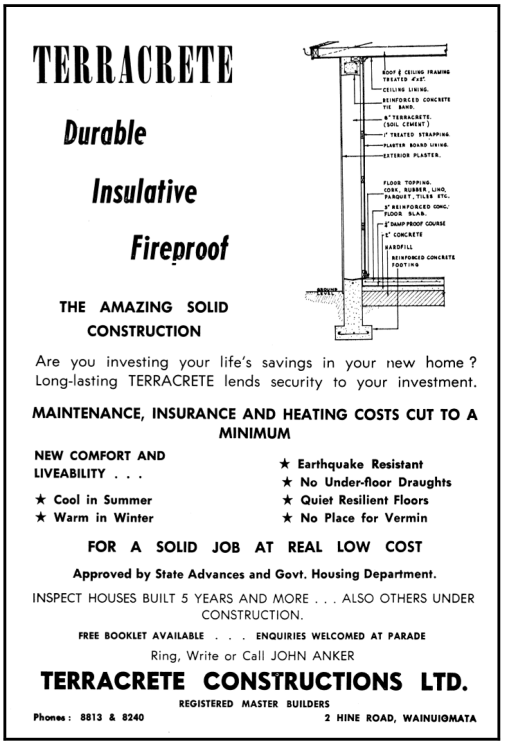


Figure 2. Terracrete advertisement in the "Official Guide to the Parade of Homes, Wainuiomata 1958."

They are still there, standing in a row on the main road into town, an overlooked reminder of what might have been.

Following this mid-century period, other intentional communities have created what may be considered local earthen vernaculars, and individual owner-built earth houses continue to be built around the country. However, the level of earth building activity has not been sufficient to re-establish earth as part of Aotearoa New Zealand's vernacular architecture on a national scale.

6 CONCLUSION

Three groups of mid-century buildings, at Riverside Community, Christchurch and Wainuiomata, are representative of significant progress in earth building in Aotearoa New Zealand after decades of decline. They provide lasting evidence of a modern approach to the use of an age-old material, and a conscious effort, on the part of the building professionals involved, to introduce earth building technology into the prevailing vernacular.

For a brief time it seemed as though this might be succeeding in Wainuiomata. Terracrete Construction's houses were approved for SAC loans to first home buyers and their six state rentals merged into the prevailing national vernacular, albeit by way of their style rather than their materiality. When the government of the day decided to cease supporting soil cement construction and focus on the dominant timber industry, the most ambitious earth building venture ever seen in New Zealand was effectively extinguished.

The Christchurch houses were important in terms of an emerging soil cement technology but were too scattered amongst the predominant timber-framed houses to ever read as a vernacular in their own right. It was only at Riverside Community, with its unique cultural landscape and embedded earth building technology that a distinct vernacular emerged on a local scale.

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Stone, clay and turf in architectural construction

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ABSTRACT: Stone is hard, clay is soft, and both are natural materials. Rough clay can be used in kneaded form, in *pisé*, as rammed construction or adobe. Clay bricks with fixed dimensions, fired in a furnace, can be used for a stronger building. Soil is composed of earth and other materials, it is not suitable for building. Plants deep in the earth without oxygen are changed into semi-carbonated peat, which can be used for burning, less for building. Sod or turf consists of several layers of roots (with dry stems and leaves), soil and grass fibres. Turf in a thickness of about 10 cm can be used as classical bricks. For standardised dimensions, it is dug out with special spades, equipped with distance edges. While the turf is not entirely dry, it has to be positioned in rows, inclined each toward each other in different directions. This method shows extremely interesting and decorative patterns.

1 INTRODUCTION

Vernacular architecture is made of natural materials: rough or hand worked and adapted for both work and use. Two types appear: stone, and vegetative, such as wood, with earth in between. All structures need a solid construction, good insulation (against moisture, coldness and heat, physical enemies and natural events), and most importantly for the user: practicability.

Our buildings are built mostly for warm-blooded human beings—namely ourselves. Some materials are cold whilst others are warm to the touch. This is important not only for man's comfort but above all for his health to prolong his life expectancy.

The basic building material is stone: gathered or cut from the rock. Rough rock is not very suitable for building (but can easily be found), smaller stones can be formed into structures, and ground stone, as sand, can only be used as a filling material or additive in complex structures. The quality of stone depends on both the structure and geological age. Volcanic stone, coming from the deep in the Earth, is dark, hard and without any fixed shape. Some other kind of stone as well as sand, on the other hand, can be soft and with several possibilities for use in construction. Some types of sand can harden in connection with water and heat.

2 STONE

Hewing rock: to cut a secure room into rock is hard work and is rarely found in architecture: Hal Saflieni, an underground temple in Malta, and Petra in Jordan are the most important examples but it can be found in Turkey as well. Architecture is hewn all-in-one and only the front elevation can be seen. In Ethiopia not even the front elevation is seen: some churches are cut into the ground.

Hewing a cave: if there are possibilities of quarrying softer stone, caves appear. Their primary use is to shelter against enemies (in the Pannonian plain, the Turks), or storing vegetables or wine. Some of them are still used today; the Slovene *repnica* (Zupancic 2014: 108) is an underground man-made cave with several rooms. Vegetables can be stored in *repnica*, because of the constant temperature and moisture. Today they are used mostly as wine cellars (Kunej 2002: 32), and some birds even use them for nesting (Merops apaister).

Hewing stone, inside and outside: cutting whole stone is easier but it is hard to find suitable stone. Such structures can be found in Old Korinthos and in Sardinia. Some buildings can be found in the central part of this island, cut into stone, although the stone remains in one piece. It is carved outside with a front opening as a stela. Inside there is a central room with some niches, used to bury the dead. The external dimensions are about 2.5 by 3 by 7 metres, with oblong edges.

Other constructions are composed of smaller blocks.

Drystone walling: this is the simplest system, a construction without any cement or mortar. To make a room, a place for living, the only possibility is therefore corbelling. It is a combination of alternation, in which each succeeding layer of stone overhangs the one below. The floor plan of this is round, in cross-section corbelling.

The final composition in three dimensions is in this case a false dome.

The next system of over-spanning is an arch. It needs cutting and is composed of cut wedges. It is

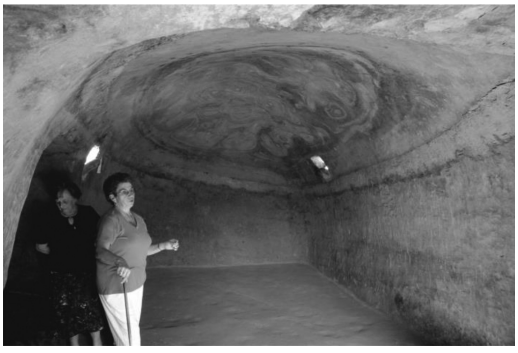


Figure 1. *Repnica* in Slovenia is a cave hewn into soft stone. Because of cutting several layers, interesting shapes appear on the ceiling, which people understood as decoration, animal figures or even divine presentation (the rabbit in this case).



Figure 2. Tomba Campu Lontanu, Sardinia, Italy is a tomb cut in a solid stone. The Nuragic culture is almost four thousand years old.



Figure 3. The stone shelter *el bombo*, La Mancha, Spain has a three-cell construction in corbelling. Around this composition is built a one meter high wall with the entrance. This structure is covered by gravel as far as the wall. This is the most natural shape and depends on the sliding factor of the material. *Los bombos* are white-washed in brilliant white.

a barrel vault and a real dome or cupola (Juvanec 2008).

The stone can be gathered in the field, grazing place or olive grove but appears without any shape or fixed dimensions. To make a construction with such material is very hard work.

The principle of controlled composition consists of stones of similar shape adjacent to each other, with a third across the two lower ones.

It is hard to find proper stones but they can be cut or partly cut—at least at the joints.

Corbelling is the principle of overlapping horizontal courses of stones. A room can be built with longitudinal corbelling (corbelling in cross section) or as a false dome, with corbelled construction in all directions, with a circular ground plan.

Even gravel can be a building material, but only as a filling and loading sense (filling and covering of some corbelled structures, especially *el bombo*. All other compositions need material between the elements: thin wedges, sand, mortar or cement. These materials are made of stone—with several chemical characteristics, mostly lime. The concrete is made of stone, but with complex technological treatment.

3 CLAY

Clay is a more or less soft natural material, found in some regions below the earth's surface. This can be a perfect raw material for building, in a mixture of clay, sand and water. Technically it is $Al_2O_3.2SiO_2.H_2O$ (Zbasnik 2002: 31).

In terms of technique, this raw material can be used in kneaded form in pisé, using a rammed construction, or as adobe.

Raw clay compositions can be moulded, rammed and dried. For better physical characteristics the clay can be fired in a furnace.

Moulding is the most primitive manual work, in which mud, clay or loam is kneaded to an even structure and hand-built into a wall. After some days, the wall surface must be smoothed with a special one sided adze. After some years, this construction becomes extremely hard and is not sensitive to moisture.

Ramming is a system utilising two wooden boards, with clay poured in between and tamped with feet or rams. The clay must be reinforced because of possible cracking after drying. This can be done with straw fibres, not longer than 7 cm, or with stones. Stones do not connect or reinforce the clay but squeeze it—squeezed clay is much stronger and hard. They are two different methods but have the same effect.

The problem with these two construction methods is the size: material is built into the whole building, together with the edges. Cracks appear and constant maintenance is needed. In Yemen there are very high houses built in this way, but the walls are inclined toward the top. Water flows down the sloping sides and dissolves the clay, which fills any cracks in the wall. So the water does not destroy but repairs the construction.

Other constructions have to be maintained by hand—at least every year. Religious feasts are of great importance for this purpose: some clay houses are usually whitewashed at Easter, every spring. This means technical maintenance of the walls and visual renewal of the surface. In Slovenia, this is women's work.

Adobe is a system of small bricks, dried in the sun and air, with fixed dimensions for building walls. The clay is moulded, with water and sand, put into wooden frames and dried. The bricks must be rotated, in order to dry evenly. The clay is reinforced with straw. Adobe bricks need to be built into walls with the help of soft, fresh clay, mixed with water. After some days, even this clay becomes hard. Problems can also be solved with other added materials, such as gypsum. This material is used in Turkey as a hardener for the adobe system. The local name for this is 'alker' (Isik 2008: 5).

Both pisé and rammed clay are sensitive to moisture.

Clay bricks, fired in a furnace, are a stronger building material, suitable for multi-storey houses. Such bricks, with fixed dimensions, can be formed into walls with alternate overlaying, and sealed with lime mortar. Constant dimensions ease construction, and the hard material gives stability. Walls of fired bricks must be covered with plaster, for a longer life span.

4 EARTH

Soil is composed of earth and vegetative material. Humus, being a natural material with constant quality, is extremely fertile and suitable for cultivating plants, not for building. However, where there is no other material available, even earth can be used for this purpose and plant stems can work as reinforcement.



Figure 4. Shibam, is called 'Yemens Manhattan' because of the tall houses, with seven and more floors. Animals live below, then goods, women and finally men, also on the terrace. This part of the house collects water and passes it through small pipes to the surface on all the walls. Constant moisture maintains them in perfect condition.

Turf as a covering material operates in two ways: the leaves cover the surface, but the roots are more important. After major rain both the roots and the soil swell and increase their weight. The layer is thickened and seals the passage of water. It thus becomes a waterproof roof.

Corbelled tombs in Classical Greece (in the first and second millennium BC) appear as green hills. They are not visible at all, except the long entrance corridor and the door with lintel and triangular opening above it. The dimensions of these structures are up to 15 m in both diameter and height. Such monuments can be found in the Peloponnesus (Atreus and Clytemnestra tombs in Mycenae are the biggest) as well as in the continental part of Greece, and in Magnesia (Juvanec 2016). Simpler structures have been built in Brittany, Italy and Ireland, some as dolmens and others with large corbelled stone plates. They are about four to five thousand years old.

Fjarborg is a stone shelter, used as an animal shelter in Iceland. It is made as a typical corbelled construction of bigger stones, with a large lintel above the entrance. The whole construction is covered by turf, and it looks like a natural hill with only the entrance being visible. Fjarborgs are still in use today in sheep farming.

'Pagliaghju' in Corsica is a common shelter for both herdsmen and animals. Its classical construction has vertical walls and longitudinal corbelling inside. The roof has short overhangs, very gentle slopes and a chimney on one gable. It is covered by stone slates, over which can be found earth. This building is made by people, nature added the seeds and the roof is covered with grass and other Mediterranean plants.

The longitudinal ground plan has an entrance on one side with no windows. Outside, on the front wall can be found many small functional details—overhangs, shelves and niches. These objects were used in the past as herdsmen's shelters (hearths and chimneys, big entrance doors); today are only used as donkey stalls. The origin of these corbelled buildings is more than 6600 years old (Orsolini 1993: 9).

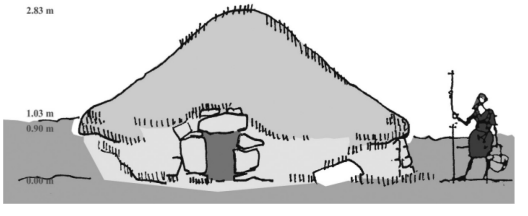


Figure 5. Fjarborg, Iceland; its construction of big stones cannot be seen—except at the entrance. The corbelled construction is covered with earth—for sealing, insulation and for growing the grass. It is mainly green.

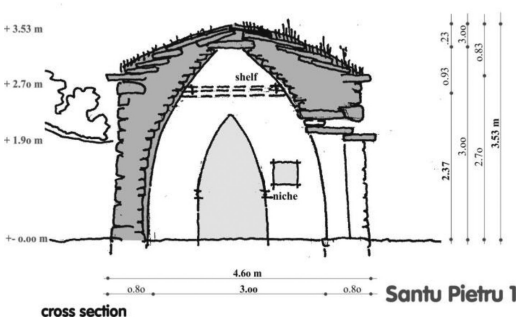


Figure 6. Pagliaghju' or French 'pailler' on Corsica, with longitudinal corbelling, has whitewashed walls inside but outside can be seen its drystone construction of vertical walls. Stone plates with a gentle inclination are sealed with earth. It is fertile material, and after few days the roof becomes blue-green, covered by Mediterranean plants.



Figure 7. Iceland: green roofs and the front gables can be seen. Houses are directed perpendicular to the isohypses of the sloping terrain. Houses are built in rows, which improves their heat insulation. They are used for living as well as for storing goods.

In Corsica and the south of France can also be found houses with a timber ceiling, with a flat roof construction of wooden trunks, covered by branches and red earth (terra rosa in Corsican, erde rouge in French, Orsolini 1993: 15). The same underground structures can also be found in Minorca (Juvanec 2015: 38). The roof with vegetation is coloured and it covers the brown earth—hence the name 'green roof'.

After a few days, grass and plants are the normal covering, helping to seal the roof.

Houses of timber construction have a wooden frame and are covered by branches and leaves, or stone plates. They are sealed with earth, which is fertile.

This type of roofing is extremely interesting in Iceland, because of the living grass. After rain, the roots expand and stop the water, while the green colour of the grass gives a special visual effect. These natural forms are constructed by man and fastened by nature and soil. The relatively high grass (up to half a metre) also protects from the strong wind.

'Plant roofs' with wooden beams in the south of France and in Corsica (French 'toit en terrace', Orsolini 1993) and corbelled constructions are not so visually effective, because the colours of the plants are moderate, in harmony with nature, and not in contrast with their surroundings.

5 TURF

Turf is a combination of dried parts of grass, roots and soil. The longer green leaves of the grass must be removed. Turf can be used freshly excavated from the earth, or after having been aged, in thin layers.

On the other hand, turf with a thickness of about seven to ten centimetres, dug out with a special spade equipped with a distancer for cutting regular dimensions, can be used as classical bricks (Olafsson 2003: 6). The basic tool is a scythe with different variations, with single-cut or double-cut blades (Olafsson 2003: 6).

A 'strengur' is a sod of turf often one metre long. Walls constructed with these long pieces were thought to be the most durable (Olafsson 2003: 6). It is meant for horizontal structures; for vertical walls in gables the elements are shorter, up to 30 cm. Various types of blocks are used in Iceland: 'kviahnaus' as straight blocks, 'kloembruhnaus' as wedge blocks and 'snidda' as slanting blocks (Olafsson 2003: 7). The shapes can be seen on the upper surface as wedges, rectangles and rhombuses.

The turf courses are assembled during building layer by layer, each on the opposite side. In general, turf gradually becomes a good building material, but not to support great weight and not for high walls.

The thickness of the walls is between one metre and 1.2 m (Olafsson 2003: 8). The front sides are mostly inclined, the inner part is built vertically, similar to timber construction.

The oldest parts of houses found were one cell buildings, called 'skalar' (the hall) in West Iceland, in Isleifsstathir, Myrasysla. They have an oblong floor plan, slightly narrower at the ends than in the middle. The length is between ten and thirty-six metres, in cross section they are the lengths of available wooden beams. In the middle of the main hall there is the hearth. Benches are located on all sides, probably divided into sections, with wooden panels dividing them up into bed lengths between supporting posts (Olafsson 2003: 10). The benches have a base of turf construction to a height of about 30 cm; the basic room is covered by wooden boards.

It is not just soft, rounded forms; vertical walls exist, which are conical in cross-section, the bottom thicker than the top. Rectangular floor plans have entrances in wood, the same as all the interior,

non-structural elements. The chimney is not seen because it is simply a hole in the wall.

The oldest houses of this type appeared in the 10th to 12th century AD (Olafsson 2003: 11).

A well-preserved house of this type (the basic turf construction is original) can be found in Thorsardalur (Skallakot) and there is a reconstruction in Stoeng. The Skallakot house has an oblong ground plan with several cells, but the Stoeng house is more or less rectangular, with a central hall, a second hall, also with a hearth, and two secondary cells for storing goods. The gable is important in the structure, in which a cross section of the turf wall can be seen.

The house in Stoeng was inhabited until the Mount Hekla (volcano) eruption in 1104 (Olafsson 2003: 13).

The vertical walls are very massive. While the turf is not entirely dry, it must be positioned inclined, one row after another in alternate directions. This installation shows extremely interesting and decorative patterns, because of the three layers of the turf: leaves, roots and soil.

Though massive, these are not very strong walls, usually connected with a timber construction.



Figure 8. Thorsardalur, construction of base, made of horizontal layers of turf, used as both a bench for people and foundation for the building.

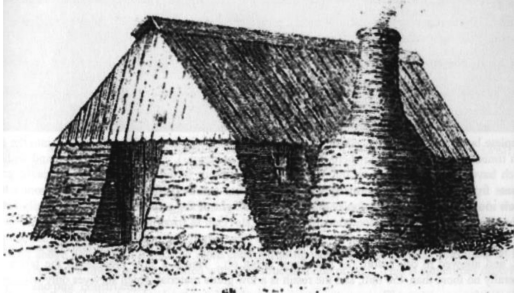


Figure 9. Middleages Ireland turf house has massive walls, inclined, even the chimney (Lewis 2016: 209).

A turf house can be extremely big outside (Lewis 2016: 209) and tight inside.

Both horizontal layers and inclined rows of turf can be found in Iceland. The first are used for basic walls and benches, the second system can be seen only in the gable walls. The same system is used in longitudinal walls and roofs, which connect the top with the ground.

The same idea can be seen in wooden structures, covered by turf as roofing material, and using turf

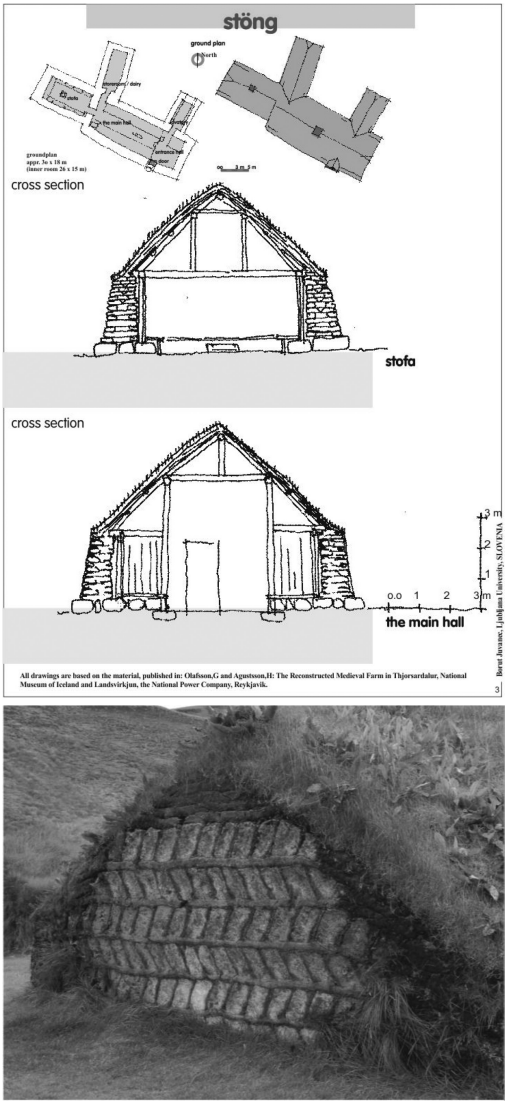


Figure 10. Gables show the turf construction of several layers (Stoeng). Turf elements are folded in oblique courses, each directed against the next, in the mode of 'Prince de Galles'. This is an extremely interesting pattern, it is decorative, even if it is not meant as an ornament.

around the wooden wall frames. Turf houses are interesting because of the living grass. This is the main effect, used not only for the roofing but also for the inclined outer walls.

The inclination of the walls on the outside increases the stability and bearing capacity but also allows the growth of grass, which is impossible on vertical walls. The inclination is therefore graduated so that plants actually grow on the horizontal, the composition grows and reaches up to the apex of the roof. The graduation regulates the flow of rain water, it slows it down and thus irrigates the plants. In bound inclined walls, the water would also quickly drain and the grass would remain without it.

The soft forms of both roof and walls appear very natural; they do not stand out in the environment—on the contrary, they blend extremely well with it.

Turf is not a particularly stable, solid or bearing material. It can be used mainly as physical and thermal insulation, with a high degree of heat retention. Turf walls are of course extremely solid, large and need a lot of space. So the architecture is large, but the yield of usable space is relatively small. The advantage is certainly the availability of the material and its cheapness, and durability in a humid environment, and architecturally speaking, its exceptional harmony with the environment.

6 CONCLUSIONS

Hewing caves is past—at least for human dwellings. Caves can be used successfully as wine cellars or storage for vegetables, with a natural, cheap internal climate.

Stone architecture without mortar or cement must be regularly maintained. The system is only suitable for provisional and temporary use. This is not suitable for public buildings but is perfect for herdsmen's huts. The problem today is the change in the way of life, with grazing and transhumance disappearing.

Roofs with constructions of beams, branches or even stone plates and covered by earth, can be nice in nature but are not one hundred percent effective in all conditions. The sealing effect of plants is questionable, depending on climate.

Turf as a building material is functional and cheap for non-pretentious buildings. Structures depend on constant moisture, not suitable for human beings today.

All these systems are interesting. They were useful in the past, with a lower technical quality of life and needs. Today, with progress and more possibilities, we need permanent materials with higher characteristics for a more successful life. Old structures are important for our culture. We must be familiar with them, we must understand them, and many of their aspects can also be used as details in composing modern architecture. Only in principle; the importance of prime natural materials cannot be minimized.

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Transforming Kasena houses and indigenous building technology in Burkina Faso

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ABSTRACT: Field surveys were conducted to explore the design and construction methodologies of Kasena earthen compound houses in the Alampoa settlement. Regarding the design methodology, villagers use their steps to determine the dimensions of floor plans in traditional housing units (i.e., *manguelo* and *diniya-didiyou*). Meanwhile, height dimensions are decided by the number of layers of adobe bricks or mud balls used as the earthen material for constructing walls. The construction process was clarified through measurement and interview surveys. These housing units need considerable community cooperation for construction; however, less participation has resulted from lifestyle changes. For this reason, another housing unit that can be constructed more easily using modern materials, the *tol-dige*, has become popular, especially since the 2010s. The housing transformation has made it difficult to sustain unique building cultures over generations. Therefore, it is time to reevaluate these indigenous building technologies before they disappear.

1 INTRODUCTION

1.1 *Kasena settlements in Burkina Faso*

Kasena people, a sub-ethnic group of the Gurunsi people, create unique houses. The Kasena population of 150,000–200,000 resides in the savanna areas in southern Burkina Faso and northern Ghana. The traditional structures are constructed using an earthen material and contain various types of housing units and sheds. Their composition is that of a complicated compound, creating the appearance of a maze or a fort. Natural materials on the exterior walls are traditionally painted black, red-brown, and white to express their original patterns. However, the traditional houses and painting patterns have been disappearing in most Kasena settlements. Only Tiebele and Tangassogo (Fig. 1) in Burkina Faso still maintain their housing cultures, partially in settlements located in Nahouri Province (Fig. 2).

The disappearance of Kasena traditional houses is mainly a result of the influence of residents' changing lifestyles. The applied indigenous building technology is an intangible cultural asset that can easily disappear if it transfers from one generation



Figure 1. Tiebele (left) and Tangassogo (right) (H. Kobayashi).

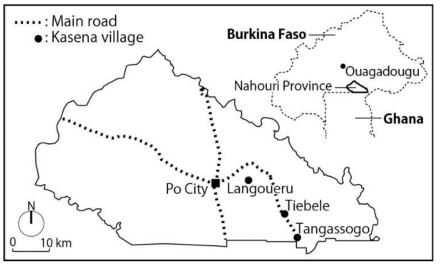


Figure 2. Kasena villages in Nahouri (H. Kobayashi).

to the next with no opportunity for construction; this is the main reason for documenting how Kasena people design and construct their houses. Additionally, authors wish to explore the extent of the difficulties faced by Kasena people in sustaining their housing culture. Field surveys were conducted using measurements and interviews in February 2015 and February 2016 as a case study in the Alampoa *songo* (settlement). A *songo* is a settlement composed of a single compound house or multiple structures. Alampoa settlement is located within Langouerou Village, approximately 10 km to the east of Po City (Fig. 2).

1.2 *Components of the traditional compound house*

A traditional compound house is introduced in Figure 3 (SIL 2007). The main component is the *diga*, a room or a housing unit such as the *manguelo*, th squared housing unit used mainly by a husband, and the *diniya-didiyou*, the twin-circled housing unit typically used by a wife. Wives' housing units are sometimes built as squares or with circular floors. Kasena's polygamy system causes the situation in which each wife lives in her own housing unit neighboring her husband's. Since the 1970s, a new type of square housing unit called the *tol-dige* has become more popular than traditional ones because it can be constructed more easily using a corrugated iron roof and fewer adobe bricks (Kawada 1979).

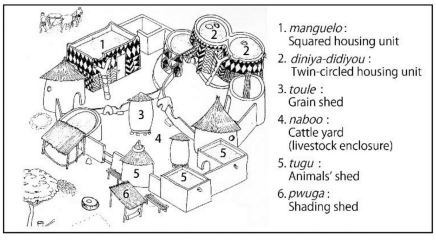


Figure 3. Kasena traditional compound house (SIL 2007).

2 TRANSFORMATION OF THE ALAMPOA SETTLEMENT

2.1 *Compound houses and housing units*

Figure 4 shows that the Alampoa settlement is more spread out, with more compound houses, than other Kasena settlements documented in the 1970s.

The Alampoa settlement has lost its traditional patterned paintings, but it still contains some traditional housing units of *manguelo* and *diniya-didiyou* styles. Of the 27 housing units, 14 are *manguelo* and 13 are *tol-dige*. There are no units featuring the *diniya-didiyou* style. Ten unused housing units (eight *manguelo* and two *diniya-didiyou*) are vacant (v); there is also a fowl house (f), kitchen (k), and storage (s) unit. Some units have collapsed, leaving only walls. Surveyed compound house 3 in Figure 5 was the last *diniya-didiyou* unit and was occupied by the wife of Songo-Tu (a clan leader) until her death in 2010. It is currently used as a fowl house. Regarding the construction year and the housing unit types, the findings of the field surveys are shown below:

1960s or before: 5 *manguelo*, 2 *diniya-didiyou*
1970s: 2 *manguelo*
1980s: 4 *manguelo*, 1 *tol-dige*
1990s: 5 *manguelo*, 1 *tol-dige*
2000s: 4 *manguelo*, 3 *tol-dige*
2010s: 2 *manguelo*, 8 *tol-dige*

Construction of the *tol-dige* style began in the 1980s in this settlement and has been rapidly increasing since the 2010s to become the dominant style.

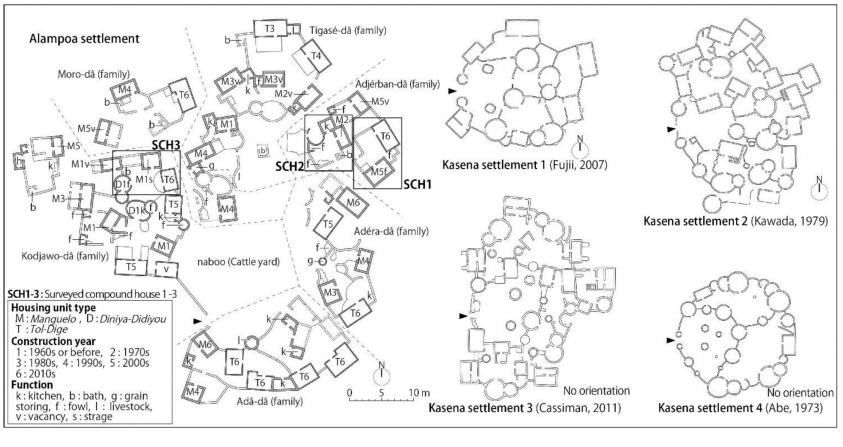


Figure 4. Alampoa settlement and other Kasena settlements (to scale) (H. Kobayashi, S. Barthoux).

2.2 *Living conditions in the three households*

The three compound houses (SCH1-3) shown in Figures 4 and 5 were selected for the interview surveys to clarify living conditions and confirm the measurement surveys regarding living spaces in the *manguelo*, *diniya-didiyou*, and *tol-dige*.

The resident of SCH1, Mr. Lirase Nagiabou (age 86), has three wives, all of whom live separately in other places; the first wife lives just next to him in SCH2, the second lives on the far side of the settlement, and the third is in her home village. Nagiabou constructed the *tol-dige* in the 2010s for his son, but his son did not return to the settlement as expected. Therefore, Mr. Nagiabou lives in the *tol-dige* in place of his son and his *manguelo* is now used as a fowl house. As it is difficult to stay in the *tol-dige* in the daytime heat because of its poor interior insulation, the *pwuga* (shading shed) is a good place for relaxing. The *gauro* (bed and bench) is the outside space for sleeping most nights, whereas the interior of the *tol-dige* is used for sleeping on cool nights.

In SCH2, resident Ms. Alarwo Dudoibou (age 73) is one of Nagiabou's wives. She lives in a *manguelo* constructed in the 1970s. Even in hot daytime temperatures, its interior can be comfortable for resting because of its thick walls (330 mm). She has a *koura* (an indoor kitchen) equipped with a kitchen stove and mill table, as well as two kitchen stoves outside for cooking. The rooftop floor of the *manguelo* can be accessed with a *natan* (ladder) to dry harvested crops and other goods. The roof of the *tol-dige*, however, cannot be used in the same manner because it is composed of iron sheeting.

Living in SCH3 in a *tol-dige* constructed in the 2010s are the young family of Mr. Akodai (age 28), Ms. Aadai (age 23), their daughter (age 2), and the sister of the husband (age 12). The compound retains two traditional housing units: cotton is stored in the *manguelo* and the *diniya-didiyou* acts as a fowl house.

Interviewed residents explained that the traditional housing custom has collapsed, meaning that they are able to live in any type of housing unit they prefer. At the moment, the *tol-dige* is preferred over other construction styles.

3 DESIGN METHODOLOGY

3.1 *Interviews about the design methodology*

The indigenous building technology can be divided into design and construction methodologies. Here, the design methodology of this unique architecture

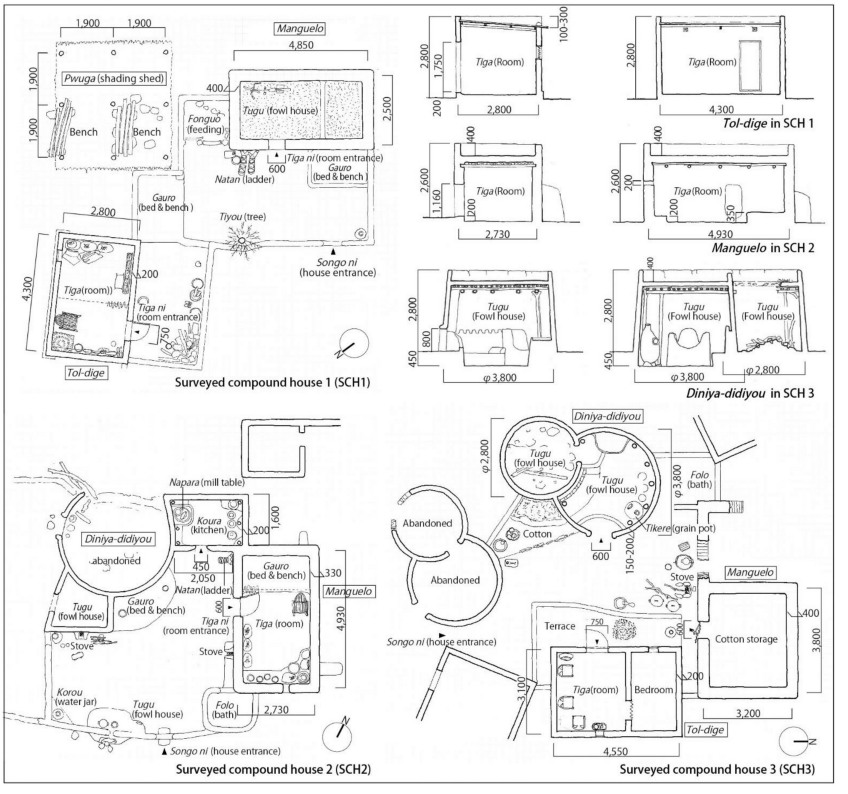
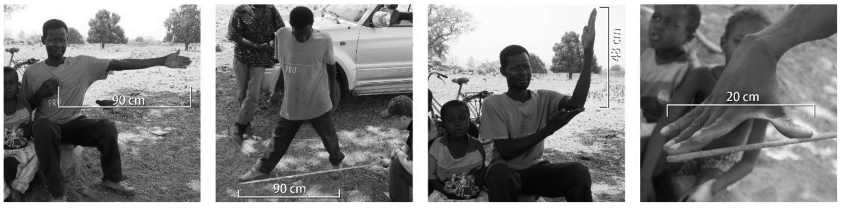


Figure 5. Floor and section plan of the surveyed compound houses (H. Kobayashi).



a: *Naba aridoi* (Arm) b: *Naba aridoi* (Step) c: *Naba titirou* d: *Abagu*

Figure 6. Body-based units of measurement (H. Kobayashi).

Table 1. Naming of the number of steps.

Basic unit		Number		Length
Naba	+	*Kalou* (1)	=	*Naba arioi* (1 steps)
Naba	+	*Iule* (2)	=	*Naba tile* (2 steps)
Naba	+	*Into* (3)	=	*Naba toto* (3 steps)
Naba	+	*Inna* (4)	=	*Naba tuna* (4 steps)
Naba	+	*Innou* (5)	=	*Naba tunu* (5 steps)

is highlighted. The author recognized the use of such technology in previous field surveys in other countries in which local people use multiple body measurements as units to determine the various dimensions necessary for the construction of houses (Kobayashi & Nguyen 2013, Kobayashi & Fujieda 2016, Attavanich & Kobayashi 2014).

One skilled villager named Mr. Banagoulougo, aged 45, provided information about Kasena building technology during the interview. The villagers in Alampoa settlement used body-based units of measurement as well, but only one kind for floor plans. For height, they used the number of adobe brick layers in the *manguelo* and *tol-dige* and mud balls in the *diniya-didiyou*. Detailed information is described in the following sections.

3.2 *Dimensions of floor plans*

Villagers in the Alampoa settlement employ only one body-based unit of measurement called the *naba aridoi* (Fig. 6a) to indicate the length from body center to arm end when determining the floor plan (measured length: 90 cm). This unit can be converted to one step by the same name (Fig. 6b). *Naba* refers to the body part as a basic unit, and the syllable that follows indicates the number of units (Table 1). The owner of the house draws lines on the ground to shape a floor plan, based on the number of steps or sometimes by the same length using a stick or a rope. Further, a clan leader checks the housing position and dimensions to give permission for construction. The floor plan of the *manguelo* and *tol-dige* is decided with three steps (90 cm × 3 steps = 270 cm) and five steps (90 cm × 5 steps = 450 cm). The surveyed compound houses in Figure 5 show the application of steps corresponding approximately to the measured dimensions:

Manguelo of SCH1: 250 × 485 cm
Manguelo of SCH2: 270 × 493 cm
Tol-dige of SCH1: 280 × 430 cm
Tol-dige of SCH3: 310 × 455 cm

Meanwhile, the floor plan of the *diniya-didiyou* is decided with three steps (90 cm × 3 steps = 270 cm) for the diameter of a small circle and four steps (90 cm × 4 steps = 360 cm) for the diameter of a large circle, which are also close to the measured dimensions below:

Diniya-didiyou of SCH3: 280 cm + 380 cm

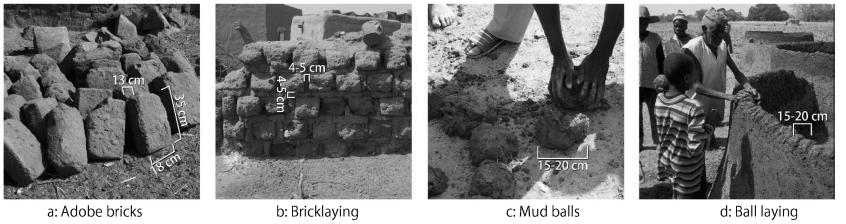
3.3 *Dimensions for the height plans*

For the height plan, the number of adobe bricks or mud ball layers can determine the required height.

The unit size of an adobe brick is measured as 13 × 18 × 35 cm, and the joint width is around 4–5 cm (Fig. 7a, b). One mud ball measures approximately 15–20 cm in diameter (Fig. 7c, d). The manguelo requires 12 layers of bricks to install wooden beams for supporting the earthen roof slab. Then, another three layers form the base of the parapet (Fig. 8 left). As the tol-dige uses a corrugated iron roof, which does not heavily burden the walls, just 16 brick layers are needed (Fig. 8 center). The diniya-didiyou requires a drying process for some layers of mud balls to ensure that the dried walls are strong enough to withstand the load of the next layer of mud balls. After six, then four layers of mud balls have dried, wooden beams are installed on them to support the earthen roof slab. Then, the next two and three layers are formed for the earthen slab and parapet (Fig. 8 right). The dimensions produced by these laying methods mostly coincide with the measurements shown in Figure 8.

3.4 *Dimensions of entrance opening*

The opening width of the entrance in traditional housing units—the *manguelo* and *diniya-didiyou*—is determined by a *war jougan* (a large bowl) to ensure a clearance of 60 cm, since all other commodities can be taken inside if a large bowl can fit (Fig. 9a). All entrances of the surveyed traditional housing units were 60 cm in width (Fig. 9b, c). Meanwhile, the height is not strictly specified by a certain method, but just by feeling, according to the interviewed villager. The *manguelo* in SCH2 is 116 cm and the *diniya-didiyou* in SCH3 is 80 cm in height,



a: Adobe bricks b: Bricklaying c: Mud balls d: Ball laying

Figure 7. Earthen material and laying (a, b, c: H. Kobayashi, d: T. Kamei).

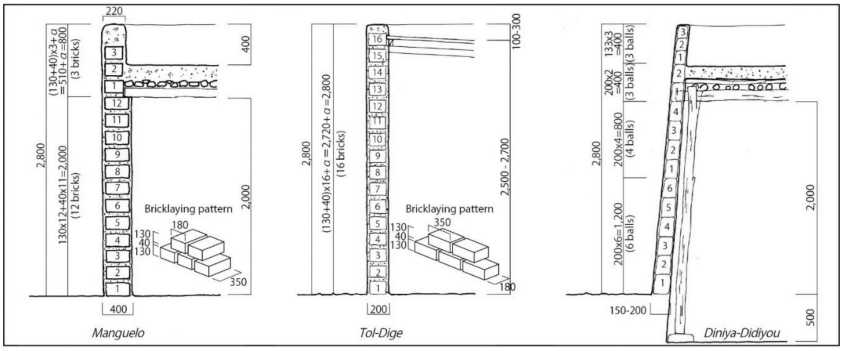
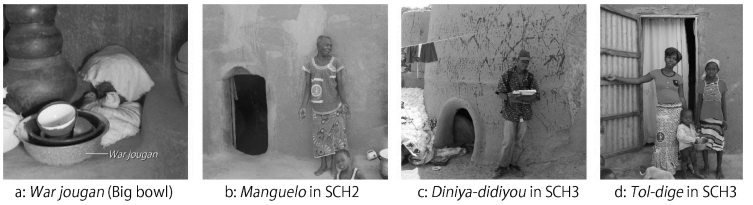


Figure 8. Methods for laying adobe bricks and mud balls (H. Kobayashi).



a: *War jougan* (Big bowl) b: *Manguelo* in SCH2 c: *Diniya-didiyou* in SCH3 d: *Tol-dige* in SCH3

Figure 9. Entrance dimensions in each housing type (H. Kobayashi).

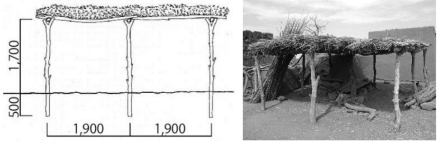


Figure 10. *Pwuga* (shading shed) (H. Kobayashi).

both of which are lower than usual to prevent the entrance of hot air, strong sunshine, animals, and enemies (SIL, 2007). The opening dimensions of the *tol-dige* shown in SCH3 are typical of the modern opening measuring 75 × 175 cm (Fig. 9d).

3.5 *Other applications of body-based units*

The other body-based units are the *naba titirou,* indicating the length from elbow to arm end (measured length: 48 cm), and the *abagu* from the first finger to the middle finger of an opened hand (measured length: 20 cm), shown in Figure 6, c and d. The interviewed villager demonstrated that 2.5 measures of the *abagu* can be converted to a *naba titirou*; however, it was not confirmed how this conversion has been applied for all occasions. The *naba titirou* is applied to the design of the *pwuga* (Fig. 10). The spans between posts are determined by the *naba tile* (2 steps = 90 cm × 2 steps = 180 cm; measured dimension: 190 cm) and ceiling height roughly by body height (measured dimension: 170 cm). Then, *naba titirou* is applied to the depth of holes dug in the ground.

4 CONSTRUCTION METHODOLOGY

4.1 *Earthen and wooden materials*

Earthen material is usually obtained around a settlement. Adobe bricks are made by mixing earthen

material and water, then molding and drying them in a wooden frame. This process usually takes two to four weeks depending on the size of the labor force. This settlement does not mix in local grasses to strengthen brick material, as is seen in other Kasena villages. Mud balls are also made with earthen material and water, but their use requires greater effort in terms of finding the desired quality of earthen material and stamping with the feet for a lengthy mixing process in order to make high-quality rammed earth. Wooden materials for the traditional housing units—the locally called *sogo* (sea butter tree), *cacano*, and *roa*—are obtained within the territory of the settlement as well, but they have been difficult to find recently.

4.2 *Laying works of adobe bricks and mud balls*

The main task of laying adobe bricks can usually be completed in one day by three persons. The *manguelo* also requires earthen roofing work and mud finishing work, which takes approximately two months. Construction of the *tol-dige* can reduce the quantity of adobe bricks and the working time required because of the different pattern used for laying bricks to create a thinner wall (Fig. 8 left and center). The corrugated iron material allows easier and quicker construction of the roof. In the case of the *diniya-didiyou*, the laying of mud balls is divided into four tasks, with each requiring three days for mud drying (Fig. 8 right). In order to reduce the load for thin circular walls, wooden posts are installed for support along the walls. Such housing construction necessitates considerable community cooperation (the interviewed villager explained that 20–30 people are needed for construction, though he might have meant that the support of many people is needed).

5 CONCLUSION

5.1 *Kasena indigenous building technology*

The field surveys from a case study in the Alampoa settlement clarified the indigenous building technology of the Kasena people. Regarding the design methodology, the body unit is applied for floor plans, and the earthen unit of the adobe brick or mud ball is applied for height. The construction methodology was clarified throughout the process from collection of materials to completion. Such technologies are unique intangible assets developed in local contexts. However, traditional housing requires intensive construction work; in particular, the *diniya-didiyou* needs considerable support from the community. Meanwhile, the new housing style, the *tol-dige*, affords savings in terms of time and labor, which makes it more suited to the modern lifestyle. In fact, the *tol-dige* is becoming a major housing unit in the settlement.

5.2 *Difficulties related to sustaining the traditional building culture*

According to the interviews with villagers, there are difficulties associated with sustaining the traditional building culture because of less community cooperation and fewer opportunities for construction and patterned painting. Many villagers are becoming migrant workers. School education requires children to stay in school for most of the day, causing less participation in the community and disturbing the transfer of local knowledge. As it has become difficult to obtain painting materials over the past 10 years, patterned paintings cannot be seen in the settlement. This situation is accelerating housing degradation. In addition to conveying cultural identity, paintings coat walls to prevent degradation from rain. Additionally, regular repainting ensures the maintenance of walls. Considering the current situation in the Alampoa settlement, it is clearly time to evaluate the status of the traditional housing culture.

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Earth and gypsum: From theory to practice in Spanish vernacular architecture

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ABSTRACT: In Spanish vernacular architecture earth is a major prime material which has made it possible to build highly resistant walls while saving greatly on costs. Gypsum, extracted and transformed for use in construction, is equally important. Therefore, these materials were used jointly in the execution of various vernacular construction techniques, as can be observed from surviving buildings. Historic constructions are undoubtedly the best possible database for the first-hand study of these techniques, in conjunction with treatises and manuals on construction written or translated into Spanish between the seventeenth and early twentieth centuries. This study compares the actual buildings with written theory in order to expound on Spanish traditional techniques which make joint use of earth and gypsum.

1 INTRODUCTION

1.1 *Aims of the study*

Earth and gypsum are two materials historically used in the Spanish building tradition, both individually and in combination. These natural resources are abundant throughout Spain, especially in the east of the country, where the main gypsum deposits are located. In addition, both are easy and economical to use: earth has only to be extracted and mixed with different proportions of water, while gypsum is converted into powder following a simple extraction process, calcining, grinding, and sifting because of its low hardness.

The traditional architecture of Spain is the primary source of information for the study of multiple applications and construction solutions of earth and gypsum, with both materials used in greater or lesser quantities. For example, gypsum renderings are found on earthen walls, in both rammed earth and adobe; adobe walls with gypsum mortar or structural reinforcements of gypsum in rammed earth walls called *rafas* or *brencas*. Similarly, Spanish historical treatises are especially interesting sources of information because they conserve knowledge from past centuries and describe construction techniques now virtually forgotten.

Thus, the aim of this paper is to carry out an exhaustive search in treatises and manuals on Spanish construction from 1639 to 1927 for the particular use of earth and gypsum in order to extract construction techniques and compare the methods from these historical texts with actual buildings. In short, the aim is to show the similarities and differences between theory and practice, recalling an important part of a construction tradition that is a feature of Spanish vernacular architecture.

2 EARTH AND GYPSUM IN SPAIN

Both earth and gypsum are frequently found in Spanish vernacular architecture, the specifics of which—including high resistance to fire—are featured in treatises or manuals (Pereir y Gallego 1853, Fortenay 1858). These individual specifics are described below in greater detail.

2.1 *Earth in Spain*

Earth, and particularly the clay soil traditionally used in the construction of rammed earth and adobe, is generally naturally abundant and accessible. As a result, it has been widely used in the construction of buildings for thousands of years.

Several experts agree that the best soil for rammed earth or adobe construction is clayey, sticky, compact, free from small pebbles, and with low proportions of sand and gravel. They also point out that the use of earth in Spain dates far back, and in the case of some provinces can be traced back to the earliest inhabitants (Villanueva 1827, Pereir y Gallego 1853). For example, Ger y Lobez (1898) notes that many adobe and mud walls—apparently more robust than rammed earth walls—can be seen in vegetable gardens in Valencia and Murcia, with the use of adobe also quite widespread in the rest of Spain. Pliny also highlights the solidity and cheapness of earthen constructions (Villanueva, 1827; Pereir y Gallego, 1853; Fortenay, 1858; Espinosa 1859); Marcos y Bausá (1879) adds how they cool rooms, and Barré (1899) also notes their incombustibility.

However, this type of construction was gradually abandoned, partly because it took up too much space, unlike the weak and hazardous wooden frameworks that replaced it (Pereir y Gallego 1853; Villanueva 1827).

2.2 *Gypsum in Spain*

In practice, eastern Spain has an abundance of gypsum outcrops (Fig. 1), as stated in some of the treatises consulted (Villanueva 1827). The fact that gypsum is characteristically easy to extract, transform, and use in building (La Spina 2013a, b, 2015, La Spina et al. 2016) encouraged its widespread use as a construction material. It should also be remembered that as a material it is very closely linked to the historic heritage of the Moorish occupation of the Iberian Peninsula (Villanueva 2004). Thus, in addition to use for renderings—both interior and exterior—and decoration, it has also been used in the construction of interior partitions, staircases and tile vaults; traditional roofs and ceilings with small vaults and timber beams as well as flooring above; false ceilings and false vaults; built-in furniture and architectural elements including doors, windows, spiral staircases, groin vault ribs, fireplaces, etc. It has even been used for constructive elements with structural functions, walls and pillars (Vegas et al. 2012), as well as to protect and insulate roofs built using wooden and reed structures.

However, despite the major historical importance of this material in Spanish rural and urban architecture, attested to by the surviving constructions, historical treatises only provide partial accounts of gypsum. An example of this is that very few written documents mention the possibility of rendering facades with gypsum paste or mortar (La Spina 2013a, b, 2015), or even sometimes ruled out.



Figure 1. Map of gypsum production in Spain, adapted by D. Sanz from the original map by Riba y Macau (1962). Gypsum resources from the Triassic period are marked in dark gray and those from the Tertiary period are marked in light gray (C.J. Grau 2016).

3 MAJOR CONSTRUCTION TECHNIQUES

Below is a detailed description of a few of the most important traditional techniques characteristically found in Spanish traditional architecture, and making significant use of earth and gypsum. All cases include a description of the actual constructions, subsequently contrasted with the accounts included in the treatises consulted.

3.1 *Renders: Plastering over earth*

Earthen constructions, both in rammed earth and adobe, have traditionally been rendered to protect them from the weather and elements, applying gypsum mortar or plaster without sand over (Fig. 2).

Many experts feel these exterior renderings are needed to extend the durability of earthen constructions using thick layers of good quality mortar, especially on their outer faces. However, very few mention the possibility of using gypsum for this: Fray Lorenzo de San Nicolás (1639), Pereir y Gallego (1853), Marcos y Bausa (1879), Barré (1899) and Barbertot (1927). This is the case in general with exterior gypsum renderings since most treatises specify the use of lime and sand mixes (in a 1:2 ratio), as well as clay and straw (Pardo 1885) and chalk: lime, clay and animal hair (Barré 1899).

According to the theory, it is first necessary to wait for the rammed earth or adobe to dry completely to eliminate all traces of damp, a process which takes between six months and a year. A pickaxe is then used all over the surface to encourage adherence or to introduce stone chips or rubble into the cavities to improve the adherence of the rendering. Cavities filled with stone chips and mortar in the *Manual de construcción de albañilería* by Espinosa in 1859 are known as *botes* while in the 1898 treatise by Ger y Lobez, these are termed *clavos*. Finally, in specific cases using gypsum, Fray Lorenzo de San Nicolás (1639) holds that first a wash should be prepared



Figure 2. Adobe construction plastered over in Navarrete del Río, Calamocha, Teruel (C.J. Grau & V. La Spina 2016).

with equal parts of earth and gypsum to irrigate the surface, subsequently applying earth and gypsum, as gypsum does not adhere well to earth or wood.

3.2 *Gypsum-crusted rammed earth walls*

In the specific case of rammed earth walls, the surfaces can also be protected by executing a rendered or crusted rammed earth wall, known in Spanish as a *tapia acerada*. The wall is built by first pouring a layer of mortar, which in Spanish traditional architecture can be gypsum, to form a wedge against the sides of the formwork. Subsequently, the earth is poured and compacted and this step is repeated with every layer, obtaining a rather unique section of wall. Although the gypsum mortar is poured in layers, on the outer face these take the form of a single continuous layer protecting the inside of the earthen wall (Fig. 3). Another option is to pour the gypsum mortar along the entire wall section and not only against the walls, thus creating alternating strata of gypsum and earth mortar vertically and in cross-sections.

All the treatises consulted which describe the execution of a rammed earth wall contemplate the possibility of using this technique for exterior reinforcement to improve resistance, using a mix to create a surface crust. However, they usually call for the use of lime (Bails, 1802) creating a crust 6 to 8 fingers high (Villanueva, 1827) and producing what is known as a lime-crusted rammed earth wall. In contrast, very few experts are open to the possibility of using other materials, and no mention is found of gypsum. In his treatise, Espinosa (1859) only states that this should be done with mortar, as he defines *acerar* as rendering a rammed earth wall with mortar, while Marcos y Bausa (1879) also adds this mortar should not be very light.

3.3 *Rammed earth walls: Gypsum reinforcements*

In addition the ends of the molds in rammed earth walls are often reinforced with gypsum paste or mortar. These supplements to the joints on these walls are designed to protect the weakest points from the elements. Thus, in Spain it is possible to find examples of rammed earth walls with reinforced joints, both horizontal and vertical (Fig. 4); rammed earth walls with *brencas* reinforcing all corners of molds, where the gypsum poured forms characteristic undulated shapes, facilitating tamping of the corners (Fig. 5); and rammed earth walls reinforced with *rafas* in the shape of small undulating or sloping pillars in each coffered layer, allowing corners or jambs to be made and long stretches to be interrupted (Fig. 6) (Vegas et al, 2014). In addition, different combinations of the elements described are possible, resulting in multiple variations of gypsum-reinforced rammed earth walls.

In general, treatises make no distinction between *brencas* and *rafas*. Those which explain the execution of reinforced rammed earth walls only mention *machos* or *rafas*, defining them as reinforcements made of rubble and gypsum placed between the individual formwork molds of a rammed earth wall, cut in a curved shape at the sides (Bails 1802,



Figure 3. Gypsum-crusted rammed earth wall in Gestalgar, Valencia (C.J. Grau & V. La Spina, 2016).



Figure 4. Rammed earth walls with horizontal and vertical gypsum joints and pillars in Alfarrás, Lleida (C.J. Grau & V. La Spina 2016).

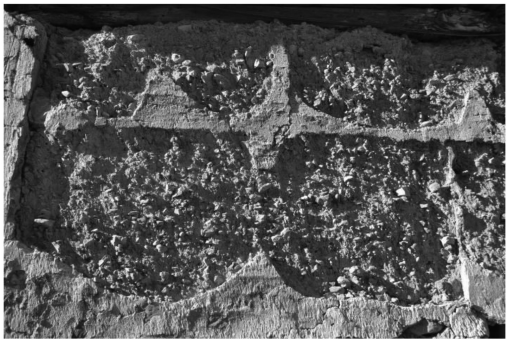


Figure 5. Rammed earth wall with gypsum *brencas* in Leza del Río Leza, La Rioja (C.J. Grau & V. La Spina 2016).



Figure 6. Rammed earth walls with gypsum *brencas* and *rafas* in Navarrete del Río, Calamocha, Teruel (C.J. Grau & V. La Spina 2016).

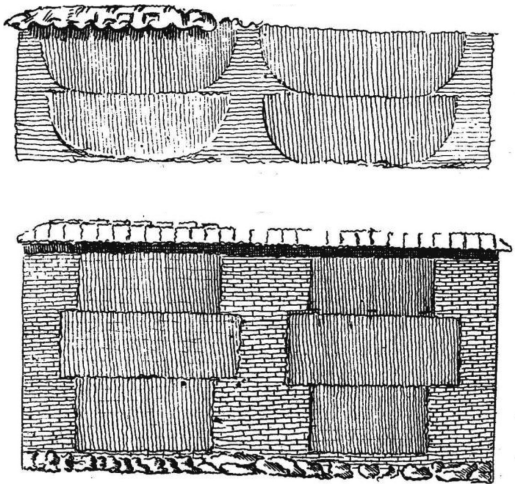


Figure 7. Rammed earth wall between *machos* or *rafas* of stone or brick, gypsum or lime rubble (Plate IV Fig. 2 and 3 in Juan de Villanueva 1827).

Adeline 1887). However, some authors hold that other solid materials are also possible, for example flint (Marcos y Bausa 1879), brick and lime (Villanueva 1827), in addition to various different combinations (Fig. 7). There are also treatises, such as that by Ger y Lobez (1898), which only describe these as reinforcements to masonry or brick, or lime and brick in the case of Matallana (1848). Therefore, there are no unanimous criteria as regards the material reinforcements for rammed earth walls, and especially not as regards the reinforcements of the joints of the different molds. In fact, only Ger y Lobez (1898, 1915) explains that a layer of mix (of unspecified materials) can be spread on each surface before building the upper one, or failing this, a horizontal course of bricks, known as *verdugo*.

3.4 *Adobe: Gypsum joints*

In areas with an abundance of gypsum, gypsum pastes and mortars are used in the joints of constructions in adobe, built using these parallelelipped bricks of clay and vegetable fibers (Fig. 8). As with fired brick, adobe can be used to build both loadbearing and simple partition walls, depending on how these bricks are bonded—using stretcher face or edges—and if a wooden structure is used.

In this case the literature is in agreement on the wide variety of materials that can be used in adobe construction joints, including earth or mud, mixes of lime with sand and gypsum, depending on the degree of perfection desired (Ger y Lobez 1898). The fact that unlike fired brick, adobe bricks cannot get wet, and can only be sprayed before extending the mix, is also specified.

Therefore joints can be of the same earth as that used for adobe bricks and this option is the most common because it provides inexpensive constructions, the best solution in rural areas, as indicated by Juan de Villanueva (1827). According to Pardo (1885) this earth can even be mixed with manure or light straw. Although it is, of course, also possible to use gypsum in the joints of adobe walls, some experts recommend this option only in locations with low humidity (Espinosa 1859).

Finally, for the execution of adobe walls both Villanueva (1827) and Pereir y Gallego (1853) highlight the option of executing thin and light, homogeneous plumb walls, with no framework or esparto grass, using special adobe bricks and laying them on edge, like brick. These blocks are made of small rubble from demolitions and gypsum mix with the desired thickness. This is an excellent and inexpensive option for producing adobe blocks and is a clear example of the recycling and reuse which have characterized traditional architecture, and to a greater extent, rural or vernacular architecture.



Figure 8. Adobe construction with gypsum joints in Azanuy, Huesca (C.J. Grau and V. La Spina 2016).

3.5 *Half-timber: Gypsum and earth*

Half-timber can be found in Spanish regions where wood is abundant. These walls are composed of timber structures made up of posts, braces, beams, and putlogs which work in combination with the filling materials. These can be gypsum masonry, with or without formwork, and with varying mix proportions of rubble or *yesones* (recycled gypsum fragments of wall from demolished buildings), as well as abundant earth, and a gypsum-rendered adobe construction, either with or without formwork (Fig. 9).

Although most experts consider the execution of framework for interior walls, some, like Rebolledo (1875), establish technical distinctions between facades, outer walls, loadbearing walls, and hanging walls, that is, whether loadbearing or not.

Filling varies greatly for these walls, from constructions with small pebbles, brick bonded with gypsum mix (Bails 1802), adobe, rammed earth or even *yesones*. In the case of half-timber facades, Rebolledo (1875) specifies that the intervals be filled with a brick or masonry construction. In increasingly less important constructions, these can incorporate adobe constructions, executed like brick constructions but rendered, or also wattle-and-daub. In contrast, Juan de Villanueva (1827) observes that in overhanging frameworks it is necessary to assemble a structure using lath intertwined with esparto grass, placing formwork behind and filling with gypsum and small pieces of rubble, or with a gypsum-rendered brick construction. In short, gypsum is the most commonly used material in fillings for this type of wall given that, as stated by Ger y Lobez (1898) it does not attack wood like lime does. However, first the wood must be tied using esparto grass in order to improve the gypsum's adherence to it. Although there are other possibilities when executing structures with gypsum rubble mortars which Barberot (1927) considers best suited to walls that give onto courtyards or for interior walls: either



Figure 9. Half-timber with gypsum and earth in Quintanilla San García, Burgos (C.J. Grau & V. La Spina 2016).

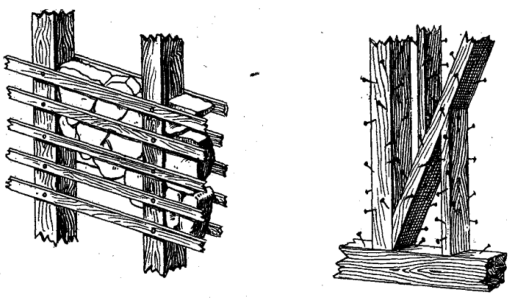


Figure 10. Timber framework with lath on both faces and filled with *yesones* (left) and framework with nails to increase adherence to the filling (E. Barberot 1927).

with *yesones* and nails; or with *yesones* and lath nailed in the timber framework, which in the end are rendered on both faces (Fig. 10).

4 CONCLUSIONS

Unfortunately most of the techniques described have not only been completely abandoned but also forgotten. This oblivion is partly due to the decreasing number of professionals, both in and outside the construction sector, who remember how these techniques were executed and what specific materials were used.

Another important aspect is the fact that no single treatise appears to explicitly include the possibility of gypsum-crusted rammed earth walls, although gypsum is considered in the execution of wall reinforcements on rammed earth and of renderings on earthen constructions.

Therefore this analysis of treatises in the Spanish language, both originally and in translation, shows that in most cases theory and practice do not match completely. The actual constructions do not coincide with the written texts. In many cases, this is because these general treatises do not cover all the building varieties in Spain, and instead focus more on the construction of individual buildings or on descriptions of the new materials and techniques which appeared between the early nineteenth and early twentieth centuries. Nevertheless, they remain a valuable source of information, soon to become the only source of information, for Spanish traditional construction.

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Earthen roofs in the region of Murcia, Spain: La Azohía

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ABSTRACT: La Azohía is a small fishing town in the Region of Murcia (Spain) in the Mazarrón Bay where even today it is still possible to find traditional construction where earth has a unique use and carries out a specific function. This is the case of *láguena* or *roya* earth, a type of expanding clay, historically used to make flat roofs or *terrados*. It is a structural solution intimately linked to the area and the local climatology that currently can be studied and analysed thanks to the examples that are still preserved. The text gives a description of this material, its structural technique, its construction and the state of the building's physical condition with the finality of leaving a record of one of the many uses this type of earth has in vernacular architecture found in Murcia.

1 INTRODUCTION

In the Region of Murcia, Spain, earth historically has been an important material used in traditional architecture, both monumental and vernacular, with multiple uses and applications such as rammed earth, adobes, renderings, etc. However, the use of earth in the execution of flat roofs or *terrados* is very interesting because of the intimate link with the Murcian territory: first, it is a structural solution it adapts perfectly to the climate of the region (hot summers, mild winters and low rainfall); secondly, it is construction technique linked to the presence of a particular type of clay earth called *láguena* or *roya* earth combined in the specific case of La Azohía (Fig. 1), with the use of dry *Posidonia oceanica* since an abundance of this marine plant can be found in its waters.

Therefore the aim of this article is to carry out a detailed analysis of the typology of earth cover that is still preserved in La Azohía and its traditional architecture and to present its uniqueness. Lastly, it is to make the state of preservation of this unique solution evident, to favour the revaluation of this technique and contribute to its protection and conservation.

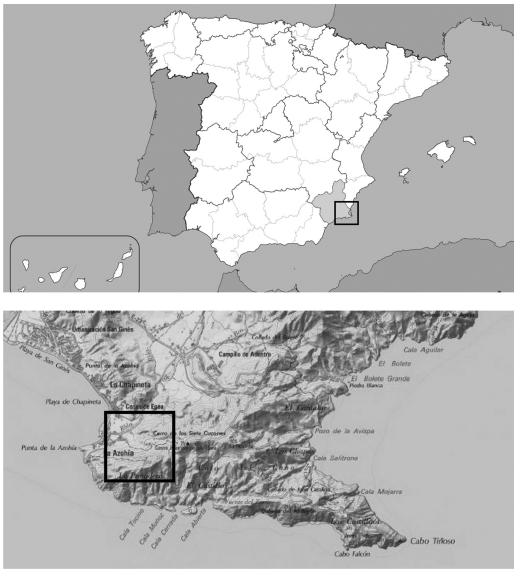


Figure 1. Location maps of La Azohía (Centro Nacional de Información Geográfica, Instituto Geográfico Nacional).

2 FLAT ROOFS IN THE REGION OF MURCIA

Terrados are tiled flat roofs with a shallow slope in the region of Murcia, with a layer of *roya* earth or *láguena* (Almán Sainz 1984). This earth, characterised by its waterproof and expansive qualities, was spread over a layer of *Posidonia oceanica* or ash depending on coastal proximity and this in turn, on a framework of reed matting or a flat roof made with slabs.

In addition, this kind of roof has characterised cube-shaped buildings, architecture typical to Murcian architecture; rural as well as urban, but also in auxiliary buildings linked to farming or

agriculture such as pigpens (Ortega 2015, Rabal 2015), warehouses and sheds.

2.1 *Láguena or roya earth: Main material*

Láguena or *roya* earth in the neighbouring province of Almeria takes the name of *launa;* it is a type of clay earth particular for its magnesium composition and its characteristic grey, green blue and purple colour. It is clay-loam sediment with a degree of metamorphism between the slate and the shale, which possess expansive properties (Martínez & Almela 2015).

Historically, it was extracted from *laguenetas* (a type of quarry where the material is extracted) (Fig. 2) with a pickaxe and then crushed, sieved and used in all types of construction. The crushing could have been carried out either passively leaving the *láguena* on a stony path where passing carts would crush it, or actively, by manually hitting it with a wooden mallet.

Its main use has been in the making of flat roofs, but also in the development of coatings due to the characteristic violet colour obtained from this type of earth (Lejárrega et al. 2015).

2.2 *Earthen flat roofs in historical constructions in the region of Murcia*

In archaeological sites of the Iberian period of the region, buildings with mainly one-sloped roofs have been found, erected on walls with logs, a reed matting covered with mud and foliage, *láguena* in some cases and, in the weakest areas of the structure, stone slabs (www.regmurcia.com). Similar evidence has been found in several areas in the city of Cartagena (Madrid, 2004).

Centuries later, in the 15th century and according to historic texts (*Actas Capitulares*), the flat roof of the old *almudí* (warehouse) in Murcia, located in the San Julian square underwent several repairs with *roya* earth or *láguena,* since its construction was carried out with very little economical resources (Carbonell 1992), despite being a public building and of great importance.

Later, at the end of the 18th century, flat roofs were very common in most towns throughout Murcia. They usually had railings, guardrails or parapets and were used to hang washing or as a viewpoint (Alemán 1984). Its increased use was a direct consequence of the tragic flood of the Santa Teresa of 1879, since the traditional adobe huts with thatch roofing of the Murcian orchard area were substituted by housing with flat terraces with a slight slope made with earth. Even in the city of Cartagena the new projects and interventions in cheap housing in the beginning of the 20th century carried out by the Cooperative society "*La Conciliation*" considered the development of flat roofs with a layer of earth (Ródenas, 2016) (Figs. 3, 4).

However, the disadvantage that this type of roofing presents is the periodic and constant



Figure 2. *Lagueneta*, quarry where the earth in the area of La Azohía, Cartagena, Spain (F.J. López Martínez & V. La Spina).

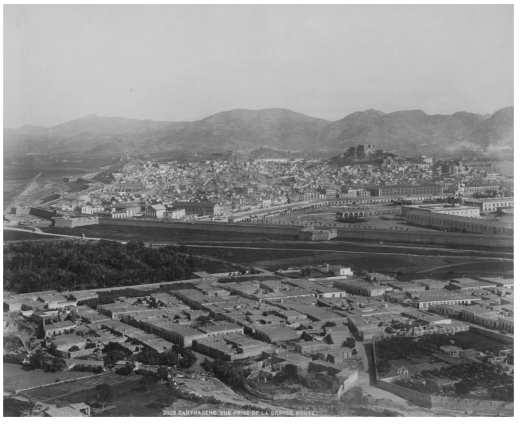


Figure 3. General view of Cartagena, Spain circa 1865–1895 (Source: Andrew Dickson White Architectural Photographs, Cornell University Library).

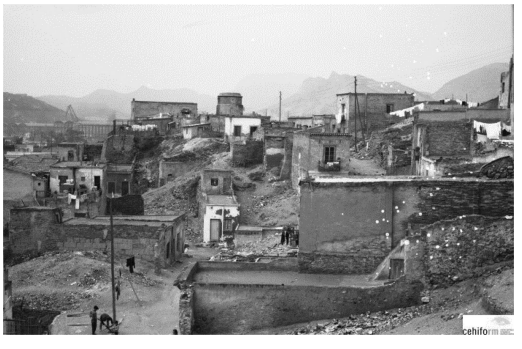


Figure 4. Housing with earth roofs in the city of Cartagena (Casaú archive collection, early 20th century).

maintenance needed to avoid water filtrations that could affect the wood and reed matting. According to the Cartagena Municipal archives, this task was carried out until the 90's of the 20th century.

2.3 *Earthen roofs and the Spanish treatises*

By briefly reviewing the treatises or Spanish construction manuals, since the middle of the 17th century until the beginning of the 20th century, very few made reference as to how to carry out the roof however, there are notable exceptions such as *Tesoro de albañiles* (Bricklayer's Treasury) Pereir y Gallego (1853) as it also specifies "… *In many towns located in the mountains, covering the houses with a type of greasy greyish-blue earth called launa. To do this, strong beams were placed horizontally or with very little slant, and covered with wedges, wood chips or branches and then a large quantity of launa is placed on top; spread evenly, and placed as an overhang. Large slates are placed on the thick walls, opening in the launa some channels for drainage. If there are leaks, the same material is used to fill in the cracks…*" This is undoubtedly a description of an earthen roof; however, it seems to deal with a typology used exclusively in mountainous areas.

In addition, the manual by Espinosa (1859) refers to a French architect, based in Germany who built flat roofs with a 15 cm layer of clay mixed with a shovel on which a layer of hot tar is applied. Before it cools, it is covered with tarp followed by another layer of clay and then tar, and finally clay or tile dust. Marcos y Bausá (1879) also considered this same technical solution in the text, while in the text by Valdés (1870) another typology was described. It refers to a solution widely used in Cadiz and consisted in first pouring on a layer of brick a very thin layer of common mortar and on the top, a layer of small pieces of sandy-clay and finally, a layer of hydraulic mortar that will receive the flooring. It also indicates how the intermediate layer of clay is very useful, firstly, because it waterproofs the roof. Secondly, with its elasticity, impedes that the vibrations of the wood, when there is additional weight, they are transmitted to the inferior layer. Thirdly, if a leak occurred, the mud could be softened and the crack could be covered immediately.

3 THE FLAT ROOFS OF LA AZOHÍA: TYPOLOGY AND STATE OF CONSERVATION

3.1 *La Azohía: Location and history*

La Azohía is a small, rural coastal town in the region of Murcia, located in the Mazarrón Bay, belonging to the Perín Council and in the municipality of Cartagena, between the estuary of El Cañar ravine and La Azohía ravine, at the foot of La Muela Mountains and close to Tiñoso cape.

Since the Roman period, it was a sparsely populated area due to its difficult location. The inhabitants dedicated to agricultural and fishing activities. It later became an area of great defensive value facing possible pirate attacks and so during the 16th century, several defensive elements were built such as the Santa Elena tower or La Azohía.

3.2 *Traditional architecture*

The use of local material available in the area is an invariant of traditional-popular architecture. In the case of La Azohía, together with launa present along the southeast peninsula, the leaves of the marine *Posidonia*, that the sea periodically washes to the shore.

Traditionally they are one-storey houses (although there are houses with two), rectangular, with masonry walls, covered with earth and with very few openings. Local stones, logs, reed, earth, and dried *Posidonia oceanica* are used (Fig. 5).

The use of *Posidonia* is very common in other Mediterranean areas such as the Balearic Islands.

3.3 *Typology of an earthen roof*

The masonry walls bonded with earth mortar support the logs, a reed matting (Fig. 6), a thick layer of *Posidonia oceanica* as insulation, earth from the area is added (the same used to bond the stone masonry walls), and finally, *láguena* or *roya* earth is added (Fig. 7). This earth is a special type of clay, which is used in the last layer and needs annual or biannual maintenance. Stocks of earth for repairing and maintaining of the flat roofs can still be seen in some places in La Azohía.

The roof was flat, with a slight slope on one of its sides. In the scarce overhang, that surrounds the roof with the aim of confining the earth, one or several tubes are in place to drain the rainwater (Fig. 8).



Figure 5. Typology of the traditional construction material in La Azohía (Photo: F.J. López Martínez & V. La Spina).



Figure 6. Interior of a flat roof *láguena* in La Azohía (Photo: F.J. López Martínez & V. La Spina).



Figure 7. Detail of the marine *Posidonia* and *láguena* earth on a roof La Azohía (F.J. López Martínez & V. La Spina).



Figure 8. Ceramic drainage of a flat roof La Azohía (F.J. López Martínez & V. La Spina).

3.4 *State of conservation*

Currently, very few houses have maintained the traditional roof in earth. The changes that the coastline has undergone over the last 40 years as a consequence of tourism have meant the demolition of traditional constructions to make way for new buildings. Besides, there has been a systematic substitution of *láguena* earth for other materials such as waterproof sheets of wood, gravels, etc. (Lejárrega et al. 2015).

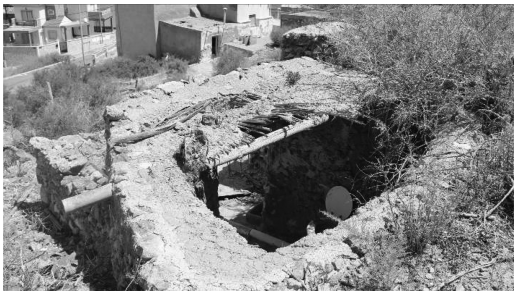


Figure 9. Abandoned dwelling and has almost completely lost its flat roof of *láguena* in La Azohía (Photo: F.J. López Martínez & V. La Spina).



Figure 10. Dwellings that have conserved it flat roof of *láguena* en La Azohía (F.J. López Martínez & V. La Spina).



Figure 11. Dwellings that have partially conserved its flat roof of *láguena* in La Azohía (F.J. López Martínez & V. La Spina).

Therefore, from the aerial photos (Fig. 12), the changes that the area has undergone are evident and specifically the progressive disappearance of the flat roof of *láguena* throughout the years can be observed. Nevertheless, they still exist:

– Earthen flat roofs in very bad condition (Fig. 9), the majority in ruins, despite this, however, these roofs are a great source of study in order to know firsthand this technical solution.

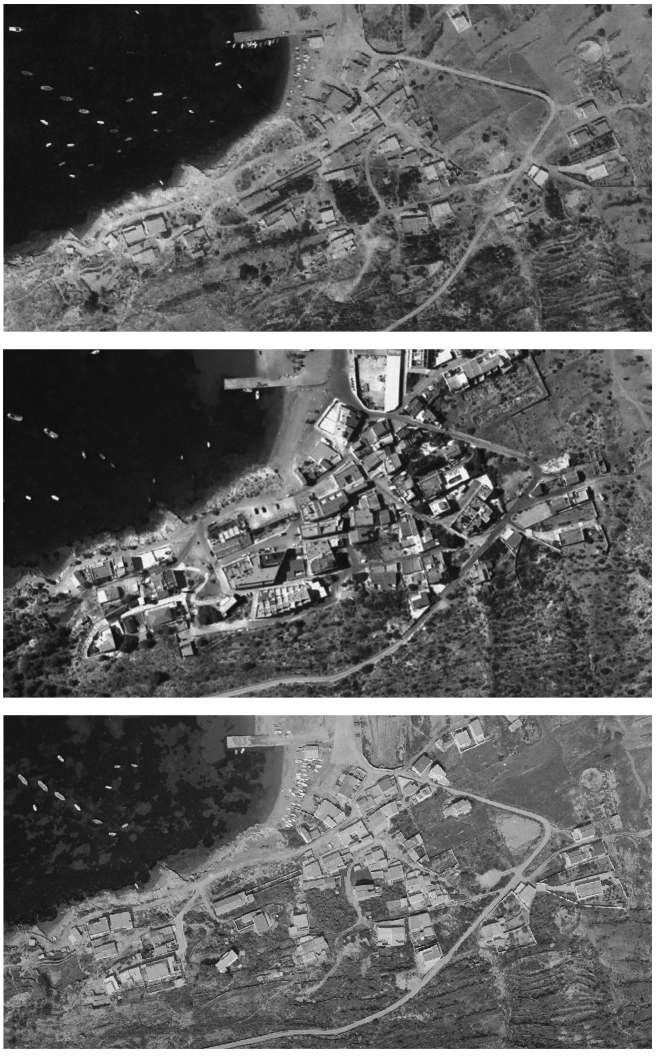


Figure 12. Aerial photos of La Azohía: inter-ministerial flight 1973–1986, costal flight 1989–1991 and flight PNOA 2014 (National Geographic Institute).

– Earthen flat roofs in an acceptable state of conservation (Fig. 10), mainly in constructions that are still being used and bear witness to the technical performance of this structural solution.
– Flat roofs that have been altered with materials (Fig. 11) these reflect a reality that is being systematically imposed on traditional architecture, where the new materials being used are unrelated to historic constructions.

4 FINAL REFLECTIONS

In the last most of survival of what has been traditional architecture in most parts of the world; especially in the Mediterranean, identifying and informing on the remains of a type of construction, which is in total harmony with its surroundings, where the peculiarities are, simply the recourses that are available, is an important task. Not only from a reminiscent point of view but also from the validity of the vital attitude that implies the exploitation of sustainable materials that nature provides. The winters, the storms, continue to fill the beaches with *Posidonia oceanica* that represents an insulating and light material that can still be used today.

NOTE

This work is part of the research project "Restoration and rehabilitation of traditional earthen

architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention", funded by the Spanish Ministry of Science and Innovation (Ref.: BIA2014-55924-R; main researchers: Camilla Mileto and Fernando Vegas López-Manzanares).

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Material and typological characterization of the *tighremt* n'Aït Makhat (Morocco)

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ABSTRACT: The High Atlas mountain range of Morocco presents an important architectural heritage built on earth that nowadays is still partially inhabited. The present research deals with the material, constructive and typological analyses of the *tighremt* n'Aït Makhat, a fortified dwelling located in Ighrem Aqdim, one of the six villages inhabited by the Aït Mraou, which is on the left shore of river Mgoun's middle course, the main affluent of river Dades. This research goes deeper into the organic character of a building constructed during the first decades of the twentieth century, and shows the different manufactures and uses of the main materials employed in its production: earth, plaster and wood; looking into the constructive processes and specific technique nomenclatures in the local language. The study also allows analyzing the evolution and transformation processes of these systems, still surviving in the region.

1 INTRODUCTION

The material, constructive and typological data of the *tighremt* n'Aït Makhat, as well as its rigorous parameters of study, allow us the detailed knowledge of one of the fortified house building types of southern Morocco associated, in this case, to a concrete geographical demarcation and to a specific chronological period. This research and subsequent comparative studies to other examples of fortified houses in the various valleys and regions of southern Morocco will help the establishment of chrono-typological and material-constructive relations that will contribute to the corroborated knowledge of this important heritage.

Likewise, in previous phases of this research (López-Osorio et al. 2012), the rammed earth technique currently used in the same geographical context was documented, which allows us to analyze its evolution and possible differences. Overall, the original knowledge of the technique and its variations through time facilitates the definition of rehabilitation strategies to guarantee the proper conservation of this heritage1.

2 THE SETTLEMENT

2.1 *The* Aït Mraou *community*

The Aït Mraou community is located in river Mgoun's middle course, the main affluent of river Dades, which starts off at the highest levels of the Mgoun peak, in Morocco's High Atlas central sub-range. The word *mraou* means "ten" in the Tamazight language and relates to the number of nomadic families that decided to become sedentary and establish their settlement in the first decades of the twentieth century. From its origin, the community was composed of six villages, one of them (Issoumar) located to the river's right watershed, and the other ones to its left watershed (Imin Ouaka, Tizghin, Ighremt Aqdim, Isusuk and Timerdan). Administratively, the Aït Mraou community belongs to the municipality of Kelaat Mgouna, located at the head of the Mgoun valley, next to National Route N-10 that communicates Ouarzazate with Errachidia.



Figure 1. Localization of the house (Google Maps 2017).

2.2 *Ighrem Aqdim*

Nowadays, Ighrem Aqdim is the longest and oldest settlement of the community. Its founding was accompanied with the construction of eleven fortified houses or kasbah, called *tiguermatin* (s. *tighremt*) in the Tamazight language. The houses were built after the collective establishment of the oasis and represented the social and economic prestige of the family, whose income was obtained through the possession of numerous heads of cattle.

According to oral sources, the first two families that settled down were the Aït Agnau and the Aït Iguztini. Afterwards, the Aït Makhat family fortified house was built—which will be analyzed in this study—followed by the family houses belonging to the Aït Beti, the Aït Daoud Mouh, the Aït Taqala, the Aït Ali Oumouh, the Aït Zeroual, the Aït Lamlamar, the Aït Boussagh and the Aït Bouhssain. There are currently an important number of houses, with a much simpler typology, that are the result of evolution models derived from the traditional type, which have conserved, in many occasions, part of the original typological and constructive features (Díaz del Pino et al., 2012). Some of these houses correspond to foundational times and used to belong to humble families, salaried people or widows.

3 THE TIGHREMT N'AÏT MAKHAT

The fortified house of the Aït Makhat was built by two brothers in the decade of 1930 and costed one hundred and fifty lambs. Its promoters lived in the building with their respective families until the decade of 1990, when their descendants started the construction of new dwellings attached to the original one.

The building was constructed, as the neighbor's ones, in a plot located outside the farming land (Figs. 1–5), which was assigned to the family by the *jmaâ*, the community's traditional counseling body comprised by the family chiefs that, until current times, still fulfils part of its administrative and arbitration functions.

3.1 *Architectural definition*

The house is a three-store building with a square floor-plan and a compact volume, flanked in its corners by four slightly leaning towers which height do not go over the terrace's protective border (Fig. 2). The access is done through the ground floor's main bay, which gives way to a corridor from where a double flight staircase starts up and goes up to the upper floors and the terrace, ending in an adobe cabin-like coffering with a slightly sloping cover. This corridor or central hallway occurs also in the remaining floors, allowing access to the rooms. In the second floor, the ceiling over the corridor has a small skylight orientated towards the zenith allowing ventilation and illumination into the space (Fig. 4). The house' ground floor is used as a main lobby and cattle stable, while the upper

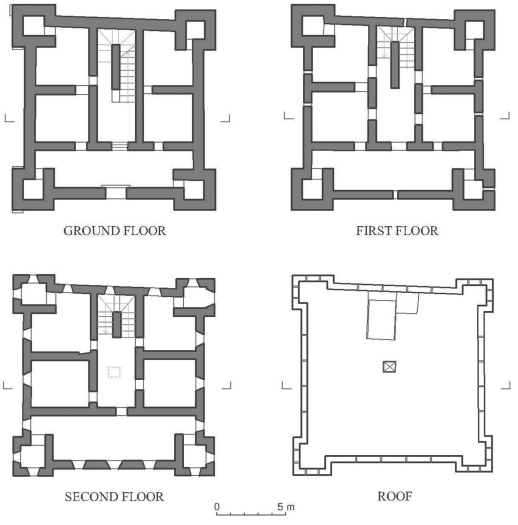


Figure 2a. Plans.

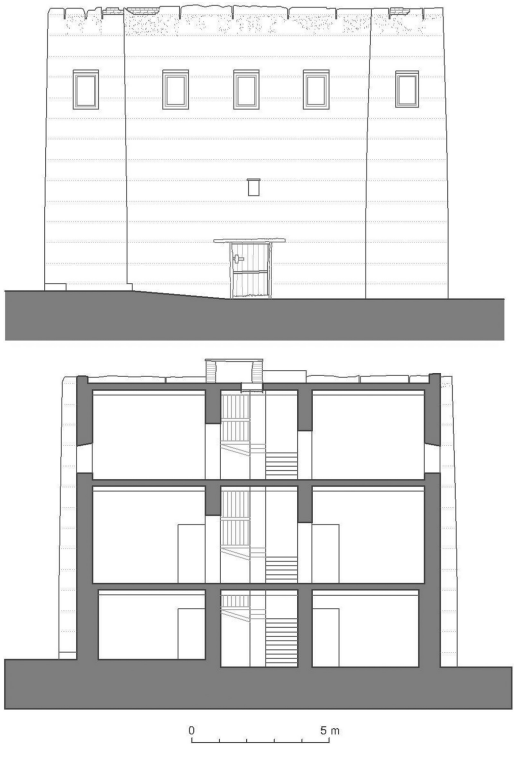


Figure 2b. Main elevation and section.

floors were occupied by the two owner families. The terrace was used for the drying of fruits and for sleeping during hot summer nights.

The main volume presents a quite square plan of 13 × 13 m with corner towers with a mean width of 3 m. The preserved maximum height on the main facade's front is 10.70 m, but this must have been over 11 m high, since part of the terrace's protective border and eaves are now lost (Fig. 8). The house currently shows an enclosed exterior patio, accessible through a door with a covered passageway.

3.2 *Constructive definition*

The characteristic constructive system of the house is rammed earth, which appears in most walls excepting the terrace's protective border and the staircase exterior cabin-like coffering which are built in adobe.

The exterior walls show fourteen rammed-earthen walls, the first one being half-buried since it acts as foundations, filled in with tamped earth and river pebbles. As a singular feature, there are wedges on the towers' corners that stand above the wall's face in its first course. This constructive disposition allows ordering the bounding as well as protecting the corner from superficial erosion. With the same purpose in mind, a mud-and-pebbled baseboard or bench was placed in the base of the walls and next to the main access door.

Both the walls in the main body and the ones in the towers are 78 cm width and reach the first floor, having four 75-cm-height rows, including the one serving as foundation. In the interior bays the wall are 58 cm width. The same width is maintained form the first floor up, where the tower's walls show a small slope, and the surface's inclination varies according to the plan's height. The slopes change in each tower going from 3–8%, having in the exterior a pyramidal shape but without reducing the walls thickness, which produces inclined surfaces in the rooms' interior, especially in the second floor (Fig. 6).

The stairway's supporting structure goes around a solid wall with rectangular in shape that goes from the ground floor up to the terrace (Fig. 4), where all the structure is covered by a closed cabin-like coffering with a slightly leaned covering resting on brick-and-a-half-width adobe low walls. The adobe bricks are 13 × 27 cm and show a high content of barley straw. An adobe masonry with a similar width is also used to round off the building facades and the terrace's protective border. Currently, this low wall has lost part of its high (Fig. 8), although this must have been the same as the other ones, reaching 75 cm. The protective border, now lost, was rounded off with a cane eave, on top of which an adobe brick and a thick layer of mud and gravel mixed with barley straw were placed.

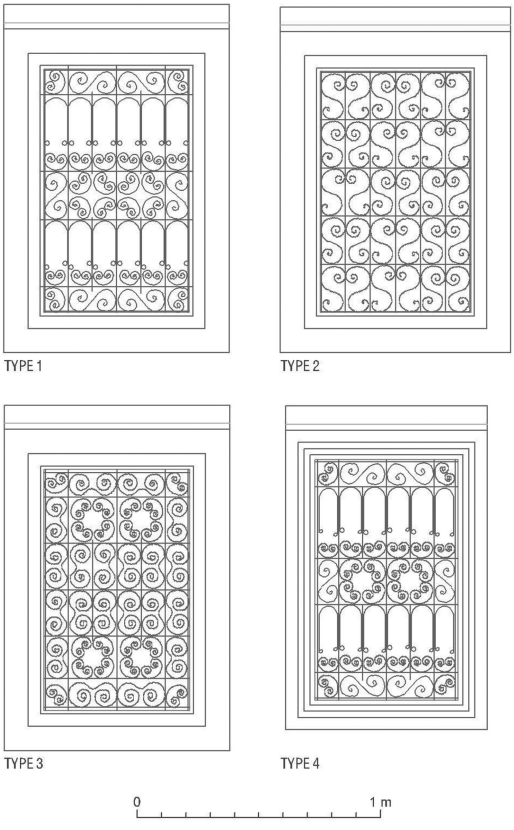


Figure 3. Different types of window grilles in main façade.

The building's facades are pierced by several openings to allow access, illumination and ventilation into the interior rooms (Fig. 7). On the ground floor, we find a single opening corresponding to the house entrance gate, which shows the traditional wooden bolt with a hinge gathered up by the lintel.

On the first floor the openings are limited to vertical narrow holes without carpentry and loophole-like, being 40 to 15 cm apart from each other. These loopholes acquire a bigger development on the second floor, with the appearance of three windows with bars in each house front and another one on each side of the towers. The windows are leveled on the exterior face and show two collapsible casement frames with no glass on them, and forge bars decorated by arches, spirals and curls (Fig. 3). Interiorly, there are small wooden shutters. All the interior doors are made of wood, with different dimensions.

Concerning the wood slab (*lwardi,* pl. *wardiyat*), there are different typologies depending on its placement within the building and the importance of the room. The beams are made of spruce wood generally extracted from the surroundings of the village. The

ceiling on the ground floor are made of wooden log beams (*assatour,* pl. *assatourat*) with diameters going from 15 to 20 cm, apart from each other circa 75 cm. Over the wooden beams rest 4-cm-thick boards and a variable width of between 20 and 40 cm, holding a thick layer of earth and a tamped sifted soil pavement. The ceiling on the first floor shows a singular feature since in the stairway's foyer and corridors the logs were splinted in order to make false framed beams, placing leaned clapboards where the wall faces meet. On the second floor, the ceilings are also made of log beams, but these are partially carved, standing out a square skylight that allows light in. This skylight is known as "the eye of the house" (*tit n'tgemmi*).

The stairways' leaned slabs are made of wooden logs grouped with irregular section and diameter swinging from 4 and 8 cm (Fig. 4), creating a continuous plan over which adobe steps with wooden bars are placed. The roof frame shows a thick earthen layer conforming a slope with a mean thickness of 25 cm, over which a layer of mud with abundant gravel and straw that facilitates the collection and channeling of waters, evacuated through wooden gargoyles. Currently, a polyethylene sheet was placed under its final layer that improves waterproofing, by means of metallic gargoyles.

On the exterior, the wall faces do not show any type of added coating in spite of having a continuous and well finished surface, resulting from a superficial battered or lateral tamped treatment applied during the very process of wall construction (Fig. 6). This technique, called *takhbat*, is made when the mix is still fresh and consisted in the application of fine dampen soil over the formwork joints, putlock holes and places where superficial imperfections are such as material loses. Then, the wall face is battered with a wooden trowel giving it small blows and rotating movements until obtaining a smooth surface, removing this way any sign of the formwork boards. The *takhbat* technique is still performed in the region and was previously documented in an initial phase of this research (López-Osorio et al. 2012).

The only external coatings can be found in the ending of the building and the terrace, where the adobe masonry was protected with a mix of mud and straw (*tamasht*), preserved in some parts of the stairs' coffering and the interior face of the terrace's protective border. Nonetheless, in the house we find some interesting features in the coatings. In the last row that finishes off the facades and towers walls, we find a coating of mud and straw especially made, since the soil used presents a light green color. This type of finish, with this or a more whitish color, coming

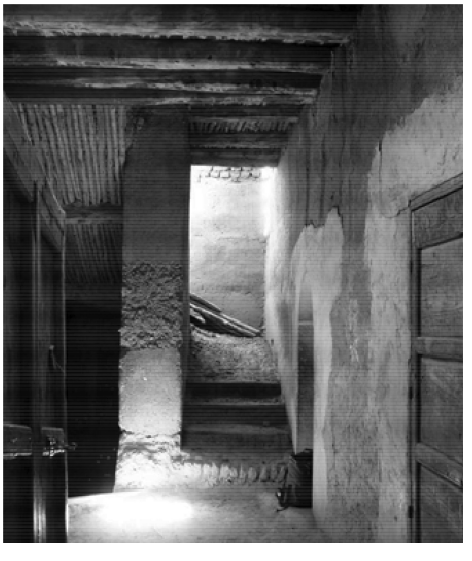


Figure 4. Second plant central hallway (M. Porras).



Figure 5. Side elevation from the outside patio (P. Iranzo).



Figure 6. Window and loophole in rear facade (P. Iranzo).

from calcareous deposits, appears also in some house at *Ighrem Aqdim* and other villages in the Mgoun valley. In this sense, remains of another singular coating covering the exterior of the terrace's adobe protective border have been found. It consists of a traditional plastering in which the plaster paste is mixed with straw and sand to making it more hardness and resistance against erosive agents (Fig. 8). This finishing strip also integrates small vertical slits similar to blinded loopholes arranged in an orderly way in the walls of the central body and towers. This decorative element identifies and completes the symbolic program of the fortified housing of the High Atlas.

The inner wall faces in the common spaces of the building are finished with the *takhbat* technique described in the previous section. Inside the rooms, however, we find plaster rendering that also covers the interior windowsills, the jambs and flared windows on the second floor. Likewise, the exterior doors of these rooms, located on the floor's hallway, are demarcated with plaster rendering. In the most representative room of the house, located on the second floor of the main facade's bay, decorated stucco with polychrome geometric motifs on the entrance door jamb and in the interior framing are found.



Figure 7. Detail of tower in corner (P. Iranzo).

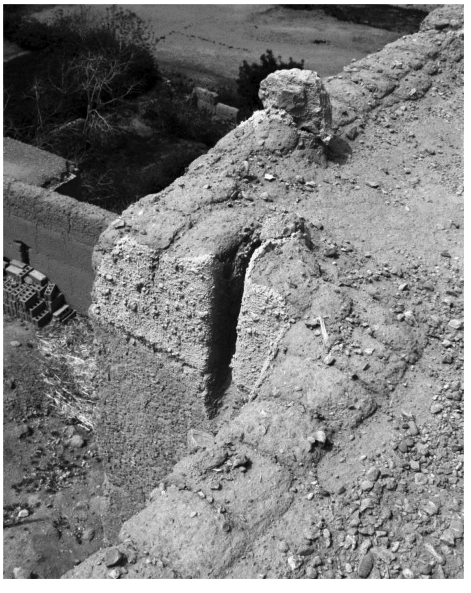


Figure 8. Remains of the roof top (J.M. López-Osorio).

4 SPATIAL TRANSFORMATIONS AND MATERIALS OF THE HOUSE

There are four families descending from the two brothers that built the *tighremt* n'Aït Makhat. In the decade of 1990, three of them built their own new buildings attached to the original building, in the inner closed patio. Two of them houses were made of rammed earth, and the third one was built with concrete blocks (Fig. 6). In 2014, expansion works were carried out in one of the earthen houses with the enlargement of one of its floors through strengthened pilasters and reinforced concrete beams.

Currently, the house is not occupied but is still in relatively good condition despite not having received any maintenance work. Each of the families keeps the share of their property and on hot summer nights some of the heirs share the terrace to sleep in the shade. The family inheritance management makes difficult the building's maintenance or even its possible sale or lease. Some years ago, the family received an offer for the creation of a tourist hostel, but the lack of agreement between the heirs aborted the operation.

5 CONCLUSION

The material, constructive and typological characterization of the *tighremt* n'Aït Makhat allows us to know its laws of internal organization and go deeper into the organic and compact character of the building. From the dimensional point of view, prevails the modular criterion established by the formwork boards (*tifraouine,* s. *tafraout*), which according to the documented imprints and the corresponding overlaps, could have measured 240×80 cm, since the walls formwork have an average size of 165×75 cm. In the case of wall thicknesses, these are well defined by the width of the bulkhead (*jbht*, pl. *jbahis*), which must have been 58 and 78 cm, depending on its constructive plan. Likewise, information on the size and arrangement of the temporary wooden stays (*lashkal*, s. *shkal*) was obtained, which should have a rectangular section of 8×5 cm, as indicated by the imprints of the existing hollows, three of them in each wall, being about 60 to 90 cm apart from each other.

According to oral information, no measuring unit or instrument was used for the construction of

the building. The layout of the building was done "by eye" but well proportioned, which means that the dimensions are not exact even if they appear within a more or less regular range. Likewise, the angles are not straight since a squad was not used. The formation of vertically "straight" walls was carried out—and is still being carried out today—with rudimentary and unplumbed systems, either by dropping a small stone next to the board or with similar approximation mechanisms. The formation of slopes in the towers could be carried out in different ways: by keeping straight the inner wall and leaning the exterior by means of wedges and adjustments in the bulkhead and spacers, or by maintaining both inclined while conserving the thickness of the wall, as in the case of the *tighremt* n'Aït Makhat.

The general conclusion is, if we make a comparative study with the current techniques of construction, that there have been no significant changes regarding traditional rammed-earthen structures, either in its dimensional values or in its constructive definition. Likewise, it is possible to observe how some recent houses preserve the outer slope of the wall, while the interiors are done to lead. On the other hand, buildings with wall faces executed with the technique of superficial battering (*takhbat*) have been documented in the same settlement, which makes unnecessary the application of an added coating. Where we do find important variations is in the construction of the wooden slabs, since the native wood that used to grow in the hillside was replaced by poplar wood currently cultivated in the riverbank. Also, the slabs solid boards have been replaced by cane, which was only used in the original house to make the eaves. In relation to the interior linings, plaster is still used in interior walls, without mixing it with slime. The tamped paving is being replaced by continuous polished cement mortar pavements. Other element that has undergone important modifications is carpentry, especially in the case of exterior and interior doors, which are now metallic. On the contrary, the windows and their embedded bars are preserved in general, simplifying the decorative motifs.

As a final conclusion, this research is based on the conviction that the detailed and rigorous documentation of a concrete example—in this case, the *tighremt* n'Aït Makhat—, presents particularly relevant information, not only for the definition of its architecture but also of the totality of social and environmental circumstances by which its construction took place. Particularly necessary are the identification of materials and the recording of construction techniques now in disuse or in danger of extinction, since, in many cases, they are not valued by the local population and by the architectural culture that generated them. Their dating and identification presupposes a necessary constructive archeology exercise that can help define conservation criteria and techniques. Also, this documentation informs us of several events that have affected the building's life, the causes or phenomena that have conditioned its transformation, replacement or abandonment, and aspects related to management and ownership related, in this case, to a family inheritance. This set of circumstances is particularly relevant in order to propose possible actions for the protection or rehabilitation of a patrimony that is in danger of disappearing. On the other hand, the mere recording of such a modest architecture, but loaded with valuable architectural, cultural and environmental information is, in itself, a first step towards its knowledge, diffusion and future conservation.

NOTES

The data collection was carried out during March of 2014 by the group LÓGICAS LOCALES: Arquitectura y Cooperación, which belongs to the Technical School of Architecture of Malaga, in the context of the project: "Paisaje y Patrimonio en el sur de Marruecos: Propuesta para el desarrollo de modelos de turismo responsible" AP/05921/11 (Landscape and Patrimony in Southern Morocco: A Proposal for the Development of Responsible Tourism).

The oral information was provided by Mr. Mohamed Oubenarir, a direct descendant of the founders of the house, who was ten years old when by the time the house was built and, according to his testimony, participated in the haulage and transport of materials.

Italics are used when referring to traditional concepts or terms written in *Tamazight* language.

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Mud architecture: Sustaining communities in cold desert regions of Northern India

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ABSTRACT: The cold, high and dry Tibetan Plateau in northern India comprising of Ladakh, Spiti and Zanskar represents a unique geographical region, which marked by extremes of climate and topography is largely devoid of vegetation, usable construction material, population and connect with rest of the world. These vagaries of nature and seclusion have forced communities to develop their own ways for sustenance which can be well understood by studying the built fabric—starting from site selection, orientation and layout to the much finer details, all of which seems to serve specific purposes. Mud being abundantly available is used for constructing all the major building components like walls, roof, floor, plaster, ornamentation, etc. This paper attempts to understand the evolution of residential built forms in response to extreme conditions, document the recent transformations and probe into reasons behind them, their implications on performance of built environment and sustainability of these communities.

1 INTRODUCTION

1.1 *The cold desert regions of Northern India*

The built environment apart from fulfilling the basic human need of shelter also represents the response of mankind towards a range of existing climatic, economic, social, political, topographic and geological situations. This stands true for all societies at all times and the varying combinations of these variables have led to the development of numerous styles of vernacular architecture across the globe. They represent the simplest modes of addressing human needs and have evolved as pragmatic solutions in response to unique needs and limitations of respective sites. One such unique system has evolved in the cold desert regions of Northern India, thereby enabling the communities to survive against all vagaries of nature since ages which currently is under transformation owing to a range of factors.

1.2 *Objective of the paper*

The paper includes a brief introduction of the region and the factors that shaped the traditional architecture of the region. The residential architecture of the region is documented and analyzed for understanding: (i) the planning and construction practices of the region, (ii) the recent architectural transformations and their underlying causes, and (iii) the occurrence of these transformations in different parts of the region and their impacts.

1.3 *Scope of the paper*

The residences of Changthang and Spiti regions have been documented, compared and analyzed for the purpose of understanding the varied forms of earthen vernacular developed and practiced in this region. Only residential architecture has been considered for the study due to following reasons:

- residences account for the majority of buildings,
- palaces and monasteries are few in number and having an element of dignity, supremacy, grandeur, wealth, religion and security associated with them cannot be considered as representative of popular architecture of the region.
- *doghris* and *rebos* are temporary in nature and are confined to certain areas only, and
- public buildings are recent additions and are few in number. Refer Table 1 for building types.

The residential architecture of Zanskar division has not been covered in the scope of this paper.

2 THE SPATIAL CONTEXT

2.1 *Geographical setting*

The Himalayan Cold Desert Region in Northern India extends from Ladakh (Leh and Kargil districts in Ladakh division of Jammu and Kashmir) in the north to Kinnaur (Spiti region of Lahaul and Spiti district and a part of Kinnaur district in the state of Himachal Pradesh) in south. It is

a trans-Himalayan plateau land that represents a transient region between the Greater Himalayas of India and the main Tibetan Plateau.

2.2 *Geo-climatic characteristics*

The region is characterized by harsh climatic conditions owing to its location on rain shadow side i.e. leeward side of the Himalayas and its altitude above sea level. A huge variation in seasonal climatic conditions ranging from short dry summers with harsh sunlight to long, windy and freezing winters with very low levels of precipitation can be witnessed here. The soil in not very fertile and the scarcity of glacier fed water resources allows for a very short growing season transforming it largely into a barren landscape. The residents have devised their own laws and systems: social, cultural, economic, political and architectural to survive in these extreme conditions with bare minimum and sparsely distributed resources at their disposal. These physiographic and climatic peculiarities coupled with scarcity of usable construction materials and their isolation from rest of the world have led to the emergence of a unique style of vernacular architecture in the region which evolved through a continuous process of experimentation, verification and adaption.

2.3 *Settlement patterns*

Despite being one geographic unit, the otherwise barren landscape is dotted with numerous small, isolated and sparsely populated settlements at locations with marginally better conditions for habitation, mostly cuddled within valleys and near rivulets thereby defending the populace from chilled winds and providing water for survival as evident in Figure 1. The settlements with their organic layouts with fixed no. of Khangchhen (big houses), Khangchung (smaller houses) and some Thuthulmas (very small houses), are mostly wet point settlements with sufficient land for agriculture and pastures for cattle. The buildings are normally placed along contour lines of southern slopes of mountains to maximize solar gain, minimize exposure to winter winds and increase their structural stability. The settlements with a *gompa* or a monastery crowning a nearby hillock, follows specific layout patterns, construction practices, facade treatments and architectural vocabulary; collectively representing the tale of human response, grit, determination and survival in such inhospitable environmental conditions. The discovery of Lower Palaeolithic tools, Petroglyphs and later art works (UNESCO 2015) indicates habitation here since pre-historic times, its continued occupancy since then and close association of its habitants with the communities inhabiting Tibetan Plateau.

Table 1. Categorization of building types.

Type	Description
Dwelling Units	These comprise of the Khangchhen, the Khangchung and the Thuthulma.
Monasteries / Gompas / Chortens	These are the repositories of Buddhist art and culture, signifying the importance of religion in the everyday life of the natives.
Public buildings	These are new interventions, mostly during the British Period or after Independence like schools, health centers, community halls, panchayat ghars and rest houses.
Summer settlements (Doghris)	These are the seasonal settlements characterized by hardly one or two unit dwellings, surrounded by small landholdings and pasturelands, usually located on the higher regions.
Palaces	These are residences for royal family, situated at commanding heights for security purposes and reflecting authority and grandness.
Rebos	The temporary shelters of pastoral nomads of Changthang, made from yak wool.



Figure 1. Settlements in the region. (a) Korzok on banks of Tso Moriri (b) Kibber (Authors).

Building types here can be generally categorized into six types as detailed in Table 1.

3 RESIDENTIAL ARCHITECTURE

3.1 *Principles of the residential architecture*

The dwelling units are designed to create habitable interiors and to ensure self sufficiency and survival of residents during long harsh winter season. Their design, form, height, orientation, structure, interiors and construction systems are all governed by the prevailing climatic conditions and the scarcity of suitable construction materials in the region. Mud, stone, scrub and wood are the commonly available and used construction materials here. The units with trapezoidal mud, stone or sun dried brick walls, flat roofs, mud plaster and bare minimum ornamentation stands in stark contrast with the desert landscape. The maximization of heat gain and minimization of heat loss in their different ways of realization appears to be the most important principles for designing, material selection and construction as elaborated in Table 2.

The houses consist of multiple rooms with ample storage, sun spaces, prayer room, kitchen and separate winter and summer living rooms as in Figure 2 and 4. These are approached through a connecting corridor, thereby avoiding direct access and at times the cattle quarters are kept in vicinity of living areas. The community following Buddhism gives due importance to religious activities. The prayer room is an essential component of every house and is highly decorated with *thankas*, images of deities, religious books, prayer wheel, brass cups, lamps, etc.

Till recently, construction of houses used to be a community event, mostly during summers due to cool climate, accessibility, and availability of scrub and labour. The construction materials used throughout the region are similar but their usage, composition and construction systems exhibit minor variations owing to local circumstances, needs and available resources. The architecture of the region with its local variants can be considered as a perfect example of mud/earthen vernacular as mud is used for construction of majority of building components like walls, roofs, floors, parapets, etc. as in Figure 3.

The houses are provided with dry toilet. The smokeless *chulhas* (cooking stove) with metal exhaust pipe keeps the room warm by convection and radiation of heat. Most of the settlements have electricity connections, alternative resources such as kerosene oil and solar power are also used due to its low reliability or very few hours of supply.

3.2 *Recent transformations in the built*

Tourism, improved accessibility, public policies / schemes and exposure to new economic opportunities are influencing the lifestyle, occupation

Table 2. Principles of residential architecture.

	Objective	Physical manifestation
Resist heat loss	Decrease exposed surface area	Orientation of the buildings
		Regular geometries for building plans
		Settlements along leeward slopes of hills
		Small/no fenestration on windward side
		Trees as wind barriers
		Smaller facades facing winter wind
	Increase thermal resistance	Roof and wall insulation
		Planning for buffer spaces
		Double glazing in fenestrations
	Increase thermal lag	Thick mud or stone walls (at least 12")
		Mud roofs and floors for insulation
	Decrease air exchange rate	Blankets as air curtains
		Air tight fenestrations
		Indirect access to living areas.
	Increase surface absorptivity	Dark colors and increased absorptive surfaces for interiors
		Soft and porous upholstery in interiors
	Reduce shading	No or very less shading devices
		Avoid plantations on south & west
Promote heat gain	Increase solar gain	Larger openings on sides facing sun
		Sun spaces/terraces in south & west
		Buildings with no shading devices
		Larger facades to face sun
		Absorptive materials on facade
	Heat from appliances	Cooking stove
		Solar water heaters
	Warm interiors	Curtains, carpets and furniture
	Trapping heat	Solariums & green houses in south-west
	Mutual coexistence	Animal quarters in close vicinity
		All family members residing in one room during winters



Figure 2. Interiors of local residences. (a) Living room (b) Storage (c) Kitchen (d) Prayer room (Authors).

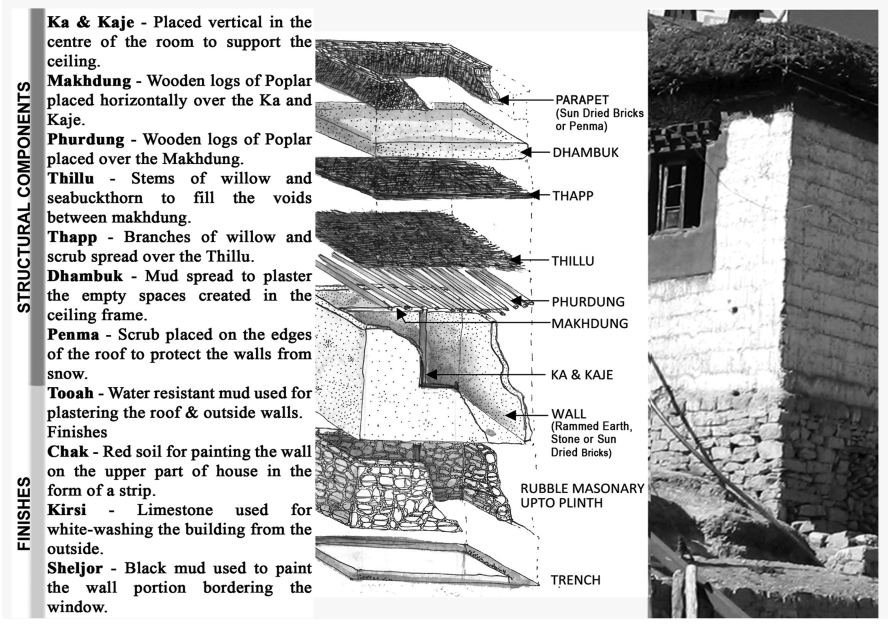


Figure 3. Construction process and building materials for a typical single storied house (Adapted from Heritage Management Team, Pragya 2005).

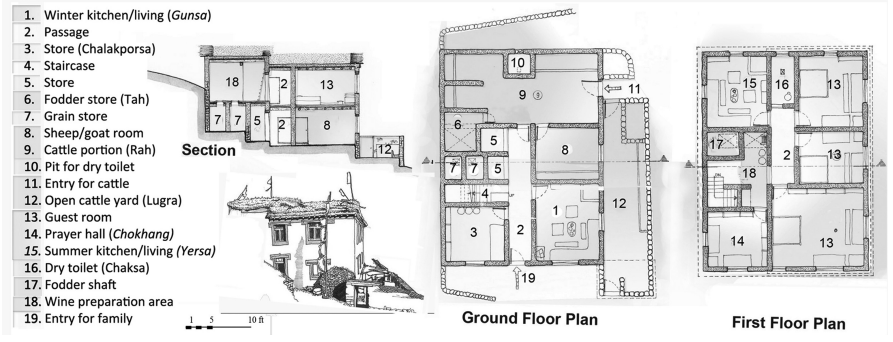


Figure 4. Layout of a typical double storied house in Demul (Meel & Nanda 2013).

Table 3. Transformations- Their reasons and impact.

S. No.	Change	Purpose	Impact
1	Settlement level		
1(a)	Introduction of Thuthulmas	Residence of younger siblings not becoming Lama.	Increase in no. of dwellings and population of settlements leading to increased burden on already scarce resources.
1(b)	Conversion to home-stays	Increased income by accommodating tourists	Rooms for home-stays have changed the layouts of traditional residences compromising with certain vital spaces.
1(c)	Construction of Govt. guest houses	For stay of govt. employees, officials and tourists.	Apathy towards vernacular construction practices serves as examples for locals to follow and are mostly against the visual character of these settlements.
1(d)	Construction of public buildings	Panchayats, schools, etc for efficient administration.	
1(e)	Coming up of hotels	Modern stay options for tourists.	These are like hotels in any other part of the world without any contextual considerations. It spoils the visual integrity of the landscape and is against the very ethos of sustainable development.
1(f)	Increase in number of restaurants and shops	Eateries for tourists and shops for locals as well as tourists.	Their placement along road leads to ribbon development of these settlements, ignoring the basic principles of orientation, thereby severely affecting their thermal performance.
1(g)	Changes in building orientation	For aligning them with access routes, etc.	The thermal performance of the buildings is severely compromised apart from damaging the visual character of the settlements.
1(h)	Increased density of buildings	Accommodating as many buildings as possible in the limited flat land available.	Buildings overshadowing each other with haphazard orientations reduce thermal performance and disturb visual character. Further, scare resources like agricultural land parcels are overburdened.
1(i)	Change in visual character	A byproduct of the various transformations	The impressive, harmonious and coherent character of these settlements is getting disturbed by haphazard incongruent development
2	Spatial layouts		
2(a)	Complex spatial layouts	To accommodate a range of functions in one building.	An increase in volume and surface area of dwellings leading to increased heat loss. Presence of habitable spaces in north and east needs additional heating provisions. Reduced thermal performance.
2(b)	Planning of rooms for home-stays	Increased income by accommodating tourists	Changed the layouts of traditional residences and compromised with certain important spaces like solar terraces, buffer spaces, etc.
2(c)	Relocation of animal quarters	Change in life style, reduced importance of livestock.	The phenomenon of collective body heat providing warmth to both humans and cattle is compromised.
2(d)	Less buffer spaces	Accommodate more rooms and changing lifestyles.	Reduced thermal lag and enhanced heat loss in individual units.
2(e)	No solar terraces		Loss of space for receiving the summer and winter sun.
3	Built forms		
3(a)	Trapezoidal walls becoming vertical	Change in construction technology	Use of RCC framed structures and brick walls impacting the appearance of buildings and their thermal performance.
3(b)	Larger fenestrations	Improved elevations, increased light indoors and view for home stay rooms.	Increased air exchange and heat loss rates, increased costs.
3(c)	Introduction of windows on all sides		Increased heat loss from north and east oriented windows. Reduced overall thermal performance of the buildings.

(*Continued*)

Table 3. (*Continued*).

S. No.	Change	Purpose	Impact
3(d)	Use of modified lintels	Ease of construction and maintenance, reduced construction time and efforts.	Impacts the visual appearance of the buildings and reduced thermal lag via concrete. Increased consumption of imported materials.
3(e)	Change in material of parapet wall		Impacts the visual appearance of the buildings and increased consumption of imported materials.
3(f)	Reduction of symbolic ornamentation		Similar visual appearance but loss of local craftsmanship, traditional knowledge and artisans. Pigments to be transported.
3(g)	Changed colour scheme	Blind imitation	Changed visual appearance of the settlements.
4	New construction materials		
4(a)	RCC	Ease of construction and maintenance, possibility of larger spans, reduced time.	Increased construction costs, material to be transported from faraway places, loss of traditional knowledge systems, need for trained workmen and reduced thermal performance.
4(b)	Steel girders		
4(c)	GI sheets		
4(d)	Double glazing	Ease of construction and maintenance, improved aesthetics and reduced construction times. Catering to changing climatic.	Increased heat gain and retention, increased costs.
4(e)	Cement plaster		Increased durability, material to be transported from faraway places, need for trained workmen and reduced thermal performance.
4(f)	Concrete blocks		Increased durability, material to be transported from faraway places, reduced thermal performance and need for trained workmen.
4(g)	Grit finish		
4(h)	Aluminium/steel frames	Ease of construction and maintenance, aesthetics and reduced construction times.	Reduced thermal lag and performance. Construction materials to be transported from faraway places, increased costs and need for skilled workmen.
5	Technological changes		
5(a)	Solar panels	Power shortage mitigation.	Increased reliability and reduced dependence on grid power.
5(b)	LPG for heating	Increased heating requirements for guest rooms.	Reduced dependence on conventional fuels but needs to be transported and stocked.
5(c)	Smokeless stove	Reduce ill effects of conventional stoves.	Comfortable interiors and enhanced thermal performance.
5(d)	Wet toilets	For the convenience of tourists.	Comfort for tourists, but water freezes during winter season leading to choking and bursting of pipes and geysers.
5(e)	LPG for cooking	Easy usage and handling.	Comfortable interiors but needs to be transported and stocked.
5(f)	Construction by non natives	Need for skilled labour and engagement of locals into other economic activities.	Dependence on outside labour, loss of traditional knowledge systems, craftsmanship and artisans. Loss of community interaction, participation and activity.

and culture of these people, ultimately impacting the architecture of the region. In this era of globalization, under influence from other styles these local practices evolved over ages are witnessing rapid transformation. The factors leading towards homogenization of architectural styles are many and vary from place to place. The most important of them are as follows:

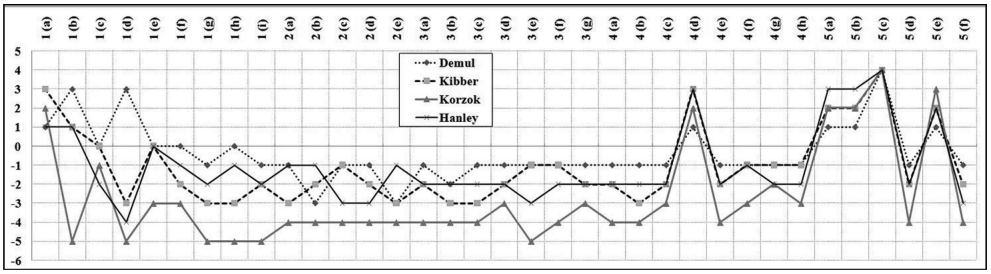


Figure 5. Impact of transformations on various settlements (Authors).

- Tourism beyond carrying capacity
- Improved connectivity of the region
- Military presence
- Construction of prototype public buildings
- Migration of younger generation
- Education
- Public policies and schemes
- Changing climatic conditions
- Other employment opportunities

The impacts are more severe near major tourist attractions like important monasteries, lakes, observatory, passes, etc. The changes, their purpose and impact on the communities surveyed through interviews and questionnaire surveys are listed down in Table 3. The occurrence of changes and the severity of their impacts are quantified on a −5 to +5 scale. A value below zero indicates a negative impact and vice versa. Figure 5 shows a graph to give a clear picture. Two representative villages as stated below each in Changthang and Spiti regions were chosen for the surveys:

- Spiti: Kibber and Demul
- Changthang: Korzok and Hanle

4 WAY FORWARD

These settlements have thrived since ages by virtue of their accumulated wisdom. Any unthought-of alteration in any of their systems may bring about spiralling changes into others and lead to unforeseen consequences. Change is inevitable for any society but at what cost and in what manner is a matter of concern. The negative externalities of accelerated tourism led growth in the region have somehow subdued their intended benefits. The impact of current tourism policies on the communities and the solutions for their holistic and inclusive development warrants for an in-depth study.

Emerging economic, strategic, political, social and environmental circumstances will certainly impact the built environment but utmost care should be taken to avoid the randomization of these impressive, harmonious and coherent settlements by incongruent development. The changes have to be selective ones with active participation of the natives, considering their social, cultural and economic values and lifestyles. The government should take lead in utilization of traditional knowledge of these communities for future construction projects not only to create employment opportunities, but also to instill a sense of pride amongst the community thus creating awareness and capacity building. Presently, the public buildings using stone, concrete and pitched roof construction are setting examples for the locals to follow. Being insensitive in its approach, the current practice is demeaning the vernacular wisdom and disrupting the visual character of the settlements.

This is just a beginning of the transforming phase of the settlements. These traditional knowledge systems will soon become extinct if not given due consideration. This paper is an attempt to understand the vernacular architecture of the region, its current state and to serve as basework for arriving at an approach for judicious and just interventions in times to come.

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Earthen heritage in the USA: Approximation to constructive techniques

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ABSTRACT: The United States of America possesses an important architectural and archaeological heritage of built earth, both major monuments and traditional architecture. The vastness of the country and the differences in climate and territory greatly affect the variety of techniques used: cob, rammed earth, adobe, wattle and daub, earthen renderings, sod, turf, tabby, etc. In addition to the different constructive cultures found in the country resulting from autochthonous cultural influences (Native Americans with their cultural differences), those imported over time by the different peoples who have settled on North American territory (especially Spanish, French, English, African, Caribbean) and the transfer of knowledge in border territories (Mexico) are also reflected in the large variety of construction processes. The study of these techniques and their cultural transfer are of great interest not only to North American researchers but also to researchers in earthen architecture, earthen built heritage, or traditional architecture in general.

1 INTRODUCTION

This text aims to present an overview of the wealth of earthen constructive techniques in the United States of America (from now on USA), and although it does not aspire to be comprehensive, it will offer an initial overall framework of the panorama of techniques linked to the geography of the country and the different local or colonizing cultures which have created a complex map over the years.

To date there is no complete work on the techniques using earth in construction, nor is there an in-depth study on the possible variants of these techniques in the USA. As it will be seen later in the text, there are, however, many scattered local studies on the techniques in some locations, as well as publications describing the constructive techniques used by natives or by colonists from different places who often used methods of their countries of origin. There is also a considerable body of research on the channels through which these constructive techniques reached and spread through North America, as well as on treatises and manuals which covered earthen construction for rural buildings throughout the 19th century, early 20th century, the recessions of the 1930s and 1970s, as well as the postwar period.

The multiple qualitative methodology used bibliography, archives and fieldwork as sources. Fieldwork focused on cases directly documented in 25 different states, as well as cases identified in the bibliography. Case studies were grouped into four broad categories, with their various constructive techniques: earth massive construction (rammed earth, tabby, cob…), earth pieces (adobe, manual adobe, clay lumps, sod…), earth in timber structures (half-timber, wattle and daub…), earth as secondary material (renderings, mortars, etc). In turn, each of these techniques can be divided into variants. This text presents the results of part of the fieldwork carried out cross-referenced with the bibliography, which has allowed constructive techniques in the territory and their current situation to be identified.

2 EARTHEN CONSTRUCTIVE TECHNIQUES IN THE USA

The USA is characterized for being formed by superimposition and often coexistence of several cultures that were local, native, or imported through the immigration over more than four centuries. Each migratory flow brought with it new colonists with their new uses and customs which included constructive techniques for dwellings. These numerous constructive cultures from Europe, Asia, the Caribbean, and Africa, were overlapped on the varied Native American constructive cultures of each place. The resulting blend of multiple cultures creates a rich panorama of techniques and variants in the use of earth in construction over centuries.

2.1 *Earth massive construction*

Massive construction is that which is executed directly on site, unlike construction by pieces which although executed on site, requires the pieces to be prepared beforehand for bonding in the wall. This group covers different techniques: rammed earth, tabby and cob.

2.1.1 *Rammed earth*

Rammed earth in historic buildings in the USA is mostly limited to the East Coast, ranging from north to south, and covers a wide range of construction periods. There have been many examples of recovery of this technique in architecture, especially from the last third of the 20th century, but they were more widely distributed throughout the country as they followed sustainability and bioarchitecture criteria.

At a historical level, the maximum increase in rammed earth construction was linked to plantation architecture or to agricultural and production needs, especially from the first half of the 19th century. This technique reached the USA mostly influenced by the treatise by François Cointeraux and its English translations (Guillaud 1997; Cellauro & Richaud 2005, 2006). The impact of construction ideas using affordable and easily accessible local materials gave rise to major experiments in construction, some of which still survive: Bremo plantation in Virginia (1815–21), by J.H. Cocke; Borough plantation (1821–24) by W.W. Anderson and the Church of the Holy Cross (1850–52) designed by E.C. Jones and supervised by W.W. Anderson, both in Statesborough, South Carolina (Golebiowski 2009). These constructions are characterized by simple rammed earth walls which were probably rendered with earth or earth and lime and later limewashed, although they are all currently rendered in cement.

This increased popularity, always linked to the world of agriculture and rural constructions in the 2nd half of the 19th century, includes the barns that can be found in the north of New York State, built on a rammed earth base (sometimes bonding agents were added) with a structure of wooden boards above (Fig. 1). An interesting example of rammed earth construction, this time in Canada, is St. Thomas Church at Shanty Bay (Ontario) (1838–1841) by Edward O'Brian, of Irish origin. This is also a simple rammed earth construction which was possibly once rendered in earth mortar with limewash or lime and earth mortar and which is now rendered in cement mortar.

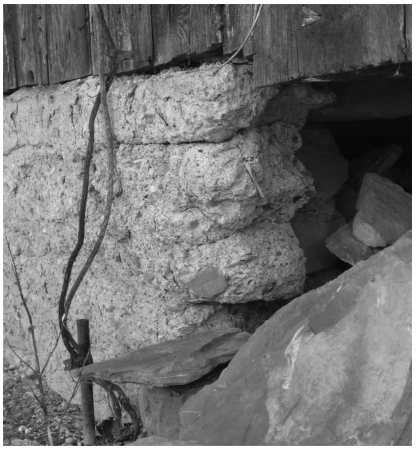


Figure 1. Rammed earth basement of a barn in the area of the Finger Lakes (New York State).

2.1.2 *Tabby*

Tabby is a unique technique included here as it uses formwork to build lime concrete walls, with a mix of beach sand, shells and the lime extracted by firing the shells (Sickels-Taves 1997). This is a mass constructive technique characteristic of the southeast of the USA and Caribbean, recorded from the time of early Spanish settlements on the east coast of Florida (Manucy 1963; Easton 1996: 7). This technique is found in the architecture of forts (Fig. 2) but is also often found in residential architecture especially in Georgia and Florida. This technique is used to build walls as well as barrel or groin vaults cast on formwork.

2.1.3 *Cob*

The presence of cob (piled earth without a formwork) in the USA is especially linked to Native American culture. The most important example still surviving is undoubtedly Casa Grande (Arizona). This imposing structure was built by the indigenous population in the 14th century (Houk 1996) in cob, although specialist literature has long been confused about the technique used (Matero 2000). The characteristic fissures caused by retraction from in situ drying of the earthen mass which makes up the various strata of cob is a phenomenon extensively described elsewhere (Van Beek 2007) and has been definitive in identifying the technique (Fig. 3).

2.2 *Earth pieces*

Techniques with pieces are those which build the walls or roofs with earthen pieces that are bonded which are prepared prior to execution. This family



Figure 2. Tabby wall in Pulaski Fort at Tybee Island (Georgia).



Figure 3. Cob degradation at Casa Grande (Arizona).



Figure 4. Fresh clay lumps bonded before drying at Barnalillo (Albuquerque, New Mexico).

includes earth loaves, clay lumps, adobe, sod and turf.

2.2.1 *Manual adobe and clay lump*

Constructions using hand-molded adobes dried in the open air or fresh clay lumps, as well as cob, can be considered mostly to predate the use of cast adobe introduced by the Spanish (Steen 1972; Iowa 1985: 14; Easton 1996). Major historical accounts are found in the literature on the expeditions of Spanish conquerors, such as *The Journey of Coronado (1540–42)* described by Pedro de Castañeda. The Pueblo peoples amazed the early conquerors with their multi-story constructions built using hand-molded earth loaves and executed using mud and ash mortar. The direct observations provided by Steen (Steen 1972) are also of great interest and describe the remains of walls built by Native Americans using hand-molded pieces (walls built by them using pieces in 'turtle-back' shape in Rio Grande Valley). The use of fresh clay lumps by Native North Americans can be seen in some constructions such as one of the kivas in the ruins of Kuaua Pueblo in Barnalillo (Albuquerque). In this case it is obvious that the earth was molded by hand in irregular shapes and bonded before drying (Fig. 4).

2.2.2 *Adobe*

It is generally agreed that the Spanish colonists introduced adobe using wooden molds into the USA (Miller 1934; Bunting 1964; Houben & Guillaud 1989; Easton 1996; Vellinga 2007). Adobe, the predominant earthen technique in the country, has been used from east to west (from Brooklyn to California, passing through Four Corners and Texas) and from north to south (from Geneva in north New York State to Tumacacori on the border with Mexico) and in a wide variety of construction types (simple dwellings as well as mansions, forts, and churches) and periods, from the arrival of the Spanish through South California and Texas in the 16th and 17th centuries to the present when adobe is still produced to repair historic buildings as well as for new constructions. The most spectacular adobe constructions in the USA include the missions in Texas (Ysleta, Socorro, San Elizario), churches in New Mexico (San Miguel de Santa Fe, Ranchos de Taos, Trampas, Truchas…), the missions in South Arizona (such as San José Mission in Tumacacori or San Xavier del Bac Mission), or forts built in the 2nd half of the 19th century such as Fort Leaton (1849), Fort Davis (1854–91), and Fort Union (1851). The size, composition, and bonds also vary throughout the country. The adobe pieces vary in size and composition. The size goes from small thick pieces of adobe ($20 \times 40 \times 7$ cm) to larger thinner ones ($25 \times 50 \times 5$ cm). In most cases they are placed in header bond although when the walls do not need to be too thick, as in the case of outhouses, the bond used is stretcher and half-header. Adobes were generally bonded using clay mortar and very occasionally lime mortar. Adobe is made of earth with coarse aggregate while the rendering uses clay and large amounts of straw (Fig. 5), while the adobe used more recently or for restoration incorporates straw in the mix.

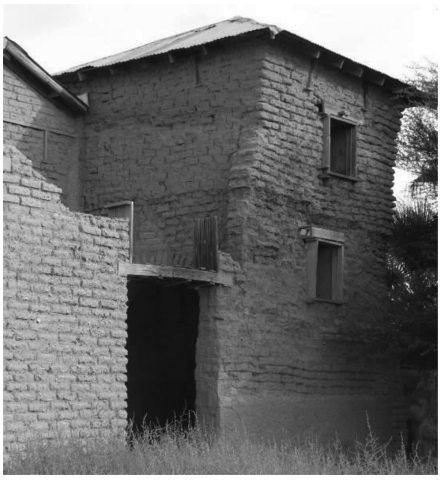


Figure 5. Adobe walls and its restoration in the Church of Ruidosa (Texas).

2.2.3 *Sod and turf*

The images of hardy settlers outside their humble sod houses in the 1880s and 1890s are well known

(Butcher 1904). Over time, those who were able to, built themselves sturdier homes in better condiction in half-timber or adobe (Carlson 1981). However, the examples that can be seen in these old photographs are very interesting, and range from simple half-buried huts or almost provisional shelter to two-story dwellings of some dignity, reflected in the aesthetic desire for composition, going from colonial homes, built in a single rectangular floorplan that could be very simple with just one room, to buildings with several rooms or groups with several simple units and functional separation between the house and stables (Mead & Hunt 2006). Sod was also used in roofs to create a waterproof layer, usually on top of the structure with logs or a combination of logs and wood boards.

The use of this technique has been identified in different states and in different periods. It is worth noting its use by Native Americans to construct earth lodges, i.e., dwellings made out of log structures sometimes quite large and covered with a layer of turf insulating and waterproofing the inside of the building (Nabokov & Easton 1989). These winter lodges (contrasting with the summer teepees) were built in villages and sometimes used as buildings for meetings and ceremonies. Many archeological remains of these dwellings can be found on both banks of the Missouri river in South and North Dakota as far as Fort Berthold Reservation. Reconstructions of quite high quality have been found on some of these sites, including On-a-Slant Mandam Indian Village and Knife Indian Village).

2.3 *Earth in wooden structures*

This group of constructive techniques includes all techniques using wooden frameworks whose voids are filled with different types of earth, like half-timber, wattle and daub, bousillage, *poteaux en terre*…

2.3.1 *Half-timber*

The constructive family defined as half-timber in the USA groups in turn several constructive techniques. Strictly speaking, half-timber, where vertical, horizontal, and diagonal wooden elements create a framework of different levels of complexity and density with voids usually filled in with adobe with different bonds or with brick or stone, was brought to the USA, to the East Coast, by migrants from England, Holland, and especially Germany from 1600 (Vellinga 2007). This technique is currently found in Minnesota, Pennsylvania, Ohio, North Carolina, etc. although in most cases the panels between the wooden structures are brick (Sickels-Taves & Allsopp 2005).

There are also other types of mixed wooden and earth structures where the wooden elements are posts set at varying distances and generally filled



Figure 6. Half-timber wall made of timber posts filled in with adobes in a ranch near Fort Union (New Mexico).



Figure 7. Half-timber made of wood boards filled in with adobe at El Peñasco (New Mexico).

in with adobe. This type of structure is frequently found in areas such as New Mexico where construction with adobe is common and is associated in most cases to the needs of single-story buildings with an enclosing wall that is not too thick and where the load of the roof rests on the wooden structure. These composite walls are usually protected by earth rendering or a wooden board structure nailed directly to the wooden posts (Fig. 6).

This type of structure is also found in North Dakota, influenced by constructions by pioneers from Russia and Germany (Carlson 1981). The same is true of mixed structures built with a framework of wood boards or logs filled in with adobe (Fig. 7). These structures are generally on the upper part of the adobe wall and are used to construct the gable wall. Finally, another technique to be included in this half-timber group is that which uses a double screen structure of wooden boards fixed to vertical posts and filled in with earth.

2.3.2 *Wattle and daub*

Available archeological and historical research (Iowa 1985; Nabokov & Easton 1989; Rohn & Ferguson 2006) shows that Native Americans used this technique to build dwellings in different parts of the country. However, given their short-lived and ephemeral nature there are few remains to be found.

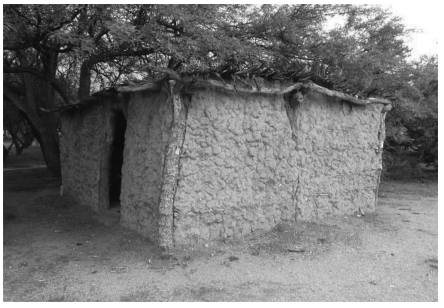


Figure 8. Reconstruction of a wattle and daub dwelling at Tumacacori (Arizona).

At present, some reconstructions such as Melhok Ki at the San José Mission in Tumacacori (Fig. 8) can be found. This small structure was rebuilt in 1997 reproducing a dwelling of the O'odham people, natives from the Sonora desert. The wattle-and-daub technique is also found in auxiliary elements of dwellings such as large chimneys or corrals.

One example of wattle and daub constructive technique is that of pit houses (Iowa 1985), dwellings built by the earliest ancestors of Native American peoples (0–700 AD). The lower part of these dwellings is underground while the upper part is a wooden-log structure covered in branches which in turn were covered with a layer of earth acting as insulation. Archeological remains of this type have been found in Mesa Verde. Unlike the earth lodges which were accessed by a side door built with logs, research shows that pit houses were accessed with a step ladder through an opening on the top.

This group should perhaps also include the constructive technique known as *jacal*, already found in Native American homes from 700–1050 AD (Houben & Guillaud 1989). This consists of a vertical structure of logs which are connected horizontally, with voids filled with cob or mud balls (Iowa 1985).

2.3.3 *Bousillage*

This constructive system consists of thinner wooden elements, squared with or without horizontal strips, and filled in with cob, and subsequently rendered in earth mortar, limewashed inside and shingle-cladded on the outside (Maygarden 2006). It is precisely this wooden shingle cladding which makes it difficult to identify these structures from the exterior of the building. This technique, characteristic of Louisiana, is derived from the French constructive technique brought by French colonists, and is influenced by native culture of wattle and daub (Blokker & Knight 2013) and the culture of West African slaves (Macdonald & Morgan 2012).

2.3.4 *Mixed constructions with logs and earth*

Mixed structures built with logs and earth are widespread throughout the USA and date back to different periods and cultural influences. In some locations it is possible to find structures with vertical posts planted in the ground at short distances (known in some areas as *poteaux en terre* due to French influence), and with voids filled in with different materials such as stone, brick, or earth (Maygarden 2006). In Louisiana, these are often likened to the *bousillage* technique but the logs are noticeably thicker and have not been carved. This section could also include the Navajo mixed constructions called *hogans*, which are log structures with an earthen cover on a wooden structure.

Finally, this group of mixed techniques with logs and earth could also include the log houses or cabins which are found throughout the country but mainly in the north. These wooden constructions can be extremely large and complex (like the hostels in Yellowstone National Park). This is especially true in less refined cabins and buildings that use uncarved logs where joints are closed or bonded with earth, wood wedges and/or mud mortar to prevent draughts. In some cases mud rendering covers the whole wall, protecting it from the elements and insulating the interior.

2.4 *Other uses for earth in construction*

2.4.1 *Renderings and mortars*

Finishes in earth or earth and straw are essential to protect adobe walls and so are always found wherever there are adobe constructions. As renderings were repaired periodically following deterioration caused by the elements, it is generally possible to find numerous superimposed layers of renderings in mud and straw sometimes limewashed inside. In places where these earth and straw renderings are still found in good condition, they are usually periodically maintained and repaired. In addition, earth renderings are also found as a protective layer or finish for stone structures, as in the case of the houses built by the native peoples in Mesa Verde in Colorado, Bandelier in New Mexico, Montezuma Castle, Navaho National Monument or Canyon de Chelley in Arizona. Some of these renderings have been painted. In some cases, structures with wooden boards or vertical logs have been discovered under these earthen renderings. Along with renderings, earthen bedding mortars are generally found in adobe constructions, and they are also commonly found with stone masonry. These mortars are generally composed of earth and fine gravel or sand and do not usually contain straw.

2.4.2 *Earth roofs*

Flat roofs of compacted earth are generally associated with adobe construction. This is the case of the architecture of Taos Pueblo in New Mexico whose uniqueness is due to its terraced adobe constructions with flat roofs, built using log structures

and a thick layer of compacted earth. In addition, as stated previously, sod roofs are a frequent feature in the log architecture of some Native American peoples and in much of the architecture of the first settlers in the central plains.

3 CONCLUSIONS

The main aim of this text is to offer a general overview of the earthen construction techniques found in the USA, reflecting the wealth of techniques and their variants and the cultural influences involved. This is without a doubt the most noteworthy aspect of this overview which interweaves culture and techniques, contributing to the outline of an extremely rich and varied heritage, virtually unknown both in its country of origin and abroad.

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SOSTierra Project. Initial results

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ABSTRACT: The aim of the SOSTierra Project (Restoration and Rehabilitation of Traditional Earthen Architecture in the Iberian Peninsula. Guidelines and tools for sustainable intervention) is to investigate the possibilities of compatible, respectful, and sustainable conservation and re-use of non monumental earthen architecture in the Iberian Peninsula, shunning standard foreign solutions and prioritizing options which respect technical and cultural diversity and the lessons in future sustainability. Traditional architecture, and especially earthen architecture, can provide important lessons for a broad concept of sustainability in the modern world. Expert analysis and evaluation of the interventions in the different fields uses a multidisciplinary methodology to draw up guidelines and a list of tools (manual, website, exhibition, symposiums, etc.) to guarantee the actual transfer of the project results to the specialists and society in general through the relevant administrations and official bodies.

1 INTRODUCTION

Earthen architecture is a major part of the monumental and non monumental architectural heritage of the Iberian Peninsula. The rich geography, geology, climate and language of the Iberian Peninsula is reflected in the wide range of techniques used in this architecture (rammed earth, adobe, framework, cob, cut earthen blocks, reeds, *launa* clay, etc.) and in the different local variants (Maldonado & Vela 1999) which are developed depending on available materials and integration with environmental and cultural surroundings (Sanz 1996). For some time earthen architecture in the Iberian Peninsula has been studied in both monuments and dwellings. However, these studies are often carried out at a one-off localized level and are rarely shared at peninsular level.

In addition, the restoration of earthen architecture has focused mostly on the restoration of monuments. In most cases, these have been localized and isolated experiences. Efforts have recently been made to combine these experiences (Mileto & Vegas 2014), within the project "Restoration of rammed earth architecture in the Iberian Peninsula. Criteria, techniques, results, and perspectives" (ref. BIA 2010–18921), funded by the Spanish Ministry of Science and Innovation (2010–13), and directed by the authors of this text. This research has provided the first opportunity to share the criteria, techniques and results of restorations carried out on rammed earth monuments, and has become a national point of reference. However, there are fewer examples of interventions carried out in the field of restoration and rehabilitation of non monumental earthen architecture in the Iberian Peninsula. These tend to be private undertakings, rarely coordinated with others, and carried out spontaneously by local specialists and companies.

Despite all the above, no systematic studies have been carried out on vernacular earthen architecture in the Iberian Peninsula to provide an overall assessment of its actual possibilities for conservation, restoration, and functional rehabilitation, or to propose compatible solutions for the recovery of constructions. It should also be noted that the restoration of traditional non monumental architecture is now subject to special attention from the Spanish Ministry for Culture which through the Spanish Cultural Heritage Institute (IPCE) and a panel of experts, has developed the Spanish National Plan for Traditional Architecture.

With this in mind, the four-year project "SOSTierra. Restoration and rehabilitation of traditional earthen architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention" was funded by the Spanish Ministry of Economy and Competitiveness (BIA2014-55924-R) and initiated under head researchers Camilla Mileto and Fernando Vegas in January 2015. The overall aim of this research is the investigation of the possibilities of sustainable restoration and rehabilitation compatible and respectful with the existing non monumental traditional earthen architecture in the Iberian Peninsula. This should avoid standard alien solutions, while favoring options that respect technical and cultural diversity and its lessons in future sustainability.

2 AIMS OF THE PROJECT

This project aims to study the current situation and restoration and rehabilitation interventions carried out to date in earthen traditional architecture in order to propose real solutions and tools for the efficient recovery of this architecture. These should take into account the needs for habitability and structural and energy efficiency, while ensuring compatibility with heritage, constructive, environmental, and sociocultural values.

2.1 *General objectives*

The three main objectives of this research project are:

1. To contribute to the valorization of traditional earthen architecture in the Iberian Peninsula as an architecture suited to the modern world, while rich in cultural, technical, bioclimatic, and environmental values. In order to achieve this general objective it is essential to research and promote this architecture on a national and international level and not be limited to localized research.
2. The main objective of the project is to encourage the sustainable conservation and restoration of traditional earthen architecture in the Iberian Peninsula. There is currently little awareness among all the agents (administrations, specialists, owners, companies, etc.) of the criteria and techniques to be used in restoration or of rehabilitation interventions that are compatible with the traditional building but also meet the current required standards.
3. To contribute to the valorization of traditional materials and techniques and their use in the restoration of traditional heritage. Traditional earthen architecture uses local materials and the traditional techniques best suited to environmental conditions and using local labor.

2.2 *Specific objectives*

The three general objectives specifically cover five further objectives:

2.2.1 *Data collection on traditional non monumental earthen architecture in the Iberian Peninsula*

The information currently available for this type of architecture in this context is currently scattered or found in general atlases of architecture. It is necessary to collect all available information, drawing up a detailed map of the techniques and materials used in this heritage and defining constructive families that are of use in the analysis and proposal of compatible interventions.

2.2.2 *Exhaustive data collection and creation of a database for interventions carried out in the traditional non monumental earthen architecture in the Iberian Peninsula*

Data will be clearly organized in a database according to constructive families and type of intervention with a view to identifying the most common problems requiring intervention guidelines.

2.2.3 *Fine-tuning and application to case studies of a methodology of analysis and assessment of the interventions*

This multidisciplinary methodology will cover the different aspects involved in the restoration and rehabilitation of traditional earthen architecture. The methodology will be applied to the selected case studies, but will also be exportable to any other geographic and architectural contexts to evaluate interventions on traditional architecture.

2.2.4 *Drafting guidelines for the restoration and rehabilitation of traditional earthen architecture*

These guidelines will be based on the results of the research carried out. The aim is to create a specific body of knowledge on criteria and techniques for intervention applicable to interventions in non monumental traditional earthen architecture in the Iberian Peninsula. This knowledge will also be partly transferable to vernacular architecture in other materials and in other geographical settings (rest of Europe, Maghreb, Middle East, America, etc.)

2.2.5 *Transmission of acquired knowledge and training professionals and students*

This knowledge will be transmitted through the different actions proposed: holding round tables and dissemination seminars, publishing proceedings and websites, books, an exhibition and any actions derived from it (seminars in masters', talks in professional colleges and schools linked to the exhibition, lectures in courses, conferences, publication of articles and book chapters, promotion of research work and doctoral theses, practical workshops, etc.).

3 PROJECT METHODOLOGY

The analysis and assessment of interventions uses a multidisciplinary analysis based on a qualitative analysis of cases studied, backed by poly-methodological data collections combining the review of all publications, the study of archives from administrations, fieldwork, compilation of catalog fiches, visits to restoration work, interviews with specialists, and experimental research in specific scientific-technical fields. Case studies were confirmed using a three-level methodology: a first level

of general study on a broad database which aims to cover as many cases of non monumental earthen architecture as possible throughout the Peninsula; a second level of case studies, only covering cases in which interventions have been carried out in recent decades; a third level exploring the different disciplines within a small sample of cases.

The first level consisted in the compilation of information from different sources (bibliography, web pages, networks, consultation with experts, etc.) and the creation of an extensive database on non monumental earthen architecture in the Iberian Peninsula. This database gathered information in the peninsular territory using a specific fiche (see point 4 of this text).

The second level focused on the analysis of intervention criteria and techniques in the intervened cases. For this, all the fiches collected to date were analyzed to ascertain the dynamics, types, criteria, materials, and techniques for intervention, as well as any problems following intervention.

Finally, the third level is a detailed study of the interventions carried out in a selection of case studies chosen from the interventions cataloged and analyzed in the first phase. These cases are analyzed from different perspectives: geographical, cultural, and architectural contexts; materials and techniques used in the construction of the building; intervention carried out according to the criteria, materials, and techniques used; structural behavior before and after intervention; climate and energy efficiency; regulations, etc.

After this analysis with successive zooms, all the data will be analyzed in detail to assess the advantages and drawbacks of each potential intervention. The conclusions will assess the suitability of each type of intervention, identifying the best types of intervention to meet the criteria for conservation, compatibility, sustainability, efficiency, etc.

The project is being carried out in parallel with other European and non-European research in countries where there is currently active policy on the restoration and rehabilitation of traditional earthen architecture, including France, Italy, United States, Morocco and Peru. The study of these situations and the results reached can be of great help in establishing the best possible approach for the problem and desirable guidelines.

Finally, the project is being intensely promoted through publications and participation in international conferences and forums, organization of seminars, webpages, etc. (see paragraph 6 of this article).

4 DATABASE FICHE

The first phase of the methodology is the collection of information through different sources, putting together a database on non monumental earthen architecture in the Iberian Peninsula. The subsequent phases are analyzed on the basis of this extensive compilation of cases throughout the peninsular territory.

The fiches used to catalog the cases in this database have been structured into six distinct blocks: a first block with general data on the building, its architecture, constructive morphology, and integration into the landscape; a second block on the environment surrounding the building; a third block analyzing the constructive techniques and variants used in the construction of the building; the fourth block is dedicated to the assessment of current pathologies in the buildings and the reasons for intervention; the fifth block, the main body of the fiches, analyzes the restoration, type of intervention and constructive techniques used in the building depending on the area intervened; while the sixth and final block features photographic documentation of the building.

5 INITIAL RESULTS OF THE PROJECT

To date over 675 fiches have been collected from forty-one provinces and fourteen communities and this data collection will continue throughout the project. The extensive database has allowed further research on constructive techniques in the Iberian Peninsula. In addition restoration actions in progress were analyzed to determine their eventual suitability and efficiency and assess what aspects could be modified to ensure better conservation and valorization of the earthen vernacular heritage.

5.1 *Constructive materials and techniques*

The initial compilation of all the information relating to materials, constructive techniques, and variants used in earthen architecture in the Iberian Peninsula was carried out to obtain geographical distribution mappings of the different constructive variants, which have been grouped by family: rammed earth, cob, excavated architecture, adobe, sod, cut earthen blocks, framework, renderings, roofs) (Figs. 1–3).

This synthesizing approach makes it possible to further examine the authors' previous mapping of the land (AA.VV. 2005, Mileto et al. 2011, Mileto et al. 2012, AA.VV. 2015), establishing correlations between techniques and variants and territorial, geographical, historical, and cultural factors.

5.2 *Intervention dynamics*

The analysis and assessment of the interventions carried out was based on a selection of interventions

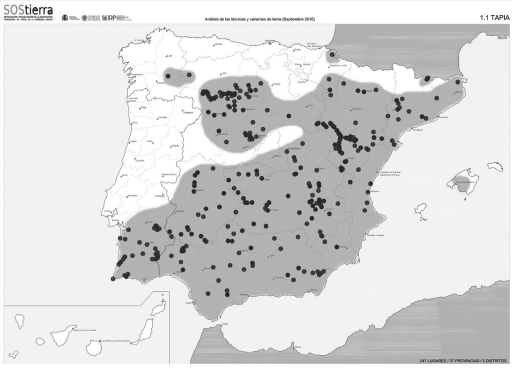


Figure 1. General geographical distribution of the constructive technique of rammed earth (data updated in May 2017).

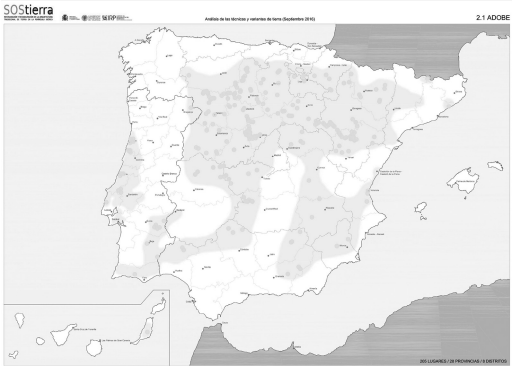


Figure 2. General geographical distribution of the constructive technique of adobe (data updated in May 2017).

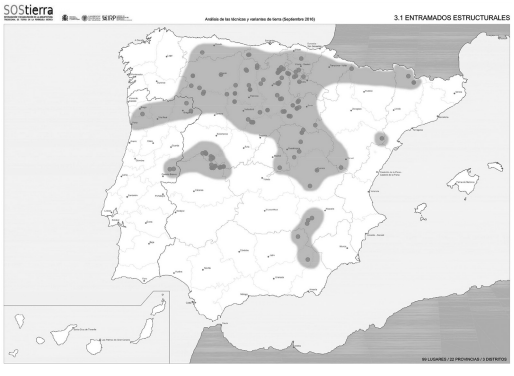


Figure 3. General geographical distribution of the constructive technique of framework (data updated in May 2017).

carried out in the 1970s and 1980s. These took the database as a starting point, at a time when there was already a break with constructive tradition. To date 125 cases have been examined. In this sample, data were cross-referenced to identify the general intervention dynamics in traditional earthen architectural heritage. The first chart of the current situation was based on this study.

The fiches produced to analyze interventions incorporate seven different types of intervention (maintenance, repair, restoration, partial rehabilitation, complete rehabilitation, expansion, demolition), as well as recording whether the intervention was premeditated or spontaneous. The interventions cataloged were analyzed in an attempt to identify the reasons for the different types of intervention in relation to the different materials and techniques. This provided an initial framework of the intervention dynamics and their motivations.

Maintenance (which accounts for 34.8% of cases) linked to buildings in use as a main residence or second home, is usually a continuum of the materials found in the dwelling, and does not involve major transformations. In general these are small interventions to repair damage, patch up the roof, paint or fix the facade, check exterior joinery, adapt bathrooms and kitchens, etc.

Repair (which accounts for 21.8% of cases) is not necessarily linked to buildings in use but is generally connected with one-off interventions on specific structural problems (cracks, collapses, deterioration of the roof) which in time would bring the building to a state of ruin. These urgent repair interventions show that the building has an owner, even if it is not used continuously or regularly.

The actions for partial rehabilitation (21%) are generally linked to chance interventions. These are mostly cases of recovery of a part of the building to be used as a store or restaurant, or as housing units on the upper stories. In addition, numerous interventions for complete rehabilitation have also been found (14.6%). In most cases these were linked to subsidies for the recovery of dwellings or rural houses or in some case to the creation of a community center.

Given their spontaneous nature, interventions for expansion or heightening (4.9%) resort to new materials without paying attention to the finishes. These interventions generally answer to functional needs such as the construction of a garage or the construction of an additional floor to extend a very small residence.

Interventions for restoration, which are very few (1.4%), correspond to exceptional situations linked to the recognition of the heritage value of the building or construction. This is the case of vernacular buildings recognized as representative elements of a past culture (Corral del Puente in Soria) or buildings which are virtually monuments such as some Andalusian *cortijos* or large country houses (Hacienda de los Maestre in Seville). There are also some cases of entire groups of buildings undergoing major

conservation and restoration action. One example of this is the village of Calatañazor in Soria, protected as historical and artistic heritage from 1962.

Finally, the cases of demolition of these buildings are almost always connected to replacement intervention (1.5%), often with neo-rural buildings which are a pastiche of traditional forms and materials using new materials.

5.3 *Detailed selection of case studies*

This first general overview has provided examples for identification and further study using a multidisciplinary methodology. As these are not monuments, there tends to be no detailed documentation for plans or construction work, which makes it extremely difficult to record the process of intervention. Studies are often based mainly on the results of the interventions themselves. Three types of examples have been selected: specific geographical regions or areas, detailed case studies of interest for the type of intervention executed, and buildings connected with specific scientific-technical studies.

To date eleven examples have been found based on the type of restoration or maintenance carried out: historic nuclei (Molezuelas de la Carballeda and Calatañazor in Castilla y León), housing that has been maintained and is in use (Béjar in Castilla y León, Serpas in Alentejo, Argamasilla de Alba in Castilla La Mancha, Feria in Extremadura), buildings restored for tourism use (Hacienda del Maestre in Seville, Corral Cañada Real de Palencia, a hostel in Avís, a restaurant in Alcobaça in central Portugal, the Casa da Rua Nova in Guimaraens in northern Portugal). These cases are being studied in detail to establish the factors which have contributed to an exemplary intervention.

5.4 *Scientific-technical studies*

Finally, numerous specialist studies have been carried out to further explore specific scientific and technical aspects in some selected cases. This final approach examines studies in structural behavior (Alonso et al. 2017), energy efficiency and bioclimatic behavior (Barbeta et al. 2017), and eventual adaptation of the intervention to regulations on accessibility and acoustics, as well as general compliance with the technical code (González et al. 2017).

This project has the necessary technology for this analysis (thermographic camera, hygrometer and dataloggers) and the cases have been selected taking into account the characteristics suitable for study (use, facade orientation, number of stories, insertion in the city) (Serrano et al. 2017).

Special attention was paid to facade orientation, which is closely linked to the use of thermal inertia in earthen walls, in the analysis of thermal behavior of the earthen buildings selected. Thus, preference has been given to cases where the main rammed earth facade faces south, receiving solar radiation for more hours of the day and so accumulating more heat, which is progressively transferred to the inside. The dataloggers were placed in areas with average shade in the facade to ensure maximum reliability of results. Thermographic cameras were also used to study the lesions visible in the earthen walls of the buildings selected, as well as latent decay phenomena in order to obtain additional information on the behavior of the building and to confirm the results of the energy simulations.

Following cross-referencing of the results, restoration proposals will be established for the earthen buildings studied, bearing in mind the consumption goals of the Horizon 2020 program, respecting vernacular heritage and showing compatibility with traditional techniques in terms of material, construction, structure, and energy efficiency.

6 PROMOTION OF THE RESULTS OF THE PROJECT

6.1 *Seminars*

To date two round tables, “Seminarios SOStierra”, have been held. Project researchers, members of the work group and many collaborators in the project took part as guest speakers. The first seminar was held at Universidad Politécnica de Valencia on 12, 13 and 14 November 2015. The second was organized at Universidad Politécnica de Madrid on 20, 21 and 22 April 2016 (Fig. 4).

These seminars have also included reflections and comparisons between the current situation in



Figure 4. Posters advertising the seminars.



Figure 5. Project webpage.

the Iberian Peninsula and other countries, crucial to the internationalization of the research.

6.2 *Webpage of the project*

The webpage for the research project (sostierra.blogs.upv.es) has been designed and set up with a description of the project and objectives, group researchers, seminars carried out, etc. (Fig. 5). The website also provides downloadable fiches in the set database format so that anybody wishing to collaborate and provide information can fill these out and send them.

7 CONCLUSIONS. RESULTS FORECAST FROM THE RESEARCH

The results of the project will constitute a scientific advance in several fields. Firstly, they will take a major step forward in terms of global knowledge of earthen traditional architecture all over the Iberian Peninsula. In addition, the analysis methodology for this traditional architecture will be improved including parameters for sociocultural, constructive, bioclimatic analysis, etc.

Secondly, major progress will be recorded in the collection of results of the interventions carried out in these buildings to date, as well as in the implications of the application of regulations in different fields. The multidisciplinary methodology for the analysis and assessment of these interventions will be a major scientific contribution.

Thirdly, the detailed analysis of the interventions will lead to progress in each of the disciplines involved (human sciences, structures, construction, conservation, bioclimate, energy, etc.), which are developing analysis and assessment protocols adapted to research in traditional architecture. Moreover, the results of this research will have major technical impact, providing tools for the administrations and specialists involved in the restoration and rehabilitation process for covering interventions in traditional earthen architectural heritage. The results—guidelines as well as a future book and exhibition—will provide basic knowledge for carrying out sustainable actions compatible with this type of heritage.

NOTE

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A method of cataloguing for the earthen architectural heritage in Santo Domingo neighborhood in Tuxtla Gutierrez, Chiapas, Mexico

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ABSTRACT: Santo Domingo is one of the oldest neighborhoods, which originated the city of Tuxtla Gutiérrez, capital of Chiapas, Mexico. It was settled in 1560 under the Spanish law for colonization in the New World. The urban grid and its dynamics remained intact until the 1940s when interests to appear as a modern city began. This along with the replacement of historical buildings by new edifications, the displacement of residential uses, and the increase of tertiary uses, broke the dynamism of the neighborhoods and the loss of identity of its inhabitants. In order to return to the roots which gave rise to Tuxtla, and in the absence of a protection model that values and recognizes its existing earthen vernacular architectural heritage, the methodology to establish a specific cataloguing system for the analysis and assessment of this heritage is proposed for one of the most devastated neighborhoods of the historical center.

1 INTRODUCTION

1.1 *Situation and geographical context*

Tuxtla Gutiérrez is the capital of the State of Chiapas, Mexico. It is located in the Central Depression of Chiapas between the Sierra Madre de Chiapas and Los Altos de Chiapas, at an altitude of 520 meters above sea level. The city is located in the valley of the River Sabinal, which until the 1960's was the northern boundary of the city, delimited in turn by the Mactumatzá Hill to the south and the Natural Park of the Sumidero Canyon to the north and east.

The State of Chiapas, located in southeastern Mexico in the area known as Mesoamerica, is currently the seventh largest state by population in the country and the tenth in area. It borders the State of Tabasco to the North, the West with the State of Oaxaca, the State of Oaxaca to the West, Guatemala to the East and the Pacific Ocean to the South.

1.2 *Settlement and urban configuration*

Tuchtlan was an indigenous settlement dedicated to agricultural activities located in a commercial crossing for the Aztecs. The foundation of San Marcos Evangelista Tuchtla, as the Spaniards named it, was established in 1560 by Dominican friars, according to the Norms of the King Fernando the Catholic of 1513. The settlements had as objective the concentration of the indigenous population for its control and evangelization (Gutiérrez Nazar 2011).

In New Spain, the first emblematic buildings, were usually those of a religious character, from which the neighborhoods are formed, with the Cathedral as the central power and other smaller churches as neighborhood centers. Thus, the first temple built in Tuchtla is that of San Marcos, by Fray Antonio de Pamplona, and later the hermitages of Santo Domingo, San Miguel, San Jacinto and San Andrés forming neighborhoods centers.

The configuration of the neighborhoods also defined their economic and social activity, for example: the neighborhood of San Jacinto, to the northeast, was dedicated to agriculture and leather tanning; The neighborhood of Santo Domingo, near the Sabinal River to the north, was dedicated to agriculture; in the south, Jocotal, to the construction and manufacture of adobes, bricks and tiles, taking advantage of the mud and the waters of the stream of San Roque (Gutiérrez Nazar 2011).

1.3 *Historical context and growth population*

In 1848, Tuxtla became Tuxtla Gutierrez in honor of Joaquin Miguel Gutierrez, a leader for the annexation of Chiapas to Mexico. And in 1892, Tuxtla became the capital of the State of Chiapas, being previously San Cristóbal de Las Casas.

With the rise to state capital, they begin to carry out modernizing projects in the city. In the 1960's, the project of expansion and paving with hydraulic concrete of the Central Avenue, the 1st South Avenue and part of the 1st North Avenue, was executed, thus demolishing in its passage all the existing buildings facades. This intervention, with procedures of *diradamento,* generated a radical change in the city and despise of its popular architecture.

In the 1970's the "modernization" of the city center was carried out, demolishing the existing monumental buildings in the central square to build new government buildings. An alternative movement called "territorial reinvolution" established the concept of "recycling of inside the city". (Mérida Mancilla, 2000). This "fever of progress" was the central theme of The Norms of Quito in 1967 (ICOMOS 1967).

By this time, Tuxtla increased considerably its population and continued this rate of demographic growth until today, becoming the city with the largest population in the State with 553,374 inhabitants. (INEGI, 2012).

2 PROBLEM FORMULATION

2.1 *The historic center and the city*

The current image of the Historic Center of Tuxtla Gutiérrez is a product of the deterioration and lack of defined character of its architecture and urban identity, due to the constant alteration of the buildings and public spaces, generating a loss of identity.

The revitalization of the Historic Center of Tuxtla and the improvement of its urban image have been central issues for the municipal government, preserving its regional and state function. Up to now, actions have been taken to improve public lighting and sidewalks. On the other hand, the rehabilitation of the old Municipal Presidential building converted into a City Museum, located in the Santo Domingo neighborhood, was an important architectural landmark and cultural focus of the city.

In 1999, the document of the Partial Planning Program of the Historic Center of Tuxtla Gutiérrez, PPOCH, was made in order to analyze and solve urban problems. However, the document has been missing essential data such as the origin and the previous transformations of the city and its buildings, the dynamics that maintains the Historic Center, as well as its values and meanings, generating changes only in transit vehicles and building height regulations (H. Ayuntamiento Constitucional de Tuxtla Gutiérrez 1999).

Thus, through the Research Project of the Master of Rehabilitation and Restoration in the Polytechnic University of Catalonian, the first step was taken to carry out a more in-depth analysis, with the evaluation and characterization of the Historic Center of Tuxtla Gutierrez using the Systemic Objective-Method of Restoration (González Moreno-Navarro 1999), to define and understand the characteristics of the environment, its historical evolution, its function within the city itself and the elements and buildings that make it up (Parra Zebadúa, 2012).

The buildings included in the category of Popular and Traditional Architectural Heritage in the PPOCH, specifically include constructions recognized as traditional or vernacular architecture by the Charter on the Built Vernacular Heritage in 1999 (ICOMOS, 1999), as local architecture with traditional building techniques.

2.2 *Vernacular architecture*

However, to date, the conventional protection models in use are not sufficient to protect these buildings. Faced with this situation, the same society tends to despise the old buildings, which translates into their destruction without any previous documentation, missing the opportunity to document traditional ways of building as well as the same local identity.

In addition, a turning point was a national movement to encourage urban development by redirecting growth vertically, including historical centers, putting at greater risk existing buildings.

3 OBJECTIVES

3.1 *Main objective*

The main objective of the research is to identify some parameters of analysis that allow us to establish a specific cataloging system for the earthen architectural heritage in Santo Domingo Neighborhood in Tuxtla Gutiérrez.

3.2 *Specific objectives*

The specific objectives are:

- To analyze the different methods of cataloging existing buildings as models of analysis of the traditional and vernacular architecture.
- To deepen knowledge of the technical characteristics of the earthen architecture and to give guidelines for future interventions in the neighborhood and in the historical center of Tuxtla Gutierrez.
- Provide guidelines to preserve and strengthen the Santo Domingo Neighborhood and, in turn, the Historic Center, as a base of local culture, to improve quality of life and the identity of its inhabitants.

4 FORMULATION OF THE HYPOTHESIS

There is a traditional architecture with specific features in the Historic Center of Tuxtla Gutierrez, specifically in Santo Domingo Neighborhood, which has not been cataloged due to the lack of a methodology that suits it.

The traditional architecture of this geographical area contains common characteristics that are identified by their ecological, urban, significant, and documentary values. Therefore, they need a concrete analysis model for their preservation.

There is the possibility of generating a specific analysis model through the use of methods of cataloging tested in other areas of study adapted to the preservation of the earthen architecture in Santo Domingo Neighborhood and later to other historical sites.

5 TEMPORAL AND GEOGRAPHICAL SCOPE OF RESEARCH

The research area is focused on Santo Domingo Neighborhood delimited to the North by the Sabinal River, to the South by the Central Avenue, the East by the Central Street and the West by the 3rd West Street, by the PPOCH.

The approximate area is 11 ha, consisting of a grid of 15 blocks square and homogeneous, with the exception of those that face the Sabinal River, coinciding with the city limit in 1892.

The buildings included in the field of study date from the eighteenth and early twentieth centuries until the introduction of new construction materials.

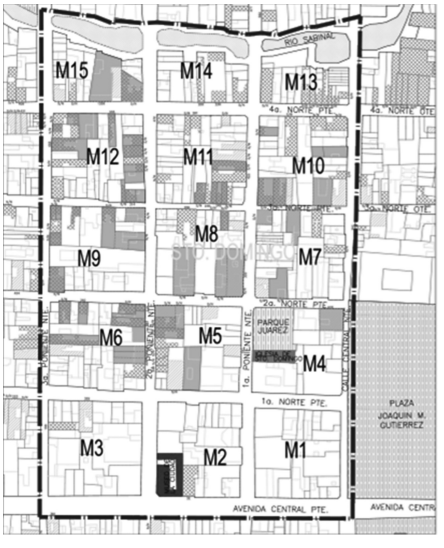


Figure 1. Limits of Santo Domingo Neighborhood and the traditional buildings analyzed (Authors).

6 STATE OF THE QUESTION

The National Institute of Anthropology and History, hereinafter INAH, and the National Council for Culture and the Arts, CONACULTA, have published the National Catalog of Historical Monuments of Chiapas (CONECULTA. INAH, 1999), which included some buildings of Tuxtla Gutierrez. Most of them were identified as Monumental and Relevant Architectural Heritage by the PPOCH, and only 16 buildings of the Traditional and Popular Architectural Heritage were taken into account, of a total of more than 1500 buildings identified. In Santo Domingo neighborhood are included the Parish of Santo Domingo and the old Municipal Presidency, now Museum of the City. The rest of the traditional buildings remain beyond all protection.

With regard to the current management and regulation of heritage in general, the difference between artistic heritage and historical heritage in terms of institutions affects the terminology used for our local heritage. The National Institute of Fine Arts, INBA, manages the buildings dated from 1900 and INAH manage buildings built with previous dates, therefore, although it was founded in 1560, the Historic Center of Tuxtla is not considered "historic" since the monumental and relevant buildings built before 1900 were replaced by new ones in the 20th century, with the exception of San Marcos Cathedral, which was also modified in the "modernization" of the city in the 1970's (Parra Zebadúa 2005).

The Construction Regulation of the Municipality of Tuxtla Gutiérrez regulates the construction of new buildings in the city and the modifications of existing buildings, being limited to building stories and minimum spaces by activities. However, it does not regulate the land occupation, building forms, building materials, or colors; giving the opportunity to generate buildings of any quality and means of construction. Specifically in the Historical Center, the height limitations are of 4 levels. No building permit is required to make a change of roofs or to change windows or doors on facades, nor even land uses.

In the State of Chiapas there is only one recognized as a World Heritage Site by UNESCO Archaeological Heritage, and four towns recognized as Magic Villages. These recognitions, especially the Magic Villages, have allowed the protection of historic sites including both monumental and traditional heritage, where Tuxtla is not included (CONECULTA. INAH 1999).

This results in the possibility of demolishing these buildings to build others without regulation of activities in the neighborhood, with the pressure



Figure 2. Example of earthen construction in Santo Domingo Neighborhood (Authors).

of tertiary uses in the first place and administrative or public activities second, affecting the inhabitants of the neighborhood by the insecurity and social problems that are concentrated because of being near government buildings and offices, such as strikes, protests, traffic and noise of public and private transport, prostitution, among others.

7 METHODOLOGY

The method used in this research has been the scientist, with the need to demonstrate the hypothesis of the existence of a living heritage in Santo Domingo Neighborhood despite the urban image, disbelief and oblivion of the local society. In parallel, the Objective-Systemic Method has been the main reference of this research to carry out the analysis and characterization of the buildings (Casals Balagué et al. 2011).

Although the research is based on the analysis of traditional housing in the neighborhood, it is essential to expand the vision towards an urban approach, as a historical urban area (ICOMOS 2011). This influences not only the deterioration of traditional buildings but also the dynamism of the neighborhood and its inhabitants. Therefore there has been taken into account urban regeneration methods for specific historical neighborhoods in difficulties and analyzed in the Research Project for the Master in Urban Design of the Polytechnic University of Catalonia (Parra Zebadúa 2005).

The main objective of urban regeneration plans for Historical Centers is to reuse existing buildings with their appropriate rehabilitation, reactivating the use of housing as a first positive impact to restore the dynamism to the historic center, seen as a neighborhood and not only as an area of isolated monuments, without falling into a romanticist sense of returning to the past, but to balance the uses of the area and achieve a integral regeneration (Cervellati & Scannavini 1976). This vision encompasses both, urban planners and restorers, and other disciplines to the global analysis of a neighborhood, which fits our objectives in this research.

In the urban interventions of neighborhoods in difficulties the participation of their own inhabitants is necessary to obtain an appropriate intervention, since they are the final users of the project. The organizations created by the same inhabitants of the place are searched and their leaders, called main actors, are contacted to facilitate the process of communication between the users and the planners of the plan.

As a first approach to the neighborhood, the Foundation of the Museum of the City and the coordinator of the Parish of Santo Domingo were contacted and they supported us to be able to contact some residents of the neighborhood.

By walking the neighborhood and with the support of students of the Faculty of Architecture of the Autonomous University of Chiapas, UNACH, we started in search of the buildings included as Popular and Traditional Architecture Heritage by the PPOCH, and identify others that were not included. However, at the beginning of the investigation, instead of the 75 listed in the document only 50 buildings were found.

For a correct analysis of the houses, the design of the cataloging sheets was determined as a document that would gather the information collected from the buildings for later analysis and evaluation.

To prepare the catalogue, we analyzed and compared different existing cataloging methods applied to the analysis of the traditional architecture specifically, in addition to analyzing the discriminants proposed by the Systemic Method and adapting them to our research and particular objectives. The catalogue should be able to gather both typological and formal information of each of the buildings, as well as include its pathology, to have a global view of the non-compliances that these buildings could have in terms of the quality of life of their inhabitants and for future interventions in the neighborhood.

Thus, by relating the different variables, it was possible to determine aspects of the construction system and its adaptation to the environment, evolutionary aspects of the way of inhabiting the spaces and the construction techniques that have been lost by the incorporation of new building materials of the last decades.

On the other hand, a survey was designed for the inhabitants of the buildings under study. It was important to emphasize the importance of the users and their own assessment of both their homes and the neighborhood, where they identify the benefits and deficiencies in order to interpret their quality of life in relation to their context.

8 THE CATALOGUE OF THE TRADITIONAL ARCHITECTURE OF SANTO DOMINGO NEIGHBORHOOD

8.1 *The cataloging system*

The cataloging sheets are organized into five sections that identify and describe each building as follows:

I. Location and identification
   a. Localization map
   b. Location
   c. Use
   d. Singularity
   e. Context variation
II. Architectural Type
   a. Description and adaptations
   b. Plans
III. Constructive Typology
   a. Vertical Construction elements
   b. Horizontal Construction elements
   b. Facade elements
   c. Interior finishes
   d. Constructive section
   e. Images
IV. Performance Evaluation
   a. Pathological lesions
   b. Images
   c. Plans
V. Annexes

Section I identifies the building in reference to the neighborhood and its immediate context, that is, including the surrounding buildings, in order to identify the physical continuity that might still exist. Also the historical and current uses of the building and recognition if any are determined.

In Section II, the architectural type defines its form and dimensions in plan and/or façade, as well as a description of the building including its subsequent adaptations and additions.

Section III, the construction materials used in building detailed, constructive section of the main facade and images are included.

Section IV, the Performance Assessment, gives us indications of the problems in the building; the mapping of pathologies and images are included.

The annexes page is included in case there is extra relevant information that is not included in the preceding sections.

8.2 *Data collection*

To facilitate data collection in the neighborhood, each building has a key, which also provides the location in the neighborhood.

A guide was made for taking data in which specifies the information to be collected to try to homogenize it and facilitate the filling out.

Thanks to the support of the professors of the Faculty of Architecture of the UNACH and their students, information was gathered. Although access to all buildings by various difficulties was not achieved, there was enough information obtained for the catalogue.

9 RESEARCH RESULTS

9.1 *Architectural types*

With the 50 buildings included in the catalog we have been able to identify three distinct architectural typologies in the Santo Domingo Neighborhood:

Type A. The most common type in the neighborhood, it has an open space of 60–80 m^2. The openings on the main façade are only a door and one or two windows. The space communicates the corridor through a door, and the corridor is open to the backyard. Services are usually located in the courtyard and the kitchen in the corridor.

Type B. The building has a main entrance that leads directly to the corridor through a central hall, in which two or more rooms are located side by side. Other rooms can be located on one side of the corridor and the kitchen and the services communicate through the corridor. The main facade has three openings, two doors and a window. The interior walls are usually made of brick. Each room or bedroom has an area of approximately 14–18 m^2.

Type C is the most emblematic typology of the neighborhood. It has three or more rooms between 15 and 35 m^2 with doors or windows open to the main facade or facades and into the corridor. The kitchen is located in the corridor and services are usually in the yard.

There are variations and adaptations in each typology depending on the number of inhabitants, or historical and current uses. Furthermore, it has been found that many of the existing buildings were originally Type C; however, they were sectioned and sold in parts, coinciding with the rooms.

9.2 *Construction systems*

The construction systems found can be classified into 4 types:

Construction System I. Usually coincides with Typologies A and B. The walls are made of adobe with a baseboard that protects the facade and cornice of brick.

Construction System II. Coincides with Typologies A, B and C. The walls are made of adobe, and the baseboard can be made of brick or stone slab. The jambs are also made of brick.

Construction System III. It is a construction system based in alternating rows of adobe and

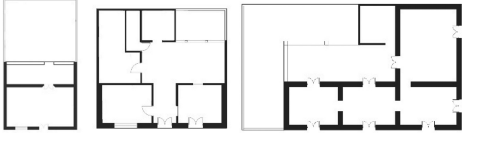


Figure 3. Schemes of the three architectural types. In order of apperance: Type A, Type B and Type C (Authors).

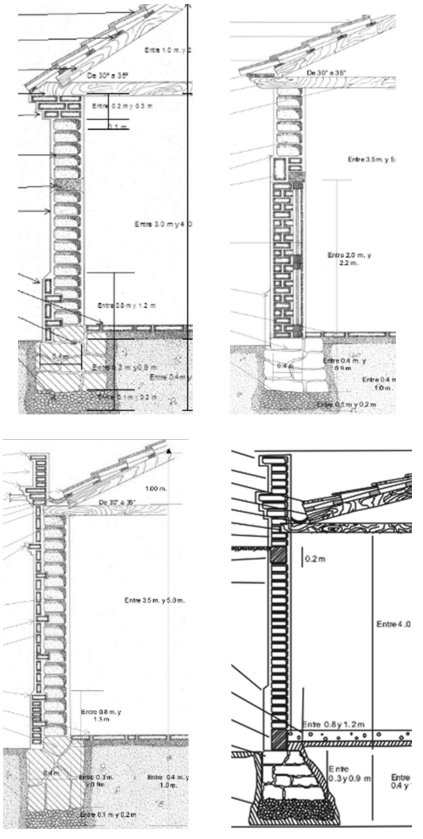


Figure 4. Construction systems founded in Santo Domingo Neighborhood. In order of appearance: Construction system I, II, III and IV (Ocampo García, 2015).

brick and ending in a parapet at the top of the main facade. The drainage system is through a chute and gargoyles out enlargement of the main facade openings, either for the entry of vehicles or to adapt the rooms as commercial premises. These adjustments are made with reinforced concrete.

10 CONCLUSIONS

The identification of architectural types and construction systems of the earthen buildings in Santo Domingo Neighborhood confirms the existence of an architecture with features in common that, although many are currently abandoned, is latent and in most cases they are still in use, they persist residential and mixed uses, which are those who favor the neighborhood's dynamics.

With the analysis made of the performance evaluation in the buildings it is possible to set future interventions for them because they share much of the pathology.

Some of the existing catalogs analyzed focus only the identification of the property, its location and its typological description; however, it is difficult to find a catalog that includes the construction system of the building or the pathology. In our case, this has been essential to a better understanding of their physical characteristics and the added value that can represent beyond its urban image, as its ecological and documentary value.

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Study and appreciation of earthen architecture in Valencia's southern farmland

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ABSTRACT: The existing architecture in the south of the city of Valencia has been determined since its beginning by the natural landform and the Albufera lagoon. Assessing the different models of the area and their structural techniques, it is worth mentioning the use of earthen building techniques. Originally, environmental conditions suggested the use of earth as the main construction material. However, the few vestiges that remain go unnoticed. This research aims to contextualize in time, type and condition all those constructions that preserve, although not in their totality, the elements built with earthen techniques: adobe, cob, rammed earth, amongst others. Besides, it looks for the reason of its former application and disappearance, replacement or abandonment of use in new construction.

1 INTRODUCTION

The city of Valencia, at present, is characterized by its limited dimensions and the area of farm fields around it. The city's socio-economic development and its immediate surroundings have not undergone major changes in the course of its history. At present, it still preserves the agricultural tradition and crop types that have defined the city since its foundation.

Flanked by the Turia River on its north side and the great lagoon of the Albufera on its south side, the city has experienced a growth clearly conditioned by these factors. The most significant expansion occurred between the end of the 19th century and the mid-20th century, colonizing both the north and south areas. Although the first traces of growth arose towards the south of the city, thereby avoiding crossing the natural boundary posed by the river, which in turn offered defensive connotations, the greater urban development took place later towards the north. This is due to the fact that the south is an area of higher flood risk, being much more affected by the successive river overflows.

For that reason, the human presence and with it the architectural, in the area known as Valencia's southern orchard, was limited until approximately the beginning of the 20th century to small building groupings whose characteristics denoted their exclusive dedication to the immediate agricultural exploitation and its associated needs, whether they were intended for housing or exclusively for storage.

1.1 *Natural environment*

The Albufera Natural Park, comprising close to 21,000 ha and located approximately 15 km south of the city of Valencia, is one of the most representative traditional humanized landscapes and of greater ecological value in the Iberian Peninsula. Included as an area of special protection both at the community and international level, it is integrated into the Geneva Protocol of 3 April 1982 as Specially Protected Area in the Mediterranean.

In origin it was a sea gulf that, with the passage of time, was closed with a coastal spit of about 30 kilometers long, formed by mobile dunes on which sits the Saler's Devesa. It is fed by fresh waters from ravines, ditches, and upwellings called *ullals*. Much of its surface is the result of anthropogenic filling for agricultural use since the environmental conditions it offers are very suitable for crops exploitation, especially rice. Thus, rice fields constitute a fundamental system for the conservation of the park's biodiversity, area known as the *marjal*.

1.2 *Vernacular architecture*

Vernacular architecture is understood as that referring to a local geographical area, to a cultural area, conceived by a certain rural society with a specific purpose in each case (Vela 2002). In this particular environment subject of study, it is an architecture dedicated to shelter the housing and work of rice farmers and to host fishermen in their origin.

At present, the industrialization of the surroundings is evident, though still the predominant image remains to be the one-family dwelling which responds to the traditional architectural typology. These dwellings are either isolated or organized as an urban set of longitudinal blocks where the characteristic unit is associated with the type of dwelling between party walls. They are a result of the evolution of the same typology.

The variety of examples we find, and that are the subject of the cataloging on which this communication is based, is governed by the same scheme, generating diversity according to style variations and certain techniques depending on their construction period.

The anthropization of this natural space dates from the 2nd century BC, having found Iberian settlements remains. But the greater permanent human presence and from which the vernacular architecture that characterizes the place originates, has its foundation in Islamic times, being the farmhouse along with the *barraca* the primitive constructions giving rise to those that we find today.



Figure 1. *Marjal* image with characteristic typological examples, the Barraca and the two space dwellings with a gabled roof example and their variants evolved to flat roof.

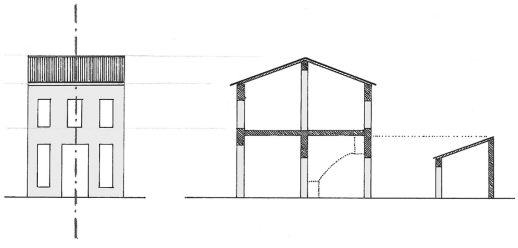


Figure 2. Elevation and longitudinal section of the two-bays and symmetry in façade type.

It is important to note that the transformation of the typology took place in a short period of time between the 19th century and the beginning of the 20th century, which in turn is associated with a substantial population growth.

The general scheme that defines this architecture is based on a single dwelling building, formed by two story areas, covered by a gabled roof whose ridge is supported by the central wall, generating small eaves over the façade walls. The main façade constitutes the compositional axis, placing the openings following a symmetry axis that, by its measures and proportions, acquires great relevance. Less importance is given to lateral walls, which are limited to enhance the main façade, thus remaining as side walls without openings, open to the possibility of hosting future extensions or attached volumes (del Rey 1998).

Materials used for this type of architecture's constructions are varied (Fig. 3). Such variety depends on the economic level of the original owners, in addition to the time period and renovations suffered.

The most abundant system found is made out of brick, used to build the three walls that define the two areas and that oscillate between dimensions of 40–50 cm of thickness with horizontally arranged $4.5 \times 24.5 \times 11.5$ cm bricks and 2–4 cm sand-lime mortar joints.

The second most abundant technique is the ordinary masonry wall with mud mortar of about 55 cm thick and that, in multiple occasions, it is reinforced at the corners and openings with brick work.

As a third technique, it could be considered the adobe work, with a thickness of 70 cm, whose pieces have dimensions of $7 \times 32 \times 15$ cm. This system, currently not very abundant, is the area's

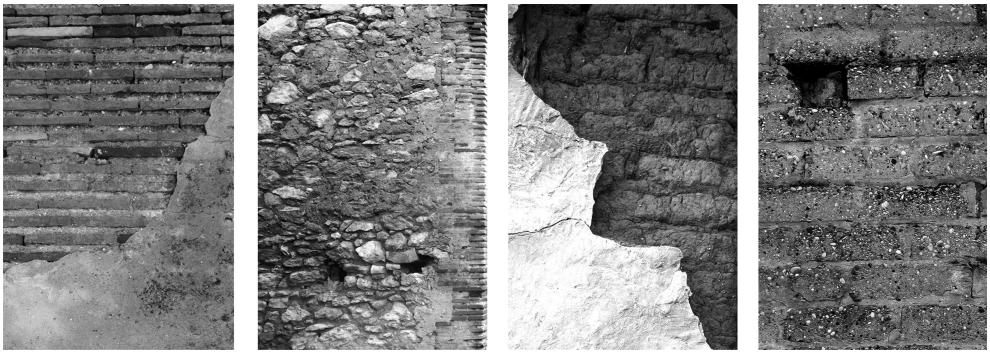


Figure 3. Existing walls variants. From left to right: Brick wall; ordinary masonry wall reinforced at corners with brick; adobe wall; lime-enriched earthen blocks wall.

most primitive construction technique. In spite of this, it is still present in many cases in buildings attached to the main volume of the house or in the formation of the wall's gable, in this case with simple brick work and stretcher bond.

Another very common technique, the lime-enriched blocks, made out of sand, beach aggregates and lime, of dimensions $12 \times 37 \times 20$ cm, is used mainly in rear walls and auxiliary constructions.

It is interesting to note that adobe and lime-enriched blocks are very similar to one another in size, joint dimensions and construction.

2 METHODOLOGY

The methodology used in this research consists of several study phases, necessary for cataloging the most significant features of the architecture of Valencia's south orchard. Characteristics ranging from operation schemes at an urban level to the compositional and constructive peculiarities, trying to determine whether there is a timeline that structures the evolution and changes experienced. The defined specific phases are the following:

1. Dimensioning and sectorization of the area subject of study. It includes urban areas and scattered architecture affected by their proximity or inclusion in the natural park and belonging at once to Valencia's municipality.
2. Compilation of available historical cartography, for overlapping and comparison in order to determine the development and urban occupation in a timeline.
3. Cataloging, by collecting all architectural and construction styles. The field work done in order to obtain this data has been carried out with the support of a data sheet (Fig. 4) including: location, type of construction according to use and morphology, conservation status, and construction characteristics of both the horizontal and vertical systems, in addition to the pathology affecting the building, if any. In this study, special attention is paid to those aspects included in the data sheet related to the analysis of the vertical construction system, which include: the type of material of the constructive elements and the joints and the dimensions and rigging, besides the use of cladding and its characteristics. In this way, data providing an overall vision of each existing building is collected.

From the different study phases, those cases where constructive systems use earth as predominant material are selected. Constructions made out of earth as the only material in the same structure are scarce in number, although this material is usually combined with other systems, which are

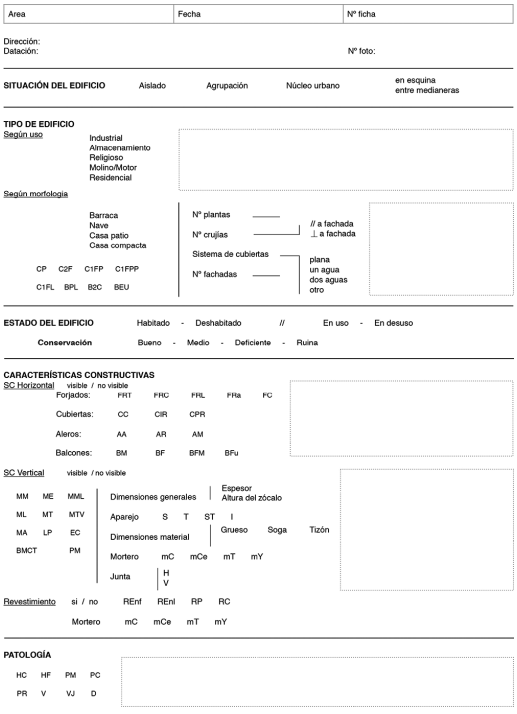


Figure 4. Data sheet used to cataloging.

usually the result of the replacement of the original earth building system.

For the comprehensive knowledge of each case, it was very important to count with the inhabitants of the place personal testimonies, which helped to clarify both the various modifications suffered over time, as well as how they had been carried out. This fact turned out to be essential in those cases where the good state of conservation of the building prevented gathering most of the data to be recorded, the great majority of them relating to the construction system.

3 PRIMITIVE TYPOLOGY

The *barraca* is a type of construction that we can find throughout several Valencian regions, being an evolution of the traditional cabin/shelter. But the image that it offers is identified as a representative symbol of the central region of the Valencia's orchard where they were found in greater number (del Rey 1998).

3.1 *Form and function*

The function of this type of structures is determined by the needs of those who inhabit them.



Figure 5. Barraca placed in "*Antigua Carretera de El Saler*" with approximately 300 years old and a good state of conservation (García 2012).

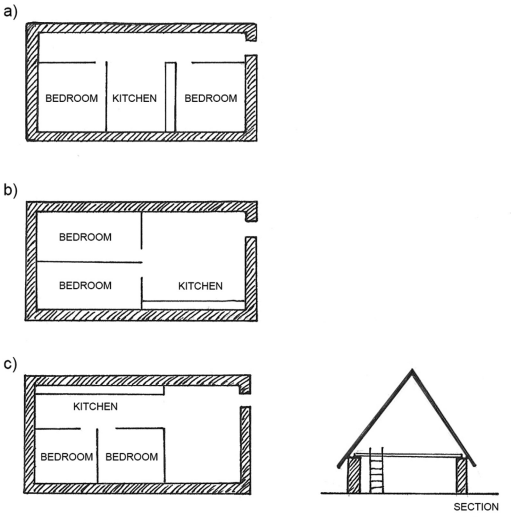


Figure 6. Three ground floor basic distribution schemes: a) With lateral corridor; b) Divided into two modules; c) With main room and kitchen in corridor facing bedrooms. Scheme in section the space division.

Therefore, their shape responds to a characteristic scheme in dimension and orientation.

With a dimensional relationship in ground plan of 1/1.5 or 1/2, its surface ranges between 50 and 70 m^2. Its most outstanding feature is the sloping gable roof whose ridge follows the direction of the longest length in plan.

The orientation to which they respond puts the ridge line in the east-west direction, placing the main access in the east elevation. This orientation does not happen in a random way; as an inherited characteristic of the primitive shelter huts, it obeys an attempt to orient them in a favorable wind direction, the east winds being the predominant of the area.

As for the interior, it is usually divided into two levels. The ground floor is dedicated to housing purposes such as bedrooms, kitchen and living area. By means of an intermediate forging that divides the volume enclosed by the perimeter walls and the cover, the second level is intended for storage and specific needs related to the activities carried out by its owners.

The ground floor may follow three basic distribution schemes (Fig. 6):

a. With lateral corridor
b. Divided into two modules
c. Combination of the two previous schemes

3.2 *Constructive system*

The immediate surrounding determines the basic materials used in these constructions, which are essentially reeds and mud. In addition to the reeds, wheat straw and *borró* (*Graminca, Amophila arenaria*), are also used as vegetal material, all of them found in the vicinity of the Albufera and the *marjal*.

For the construction's supporting base (the perimeter walls) adobe work is used, sometimes supplemented or reinforced with firebricks. For the manufacture of adobes, special molds are used to shape the mud and straw mixture, where the mud is basically composed of clay and water. Once the mixture is unmolded, it is allowed to dry in the sun for one to two weeks. The blocks are used to execute walls of between 50 and 120 cm (García 2012) of thickness employing the same mud and straw mixture used in the adobes as joint mortar, so that the final result of the wall once dry is of a homogeneous materiality. For better joint and corner reinforcement, reeds are arranged between courses in a horizontal position.

For both the execution of the gables and the interior partitions, reed thatch panels reinforced with the same mud and straw mixture are used. These surfaces are also treated with a mud coating in order to provide a smooth surface finishing.

All these vertical walls are finished with a coating of lime that serves to protect against the possible degradation caused by rainwater, among other atmospheric elements.

For the construction of the roof, a structure is built formed by a *carena* beam that constitutes the ridge's axis supported by *costelles* (ribs) that form the roof's slope and lean on the *cadarsa* beams that are placed directly on the wall as a perimeter tie beam. This substructure is covered with twisted reed panels on top of which the *borró* is attached constituting a superficial and impermeable layer that prevents water infiltration to inner spaces.

3.3 *Evolution and reuse*

The *barraca* typology does not experience great variations and changes in its constructive system, as opposed to what respects to its material composition. This only happens in the constructions made in the last decades following the same typological scheme.

A regulation passed at the end of the 19th century as a result of several fires occurring in *barraca* groupings at different locations, prohibited their construction and repair. This fact, along with the incapacity of the structure's evolution, which would allow adapting to the new needs brought by the socio-economic growth and the industrialization of the zone, gave origin to the transformation producing the most abundant architectonic typology found at the time, the two space dwellings.

The impossibility of repairing the structures, especially the roof, and the need for development, imposes the change of typological scheme on its owners and inhabitants. The transformation of the *barraca* into a two-story structure covered by a flat or gable roof of much smaller slope, made both stories useful for housing purposes. The need for storage that was previously solved by the elevated space within the *barraca* is resolved by auxiliary constructions attached to the main volume or isolated ones located in the immediate surroundings. Under these specific conditions, advantage of the adobe perimeter wall is taken to expand, generally using a different material system, that is, completing the volume employing ordinary masonry or brick work and homogenizing the entire wall surface usually by applying a coating of lime mortar.

On the other hand, although the new constructions started to be built using materials not so closely linked to the immediate natural environment, such as brick in the first stages of transformation, the use of adobe walls as a construction system is still frequent although relegated to the construction of auxiliary volumes of lesser entity and importance. This fact is assumed to be due to the immediacy and economy of the system.

4 CONCLUSIONS

At present, the natural park is highly valued at both ecological and cultural levels. The same applies to the *barraca* as image and representative scheme of the Valencian agricultural society. Conversely, this fact is not reflected in the architectural element itself, since many structures collected in the cataloging made just four years ago are, at the time of this writing, highly degraded or in a situation of ruin (Fig. 7). This fact being a clear reflection of its lack of maintenance and appreciation since there is no legislation regulating its conservation.

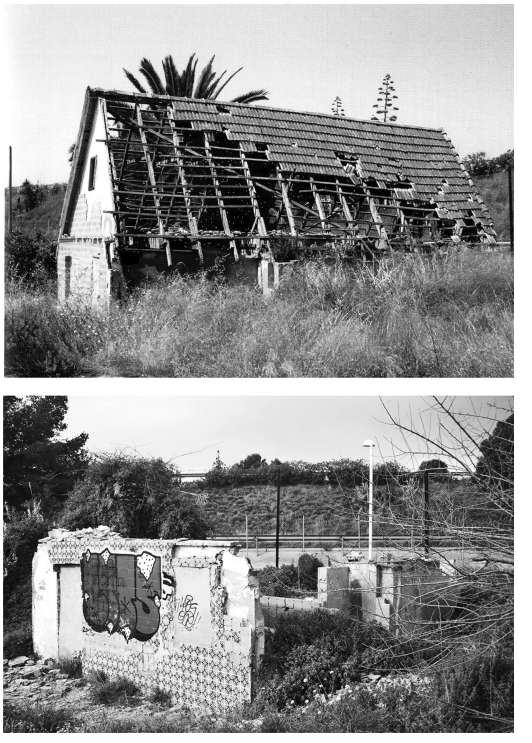


Figure 7. *Barraca de Flores* placed in district 10: La Punta. Upper image: *barraca* state on sheet 09 of "*Catalogo de Valencia y su entorno*, 2012"; Image below: *barraca* state in January 2017.

As far as the primitive constructive system is concerned, something similar happened over the course of time. Consequently, the abandonment of the technique has resulted in its lack of knowledge. Although the system is still recognized by this area's older inhabitants, its disuse has resulted in a lack of understanding and value by subsequent generations that they have come to believe that its replacement by contemporary systems and materials is much more favorable for the structures than their repair and/or maintenance.

In general terms, the different schemes of vernacular architecture found in the subject of study area do not have adequate recognition by their inhabitants as architectural elements. The value given to them, in most cases, depends on the sentimental component attributed to them as ancestral homes. As a result, when the construction is no longer inhabited by the family of the original homeowners, inadequate modifications or transformations are introduced, causing prejudice to the construction itself.

In spite of all this, many vestiges of this architecture are still present. Hence, its valorization is more than necessary. This means that not only its degradation is interrupted, but knowledge of the techniques used is spread and the benefits it could possibly bring to new constructions are studied in addition to assessing the most appropriate tools for adequate repair and maintenance.

It should also be noted that modest valorization effort would be widely accepted by the inhabitants of the area of study and can be easily assessed. Proof of this is the recovery, entirely by means of traditional techniques, in the last years of one of the auxiliary constructions also very characteristic of the area: wood-burning ovens. This has occurred by a revaluation of the primitive techniques for bread baking. This could be considered, and encouraged, as the first step towards the appreciation and recognition of the use of vernacular techniques.

NOTE

All photos belong to the author.

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Mestizo and hybrid typologies. Vernacular rural housing in Colombia

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ABSTRACT: Traditional typology of vernacular rural housing in the central area of the Andean Highlands of Colombia is suffering irreversible changes. As a result of the transculturation process between Indigenous and Spaniard elements, it was one of the most representative examples, remaining unaltered for nearly four centuries. However, recent modifications in the functions and ways of inhabiting spaces, and the introduction of industrialized materials used for building houses, mainly promoted by State policies and a price increase of raw materials, have lead to a process of change from the original mestizo to a hybrid typology. Some older elements have been preserved, but at the same time new ones have been introduced in the last twenty years; this is an ongoing process in the area of study, where in the recent past several elements mentioned in the ICOMOS' Charter on Built Vernacular Heritage were easily recognizable, but today have mutated.

1 TYPOLOGY: A TOOL FOR THE STUDY OF VERNACULAR RURAL HOUSING

Several authors mention typology as a tool for the analysis of the internal structure of buildings, architectural design of new ones and urban planning. Although the efficacy and pertinence of this concept has been reappraised in recent decades in relation to the last two topics (Montaner 2011), its utility has been demonstrated in the study of traditional architecture, particularly for the Andean region of Colombia.

According to Guerrero Baca (1995), the elements that define typology are function, form, building systems, semiotic and location. This also works as a tool for a diachronic and synchronic architectural analysis.

As a diachronic analysis tool, it has demonstrated that vernacular rural housing in the area of study has remained hardly unaltered for the past four centuries, and only recently it has in fact suffered transformations. As a synchronic analysis tool, it has revealed the type of changes every house has had, in comparison with others from the same historical period.

In sum, typological analysis allows a comparison between houses built in a specific time as well as the study of their evolution over the years, verifying this type of architecture is the best example of the material culture in societies (Woodward 2007), and an always evolving product.

2 THE STUDIED AREA

Arcabuco, Gachantivá, Ráquira, Sáchica, Sutamarchán and Tinjacá, are municipalities conforming an area of approximately 686 Km^2, located about 120 Km north east of Bogotá, Colombia's capital. This is a zone recognized throughout the country by its cultural and natural heritage.

This area came to be inhabited a few centuries later than its neighboring territories. It has been proposed that a pre-Hispanic indigenous population settled c. 400 BC (Langebaek 2000) in a region characterized by its dry lands, scarce fertile valleys and high mountains.

Contact between natives and Spaniards in the sixteenth century originated a process of "Transculturation" (Ortiz 1983), resulting as can be seen even today not only in vernacular rural housing but also in other aspects of the inhabitants' daily life as music, food, dressing, language and religiosity, among others.

The principal economic activity has been agriculture, which has changed from low scale and assorted crops, to high scale monoculture in recent years. So, not only recent interventions in the vernacular rural housing with new volumes are modifying the landscape, but also new forms of agricultural production.

2.1 *Geographical environment*

The Andean region where the six municipalities are located have altitudes varying from 2200 to 3400 meters above the sea level, allowing the coexistence of three life zones: Dry Forest, Rain Forest and Wet Forest. The concept of life zone (Holdridge 1987), defined by vegetal associations existing in a specific area, has been applied successfully to the analysis of inter tropical zones of America and is referred to a relationship between bio temperature,

precipitation and potential evapotranspiration, as well as soil compositions, and which contain several ecosystems within each one.

In this case, these life zones define the existence of specific raw materials traditionally used by the inhabitants for the construction of their houses; despite typological similarities in their form and spatial distribution, the variety of vegetal fibers, woods and clays exploited in each life zone (varying from scarce to high humidity), have generated an interesting esthetic repertoire in a relatively small area, which can be demonstrated in different clay colors and wood textures, among others.

2.2 *Demographic patterns*

According to the Population's National Census of 2005, there are 28,500 inhabitants approx. in the studied municipalities; in contrast with the rest of Colombia 70.16% of them live in rural areas. Datum from the 2014 National Agricultural Census (CNA by its initials in Spanish) report that 22.5% of the homes are occupied by a single person and 50% of their inhabitants are 60 or more years of age (above the national average), in contrast with a 42% of the population under 15 years old. The average of inhabitants in each dwelling is barely 2.91, and only 63% are occupied permanently (under the national ratio). In this region a similar percentage of women and men inhabit the houses.

An analysis of this information allows establishing a progressive tendency of abandonment of rural areas by its inhabitants, encouraged by Colombia's historical economic politics linked to harsh conditions in agricultural production (Fals Borda 1973). This situation has encouraged the migration of the working force to the big cities, in search of better jobs and wages, thus leaving the care of vernacular rural housing to the elderly and adolescents, with a strong impact in the permanence of traditional building systems, the survival of the traditional way of living and their maintenance.

2.3 *The houses*

According to CNA's datum there are 7891 houses in the municipalities' rural area, and currently the great majority of them combine the use of raw and industrialized materials. A total of 97 domestic buildings, with an antiquity varying between 3 and 120 years were documented between December 2014 and May 2016 in different life zones: 35 in Dry Forest, 42 in Rain Forest and 16 in Wet Forest. Another criterion of selection established that each house should have at least one volume built with traditional techniques.

According to datum from the fieldwork, 78.5% of the houses are occupied permanently, 9.7% are occupied temporarily and 11.8% have been abandoned. 80.65% of the dwellings have incorporated industrialized materials to an old volume or have been used in new ones.

Because of interdisciplinary characteristics of this research, it was necessary appealing to methods and theories of architecture and cultural anthropology (González 1971). On one hand, it was used the comparative case study and the typological analysis; on the other hand, elements of ethnography (Hammersley & Atkinson, 2014) were applied in the field work with the assistance of local inhabitants (performing as mediators) to achieve the closeness to houses' dwellers and owners.

3 MESTIZO TYPOLOGY

As a result of the transculturation process, in which combining features from two cultures can also vary according to the life zone, mestizo typology of vernacular rural housing has remained unaltered for about four centuries, since the arrival of Spaniards to this area in the sixteenth century. On the one hand, techniques like stone and adobe masonry were incorporated, as well as the houses rectangular form and the functions of spaces have persisted until a few years ago. On the other hand, raw materials and techniques like wattle and daub were incorporated to the building systems' repertoire, while Indigenous labor was used by Spaniards to spread this type of architectural expression.

A similar pattern of spatial distribution, materials and built systems can be found in municipalities surrounding Bogotá and in the Colombian southwest zone, nearing the border with Ecuador. Nonetheless, particular features of raw materials used in the area of study give vernacular rural housing of this area a singular aesthetic expression.

Oral transmission of knowledge (Anderson 1999) has been the best way of preserving mestizo typology. In this case study, each house represents a document that has enabled the transference of typological related information from generation to generation, although slightly mutating with every new building.

Accordingly mestizo typology reflects a pragmatic and experience based wisdom, and it is one of the best samples of popular knowledge through time. As well historical photos of the area of study attest a limited typological variation between dwellings built in the nineteenth century and even those built at the end of twentieth century, when industrialized materials were introduced.

3.1 *Location*

Environment defines greatly the way a house is located in a particular life zone (solar orientation,

topography, presence or absence of nearby streams, vegetation, availability of raw materials). Similarly factors as presence of nearby roadways, property division, neighborhood relationships and possibility of economic activities in the property have broad influence in house's location, and are reflected in the volumetric configuration and in the use of interior and exterior spaces. Property's access location, dwelling's visibility, existence of water reservoirs and their size, a certain type of farmyards and home orchards and farming location are fixed after a previous evaluation where traditional knowledge does not leave anything to chance.

For example, an inclining topography determines that some dwellings are to be formed by at least two volumes, in contrast with those located in flat lands, where it is easier to group all the spaces of the house in a single volume.

A dispersed settlement pattern appears also as a product of transculturation, when indigenous groups begun to leave the fertile valleys after Spaniards' arrival by several reasons, and settle in mountainous areas, scarcely inhabited before the sixteenth century (Langebaek 2000).

3.2 *Materials and building systems*

Throughout the centuries, inhabitants of these municipalities used raw materials from their natural environment to build their houses. Until recently straw, clay, stone, vegetal fibers and wood were the main supplies used in building techniques like wattle and daub, adobe or stone masonry and roofing.

Traditionally, building materials and systems are an indicator of the homeowner's income, as well as the stage of the house's construction process.

Frequently people with low income use wattle and daub and stone masonry; as money is available, adobe masonry replaces ancient walls and clay tiles the thatched roof. This fact confirms theories that establish a direct relationship between regional economy and architecture (Fonseca & Saldarriaga 1980).

Fieldwork datum proves that 88.1% of the dwellings have at least one volume built with adobe masonry versus 20.4% built with wattle and daub walls whereas 12.9% use stone masonry (it is common that a house composed by several volumes may present two or more building systems).

Traditional builders are hired to direct the building process, which in many cases includes all the family members' performing different tasks, like preparing and kneading mud or tying wood. Traditional builders can still be found in the municipalities of Sáchica and Ráquira (where raw materials and traditional building systems are still in use), while in the other municipalities they are already elderly or have passed away.

3.3 *Spatial distribution*

The limited repertoire of forms in vernacular rural housing hides a broad versatility in adapting its spaces to the uses homeowners requires. A spatial program, as in building traditional techniques, also results from a matured knowledge's corpus (Caniggia & Maffei 1995).

Vernacular rural housing is composed by generic spaces, distributed in two simple patterns that differ by the presence or absence of a covered gallery. When two volumes form a dwelling, possibly an inherited indigenous pattern (Boada 1999), the kitchen occupies an entire volume while other activities take place in the other. Houses with a covered gallery are located in all life zones, while houses without it are located mainly in Dry Forest.



Figure 1. Mestizo typology in the municipality of Tinjacá. In this case the kitchen (left) is separated from the bedrooms' volume (right) (Yarleys Pulgarín 2016).



Figure 2. Mestizo typology in Ráquira. The oldest volume (left) keeps its original thatched roof (Yarleys Pulgarín 2015).

3.4 *Uses of the space*

As a generic container of activities, vernacular rural housing comprises a repertoire of spaces determined by the uses given by its homeowners according to their experience and needs. Scholars as Fals Borda (1956) have mentioned some uses, such as shelter, resting, subsistence, defense and privacy as the house's main psychological functions, and social, religious and work place as their secondary functions. In this sense, spaces like the bedroom, kitchen, deposit, gallery, farmyard and exterior zones have been fundamental in the houses' spatial configuration, but with time these functions and the houses interior and exterior uses have changed because of the loss of some of them or the addition of new ones.

3.4.1 *For sociability*

By its function, the covered gallery is used for rest and dialogue during workdays, and even for food consumption, thus becoming one of vernacular rural housing's most important spaces, and also its principal façade. Additionally, in those houses where complementary economic activities are carried out (for example knitting), the gallery is used as the homeowners working place.

3.4.2 *For resting*

This is the house's most private and intimate space, used by their inhabitants mainly during the night, therefore, lighting requirements are minimal and remains closed all day. Here people usually place photographs of beloved ones, worship objects, wardrobes, and keep calendars of past years and even children's toys. It becomes a significant place to know the beliefs, affections and practices of its occupants.

3.4.3 *For cooking and feeding*

In the absence of a covered gallery, as it happens in some dwellings located in Dry Forest, the kitchen is another important place for social activities inside the house. This is a space not only for cooking and feeding, but also for sharing.

As associated spaces, the home orchard and the farmyard provide a broad part of the familiar basic feeding needs, functioning as well as a repository of local species traditionally used for cooking and medicinal purposes.

3.4.4 *For hygiene and cleansing*

Before the appearance of bathrooms, some personal hygiene activities took place in the covered gallery; in some houses utensils like mirrors, combs and toothbrushes are still visible in this space.

On the other hand, washing of clothes and cookware is done in a simple wooden shed or a stone structure with a small water deposit, located in nearby zones of the house; in Dry Forest, shortage of water forces to build bigger deposits, which have become an important factor in the house's spatial organization.

3.4.5 *For storing*

Agricultural activity requires a space where produce, tools and supplies can be stored, but it is not used during all the year. If there are not crops in the property, it can be used as a guest room, or a deposit for furniture or raw materials.

4 HYBRID TYPOLOGY

Theorists as García Canclini (2011) propose hybridization as a process linked to the irruption of modern era elements that changed traditions. Hybridization materialized in vernacular rural housing by the implementation of State policies, through the increase in cost of raw materials and access to cheaper supplies, and with the improvement of municipal rural roadways and the population migration process.

Raw materials and traditional building systems historically have been considered as a source of poverty and illness by the State (Fals Borda 1956), underestimating their cultural values and discouraging their use among the people. It is therefore argued that the State has been one of the main hybridization agents in this zone of Colombia.

The State has then influenced vernacular rural housing's mutation from mestizo typology to hybrid typology through its municipal house improvement programs in three ways: building of sanitation facilities, replacement of raw materials mainly in roofs and floors, and building of complete volumes. Design quality and number of beneficiaries can vary according to the limited budget of each local administration, so there is not a unique architectural design for all the municipalities.

On the other hand, in private initiatives of home improvement, road construction and increase of cost of raw materials have favoured the irruption of industrialized supplies, which are cheaper, durable and of easily maintenance in comparison with traditional ones.

It is remarkable that 80.6% of the houses visited during field work have one or more volumes built or "improved" with brick walls and/or asbestos cement roofing. But as García Canclini states (2011), hybridization is a two-way road. While increase in cost of raw materials has compelled most of the traditional population in rural zones to use cheaper supplies, newcomers with higher incomes use raw materials to build their country houses; and frequently it is an architect who designs them.

Progressively social memory, so important for mestizo typology of vernacular rural housing in

the area of study, has been replaced by decisions or design choices made by third persons outside the community, that traditionally built its dwellings and kept a close (though not necessarily mandatory) link with the natural environment.

4.1 *Changing process of typologies*

Dwelling improvement State policies and private improvement initiatives have resulted in the addition of new volumes, originating unusual spatial distributions and uses of spaces inside traditional vernacular rural housing. The earliest changes occurred with the introduction of the bathroom, an elementary volume nearby the principal volume, equipped with basic hygiene facilities.

Later the change was reflected in the use of building materials, in which raw materials were replaced by industrialized ones, specifically straw and clay tiles by asbestos cement or zinc sheets, and earth floors by floor tiles.

A third modification consists in new volumes built with industrialized materials, replicating consciously or unconsciously some traditional spaces (as the covered gallery) and adding new ones (as the bathroom) in a single volume. When homeowners introduce these new materials, most of the customary uses of spaces are preserved. However, inhabitants complain about lack of thermal comfort because of clay bricks and asbestos cement roof sheets' physical properties.



Figure 3. The original volume has been transformed by its owner, to the point that it is unrecognizable (Yarleys Pulgarín 2015).



Figure 4. New volume built with industrialized materials, keeping traditional distribution of spaces, such as the covered gallery (Yarleys Pulgarín 2015).

A fourth change is related to new volumes built with unusual spaces added and customary spaces disappearing; this is the most drastic modification, as it changes the ties of the inhabitants and their built environment. In cases of extreme alteration, generally introduced by State home improvement policies, inhabitants reject the architectural proposal and remain in their old dwellings, even in precarious or risky conditions.

The death or illness of elderly inhabitants, who have been traditionally linked to the care of home orchards and farmyards, has as a consequence the disappearance of this type of spaces, threatening also the food security of neighbouring people in the area.

4.2 *Substitution of uses of spaces*

As well as the previously mentioned aspects, processes such as migration to the big cities, use of electrical appliances and new technologies are changing the form inhabitants experience and use spaces inside and outside of their houses. On the one hand, as agricultural activities decrease or disappear, one of the characteristic spaces inside vernacular rural housing, the grain deposit, is changing its original use to guest room, tools or furniture deposit. In contrast, spaces usually present in urban dwellings, such as the living room or the dinning room, are appearing especially in those houses with high-income homeowners.

On the other hand, but no less important, the use of satellite television antennas, washing machines, gas stoves and refrigerators are changing dwellers habits of resting, cleansing and cooking, reducing or lengthening the time destined to housework and of stay inside certain spaces. Profound changes result in adapting the entire old building as deposits or guests rooms, moving other uses (socializing, resting, cooking and cleansing) to the new buildings made with industrialized materials.

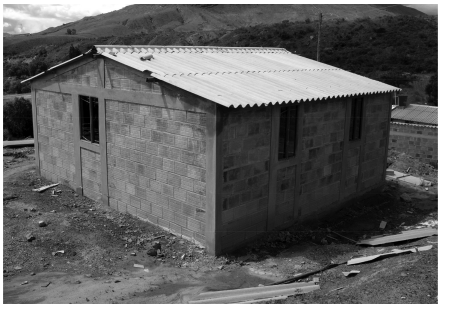


Figure 5. State's housing improvement project, using industrialized materials and suppressing traditional spaces (Yarleys Pulgarín 2016).

4.3 *Modifications to the house's external appearance*

As industrialized materials irrupt, wood is replaced for iron, clay tiles for asbestos cement roof sheets, soil for floor tiles, adobe and wattle and daub walls for brick and lime for cement. At the same time, the house is no more a reserved and introverted place. Wooden windows and shutters are replaced by iron and glass materials, panes are enlarged and elements as curtains make their appearance.

Houses formerly camouflaged with their environment now progressively attract attention to them in the landscape and mark a difference with it.

Changes of typology turn vernacular architecture in an object of observation instead of an inconspicuous structure embedded in the landscape.

5 CONCLUSIONS

Vernacular rural housing, as a product of cultural interaction between the native population and Spaniards and conforming a mestizo typology in this zone of Colombia, has several cultural values. Irruption of a hybridization process marks a new era that has left behind a rich period of transculturation, cultural exchange, creativity, closeness to the surrounding environment and transmission of knowledge from generation to generation. Mestizo typology is not only a way to name an architectural structure, but denotes a whole ensemble disclosing the rural way of life.

Vernacular rural housing's mutation toward a hybrid typology leads to propose an alternative definition of Built Vernacular Heritage as a dynamic architectural expression, necessarily open to the introduction of new materials (as homeowners are using cheaper supplies) but preserving local community participation in its design and building process, as some theorists propose (Ettinger 2010).

In this area of Colombia individual improvement initiatives and well-intentioned State housing improvement programs, are threatening the preservation of this type of architecture's cultural values. State policies that guarantee better economic conditions for agricultural production and stop the population's migration process, as well as stimulate self-repair and adapt older structures to new uses (even using industrialized materials), instead of demolishing or abandoning them, could be the way to reconcile the traditional values with the inevitable arrival of globalization.

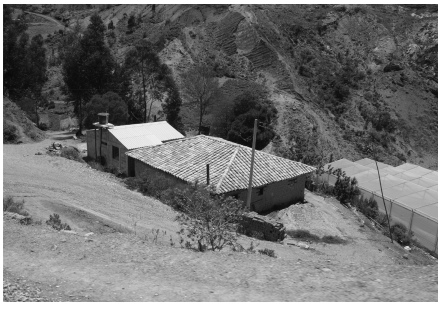


Figure 6. State's housing proposal next to a traditional dwelling. Inhabitants are moving their activities to the new one (Yarleys Pulgarín 2016).

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Mexico's central area earthen architecture. Rammed earth construction: Use and technique

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ABSTRACT: In Mexico, earthen construction techniques were improved during Colonial era as part of culture fusion and cultural melting pot; a mixture between Spain's techniques and indigenous labor. The use of rammed earth was not as spread as adobe and framework. Nevertheless, it has been identified in Mexico's central area, where this research was conducted. In this region, several factors influenced the use of rammed earth, such as weather conditions, water scarcity, raw materials availability and worker's skills. The present research evaluated the technical, constructive and morphological characteristics of rammed earth in Mexico and identified some of its peculiarities and differences, which correlated with the technological development of the region. These characteristics were strongly influenced by environmental and historical conditions. Overall, we propose that this characterization could lead to a more realistic and objective perspective of the built heritage, contributing to a sustainable architecture approach.

1 INTRODUCTION

Architectural rescue and heritage protection are highly related to the interpretation given to its historical, aesthetic, cultural and technical qualities that make them particular items.

Destruction of earthen heritage in Mexico has not been due to a lack of control mechanisms, but mainly because of lacking the appropriation of expressions that bind us with the historical memory that is reflected in the populations and their buildings.

The use of rammed earth has been relegated, suffering a mimicry inspired by foreign models, techniques and materials which homogenize, but above all, generate the loss of their authenticity and its unmistakable and typical demeanor.

Another important factor in the modification of the technique can be seen in the changes to the typology of the site, propagated by the populations' seek of modernity. In this context, the symbol of modernity implies using new constructive materials that rapidly deteriorate heritage.

Nowadays, we face new problems related to technological innovations in production and exchange systems.

Urban-regional economy is influenced by the model of the international economic markets.

Rammed earth conservation can be initiated through a systematization of the methods of intervention, which should be preceded by a thorough research study, considering its position on the territorial context, typological aspects, singularities, formal qualities and constructive particularities.

It is important to emphasize that the aim is not to force to build with constructive and formal characteristics of traditional architecture, but rescue their spatial, formal, technological and material characteristics; in order to define the basis for the contemporary architecture to respond to site's cultural heritage.

1.1 *Objectives*

Preservation and rescue of the heritage starts from identifying the traits and techniques that characterize the architecture, which can be the technical and conceptual bases for both, their rehabilitation and alternative integration development on cultural and natural environment.

Objectives: identify the constructive system as part of the cultural heritage and develop a conservation criterion to promote their future significance.

In addition, we seek to define their formal and constructive characteristics.

The present analysis resulted in the identification of the particular characteristics of the rammed earth constructive system in the central area of Mexico, Moreover, it assessed the most appropriate way to meet the conservation, maintenance and sustainability needs; and to build up criteria to incorporate the design into contemporary buildings.

1.2 *Methodology*

The objective of the restoration consists of the conservation of the building characteristics, which transmit and boost its recognized values.

Restoration must be understood as a complex project process (Mileto & Vegas 2014).

It should follow a methodological procedure providing the necessary tools to achieve the most appropriate solution.

These guidelines generate the linking of the historical representation and building measurable values, with the current needs and habitability.

The process proposed rises different work phases, which together form part of the initial process for conservation of architectural constructive and heritage:

1. Documentary study. Data collection of pre-existing information of traditional *in situ* techniques, homing social and historical values reflecting the ideology and political, cultural and economic growth at a given time.
2. Historical and geographical framework. Spatial reading of the territory and of the geographic features that give materiality and definition to the object of study. Each place has its complex forms, according to the particularities of the area.
3. Conservation and restoration. By defining the material qualities, it is possible to identify any present pathology and generate a reference framework for possible solutions. We seek to maximize its use and not only limit it, but give it a value for their energetic properties.

2 CONSTRUCTIVE CHARACTERISTICS OF RAMMED EARTH

Earthen construction techniques were improved during Colonial era as part of culture fusion and miscegenation; they are a mix between the methods from Spain and indigenous labor.

Rammed earth usage did not have a great diffusion, as was the case of adobe and frameworks; however, it has been possible to identify the use of this technique in Mexico's central area (Guerrero 2014). Some examples are located in the states of Puebla and Tlaxcala.

2.1 *Geographical location*

Some factors involved in rammed earth usage are climate, lack of water, existing raw material in the region and ability of the worker's skills.

Mexico has great mountain chains that limit the geography of the country; central highlands have a height greater than 2,000 m above sea level.

This phenomenon causes a predominance of temperate climates although it is in tropical and subtropical latitudes (Fig. 1).

In the central area of the country due to the existence of the equatorial convergence zone, the rain and dry seasons are well defined, causing that most of them are pitched.

This factor generates changes in rammed earth usage; to obtain adequate slope on the cover, two rows of adobe are added on one of the walls limiting the space (Fig. 2); in addition, the existing vegetation limits the availability of construction materials.

2.2 *Rammed earth in Mexico*

In Mexico's central plateau, rammed earth walls have been identified in chapels, churches, convents, haciendas and cement and traditional houses.

They are one or two-level buildings, managing to survive despite local climate conditions and seismic activity in the area.

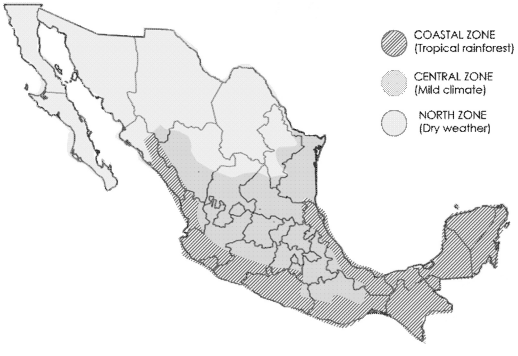


Figure 1. Schematic map of climates in Mexico in three main areas, based on V. Prieto book of Rural Housing in Mexico.



Figure 2. Rammed earth wall in Calpan (L.F. Guerrero).

Unfortunately, there are neither accurate data, nor enough studies to precisely date rammed earth architecture. However, it is very likely that several of the buildings correspond to the colonial era.

Studies carried out by L.F. Guerrero propose that the constructive processes in the region suffer from shortcomings in their sizing and structural performance (Fig. 3), especially if they are compared with rammed earth buildings of European tradition.

These deficiencies may have limited the development of the technique in the rest of the country for it did not have the same dissemination as adobe or *bajareque,* that were systems technologically improved by the Spaniards. Thus, it is necessary to study and record rammed earth constructive tradition, in order to identify its formal, functional and material characteristics.

Rammed earth in Mexico raises several questions, particularly with regard to its origin and level of dissemination. Prehispanic cultures knew about the technology of compacted earth; however, rammed earth wall constructive devices (*tapiales*) have not been documented until now.

2.3 *Constructive process*

Depending on materials, particular needs and labor, variants in rammed earth wall construction are endless. However, in Mexico, technological development was limited, so it is not possible to notice the presence of different typologies of rammed earth as is the case in Spain.

- Foundation. It is advisable that the walls are seated on a stone or brick base that protrudes 0.30 m from ground level, fostering the evaporation of moisture from soil water table and avoiding the ascension by capillarity. In some cases, there is not a stone foundation, yet because of the good quality of the material they have been preserved.
- Formwork. Containing earth forms are similar around the world, although there are variations depending on the development level achieved through the technique. In this case, it is made with wooden planks, fixed by a series of stakes nailed to the ground, reinforced by the *horcones* and struts tied with ropes of *ixtle* and *maguey* vegetable fibers (Hernandez, 2002).
- Rammed earth making has a small variant; the walls do not have the mark left by the needles, for the formwork is hold through struts leaned in between the rammed earth device and ground. (Fig. 4).
- Compaction. Within formwork, artisans receive baskets of earth, which slowly spread with their feet, for compacting it by layers or *tongadas* ranging from 10 to 30 cm thick.
- On the walls outside face, a plaster is spread through a lime and clay grout, or lime mortar—thin sand or ash.

2.4 *Technical characteristics*

In order to determine the constructive and particular elements of the rammed earth, a constructive characteristics and technique analysis—consisting in essential component abstraction by comparison and principles of organization present on a regular basis, in a series of study subjects—is proposed.

This theoretical and creative activity can define a system of conceptual relations yielding a first approach to the main variants of the technological system. Results will be crucial to have a first approach to the techniques and establish the order of its components, and their main technical and constructive characteristics.

It is necessary to organize the data, so it we had to make work sheets. The steps in this process are the following:

1. Literature research, 2. Site approaching, 3. Sample collection, 4. Photograph analysis, 5.



Figure 3. Housing with rammed earth walls and pitched cover. Area of the central highlands (LAB 2016).

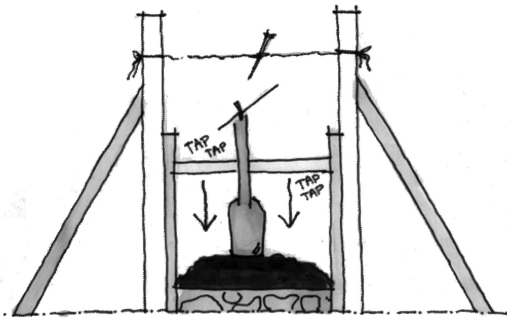


Figure 4. Representative sketch of a rammed earth (D. Romero-Olguín).

Sample comparison, 6. Main technical and constructive characteristics, 7.Sketch of observable details, such as conclusions of the previous analysis where the most significant traits identified, taking into account there are always guidelines outside the norm and not necessarily exclude other patterns that do not follow the same formal process.

From examples observed in the Mexico's central area, we obtained the following characteristics that give shape to the tradition of the constructive technique of the place.

Basically, rammed earth usage spread among population to use it in bordering and closing walls; inside, a mixed system with adobe walls was used. In some cases, houses were closed to the outside, taking as the only open span the main access; indoors towards the patios with some windows (life was carried out outside) (Meraz & Guerrero 2011).

Regarding rammed earth in larger-scale buildings, for instance churches, haciendas and public buildings, its characteristics may vary in proportion and size.

The analyzed constructive characteristics—seen throughout several cases—were as follows:

- Stone masonry foundation. Usually found in large format architectural ensembles, as churches, haciendas and buildings of some importance. In some cases, foundation stretched out of the floor level up to form the baseboard. These walls could have wide up to 0.60 m.
- Same material foundation. Extension to the rammed earth wall basement, with the same existing section. This type of foundation was frequently used for the construction of housing and perimeter walls. Approximate measures are 0.40–0.50 m, with stumps of approximately 0.80 m, but can vary depending on the width of the rammed earth wall.
- Rammed earth with adobe wall finish. This is the most consistent and more peculiar characteristic. Due to the climatic conditions and periods of heavy rainfall, the roofing presents slope in approximately 15% of the cases. These slopes are oriented towards the inside. Slope is achieved through the incorporation of adobe rows in the wall cope (Fig. 5).
- Wall coping. Due to rammed earth wall characteristics, it is necessary to protect it from the weather and rain. In its crest, some protective element is built; it can be stone masonry, cobble stone or brick and lime mortar (Fig. 6).
- Span system. Wooden, brick and/or stone lintel. Windows open toward the inside, by boring technique. Rammed earth walls were pierced with chisel and hammer; through a horizontal line that enabled a wooden lintel to be fit a test hole was made. Once it was placed, the window was bored through and was given rectangular or square shape characteristics. Carved stone or plastered brick lintels were used.
- Plastered coating. Coating applied on the facades; it has an even finish and better looking. It was applied in two or three layers and lime mortar (Fig. 7).
- Lining plastering. Covers the facades and serves as protection against weather. Rough finish, immediate application. Made of lime mortar or lime and clay; ashes can be added, resulting in a same tone finishing and protective coating.
- Rammed earth wall sections. Due to the great heights of the hacienda walls and religious buildings, the approximate thickness of these walls was 0.80 m, but it could also vary according to the lining. It was and is not possible to build walls of more than three blocks due to region seismic characteristics.

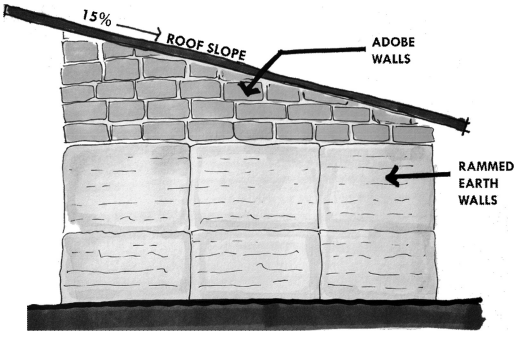


Figure 5. Schematic sketch of work. Rammed earth and adobe wall finish (D. Romero-Olguín).

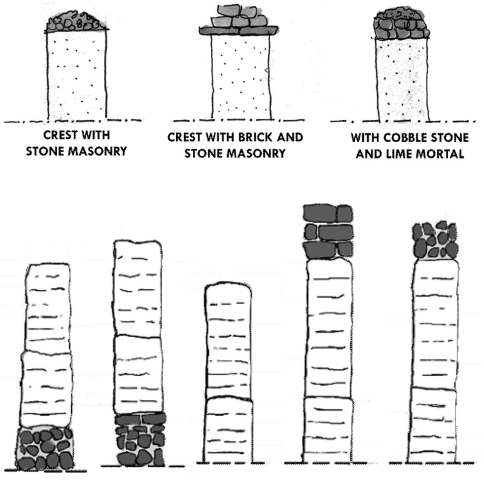


Figure 6. Schematic drawings. Rammed earth walls and wall coping (D. Romero-Olguín).

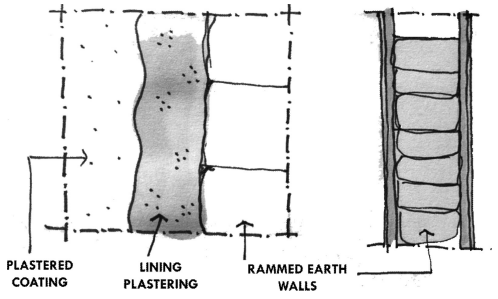


Figure 7. Schematic drawings. Coating details (D. Romero-Olguín).



Figure 8. Rammed earth in Calpan (L.F. Guerrero 2009).

- Enclosure walls and traditional housing have a lesser thickness, approximate section varies from 0.30 up to 0.50 m.
- Rammed earth inner sections. Most of the thickness of earth layers or *tongadas*, vary from 0.20 to 0.30 m; it is very difficult to establish a precise measure of the *tongada* size. This shows that they can vary according to the site and the characteristics of the soil.
- Rammed earth block size. It is not possible to standardize measures, for they vary according to the constructor, technique and land; thus, reference measures were identified. In traditional houses and perimeter walls, blocks used to give the heights were usually two rows of height. In public and religious buildings could be up to three rows (Fig. 8).

  Blocks 1. 1.00×2.00 m long.
  Blocks 2. 1.80×1.80 m long.
  Blocks 3. 1.00×1.50 m long.

- Joint placing. Rammed earth wall is monolithic; however, due to its construction system it seems it is a rigged wall, divided by large block sections. To have greater resistance it must have discontinuity in the rig.
- Joining of two walls. Due to the continuity of primer on the rammed earth blocks, wall joints may have structural problems in the corners; if there is no overlap, there can be cracks because of the horizontal thrust.

3 CONCLUSIONS

Studies on conservation of earthen built heritage in Mexico are relatively recent and are at an experimental stage. Therefore, there is a need to deepen the understanding of this technique to rescue and preserve the earthen architecture heritage still remaining. The knowledge of the traditional architecture techniques could facilitate their recognition as a valuable architectural, artistic and cultural asset.

The aim of this research was to identify the formal characteristics of the rammed earth technique in the central area of Mexico by analyzing the technological aspects and the characteristics of the traditional architecture. In addition, we characterized and classified the conditions influencing the decay of the structures present in the region. We showed that most of the damage to the built heritage occurred due to the lack of understanding and the failure to integrate the technique into the current constructive systems.

It is important to note that this work represents the first stage into deepen the understanding of this technique. The long-term perspective seeks to build up a framework to promote the appropriate preservation, restoration and maintenance of this ancestral and relatively unknown technique.

Study of the zone's characteristics allows us to understand the importance of local events that occurred as fundamental part of the site's processes of construction, whose consideration makes possible to understand the urban transformation faced by rural populations. Above all, foresee the conditions that may threaten the preservation of their heritage values.

The analysis of these constructive techniques, as is the case of rammed earth, may be a tool to undertake a more realistic and objective perspective of the built heritage. In consequence, this will narrow the idealistic concepts that are normally the result of subjective visions and that usually are not in agreement with the community.

Based on this technological analysis, we confirmed that the characteristics of the technique adapted to the natural and historical conditions *in situ*, resulting in an optimal architecture from a sustainable perspective. Therefore, it is important to consider that the design of new spaces, the rescue and preservation of built heritage must be a constitutive part of the sustainable development and evolution of a community.

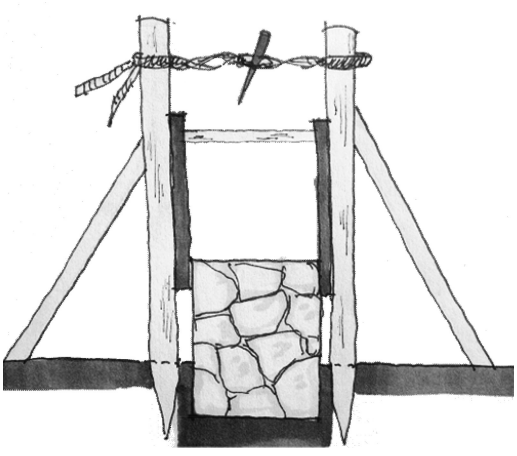


Figure 9. Schematic drawings. Stone and rammed earth rammed earth foundation (D. Romero-Olguín).

This analysis intends raising awareness of the need to incorporate every historical, social and natural elements, as part of cultural heritage, to traditional architecture, regardless of the scale or the predominant materials. In Mexico, the main objective would be to rescue and preserve the remaining buildings constructed using the rammed earth technique.

ACKNOWLEDGMENTS

Particular thanks to Dr. Luis Fernando Guerrero Baca for providing the facilities for the development of this research work. Likewise, to the Traditional Construction Systems and Procedures Laboratory, F.A. UNAM, for allowing the use of some of its pictures.

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Domestic wineries in the Urz-Vidriales countryside (Spain)

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ABSTRACT: In the north of the province of Zamora (Spain), vineyards have been traditionally maintained by farmers to produce wine on a small scale. Wineries were built for the preparation and preservation of the wine. In this article, it is explored the main features of a representative winery, focusing on such aspects as location, space distribution, ground plans, the construction process, and the tools and auxiliary devices used. The materials as well as social aspects (such as the rural lifestyle) allow these wineries to be considered an example of vernacular architecture, as defined by the PNAT.

1 INTRODUCTION

In the Urz-Vidriales region of the northern part of Zamora, subsistence agriculture based on the cultivation of cereals (including wheat, rye, and barley), wine, flax, fruits and vegetables, combined with the use of forest resources and shepherding, has been practiced for centuries (Hernando 2007).

The people who live in this region had to diversify their activity in order to survive, and so they took advantage of their natural and cultural environment.

Historic accounts (Respuestas 1750) reveal the significance of the cultivation of grapes from as far back as the medieval times, at least, to produce wine. A part of this wine was for personal consumption. The rest was used to trade in local markets, allowing the farmers to improve their domestic economy.

In this study, they are examined the wineries that were built to produce and preserve the wine by the peasants of the Urz-Vidriales valley. To our knowledge, there are no existing scientific studies published on the traditional architecture of this type of winery in this Castilla-León region (Benito 2014).

To prepare this work, they were visited fifteen domestic wineries in the villages of Brime de Urz and Cunquilla de Vidriales. The owners explained the denomination, management and the winery's elements to produce wine, as well as constructive aspects which were transmitted by ancestors. The latter information was contrasted with that of other elderly neighbours who still preserved relevant memories.

2 A DOMESTIC WINERY

2.1 *The site*

The traditional winery is constructed by excavating into the ground. The purpose of the structure is, on the one hand, to shelter the necessary mechanisms and tools used in obtaining the wine and, on the other hand, to preserve the wine over a period of time (usually, a year) in appropriate conditions, at a nearly constant temperature and humidity (Cañas 2009, Ruiz 2011). With this in mind, in choosing an appropriate location, several aspects must be taken into account.

Wineries are built in clay mounds in order to avoid direct contact with the water table (Fig. 1), and also so as to be easy to dig while being durable over time. Due to its hygroscopicity, the clay, out of contact with the air, remains moist, facilitating the excavation. When the digging is finished, the clay surface becomes dry and firm.

2.2 *Description of sections*

The winery is distributed into different section seach of which is used for performing a separate function. In Figure 2, a schema showing the simplest and most frequently found typology for these sections is provided. The cave is divided into four main areas connected by a corridor (*callejón*). At the top of the figure, it is observed the winepress (*lagar*), a reasonably large area where the grapes are pressed. Next to it, one can see the grape juice



Figure 1. General view of Brime de Urz wineries.

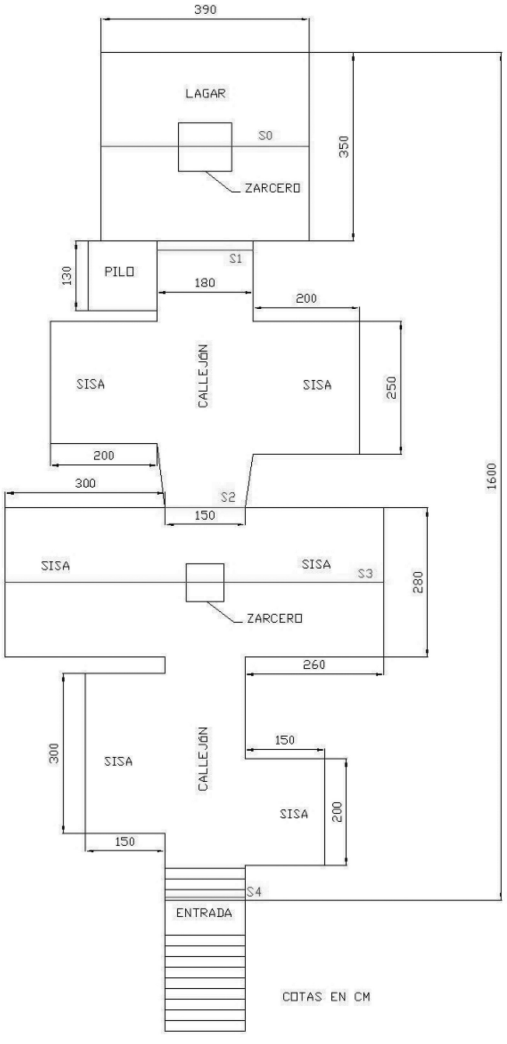


Figure 2. Ground plan of JM Winery.

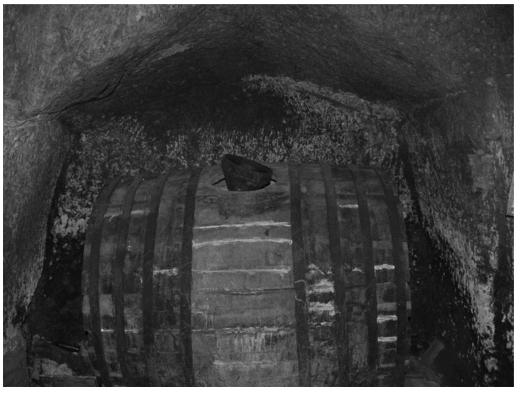


Figure 3. Lateral chamber and barrel.

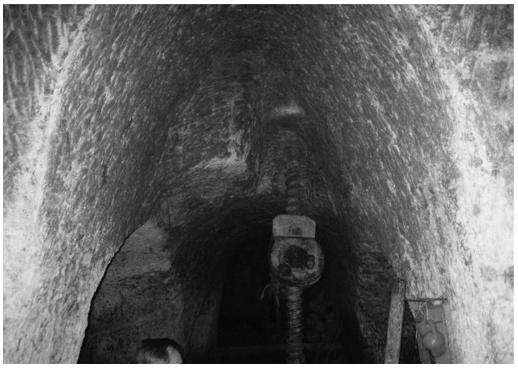


Figure 4. Winery ceiling.

vessel (*pilo*), with its floor at a lower level than that of the winepress, so that the grape juice (*mosto*) can flow from the winepressto the grape juice vessel through a small channel (*canaleta*), usually dug into stone. To the left and right of the corridor, there are several chambers (*sisas*, Fig. 3) for housing wooden barrels used to preserve the wine, although some of them could also be used to store auxiliary devices related to the grape harvest. Finally, at the bottom of the figure, it is located the entrance with steps leading into the cave. Movement from one area to another is achieved by tunnels in the shape of French or round arches.

The walls preserve the original marks of the pickaxe used in their formation. The cave's ceiling (see Fig. 4) generally has a rounded form and appears at a variable height between 2 m and 3 m, except where there is a hole in the ceiling, termed *zarcero* (sections 1 and 3 of Fig. 2). The hole is similar to a square chimney between 5 m and 8 m in height (from the ground level), and in shape it resembles a pyramid trunk. In general, each cave has two holes, both of which are used to illuminate and ventilate the interior, while the wider of the two is also used for dumping the grapes into the winepress. To allow for this task, it has a kind of grille made of wooden sticks at the top. Depending on the type of winery, the grapes being dumped into the winepress can hit the beam (*viga*) or pile up just beside it in a small place called *lagareta*. Usually, the beam is a poplar tree trunk placed along the length of the winery (Fig. 5).

The cave described here is a simple one, but there are caves that are somewhat different. For instance, when the ground conditions did not allow the cart carrying the grapes to approach the hole over the winepress, the cave was usually made in the shape

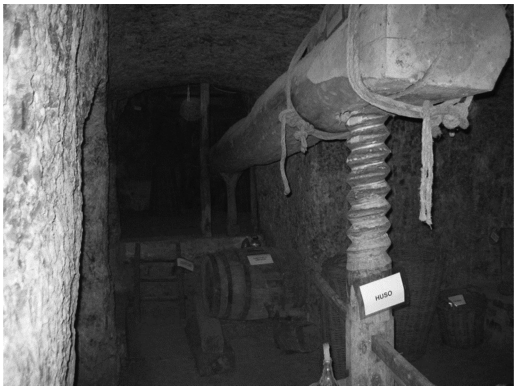


Figure 5. Beam and screw.

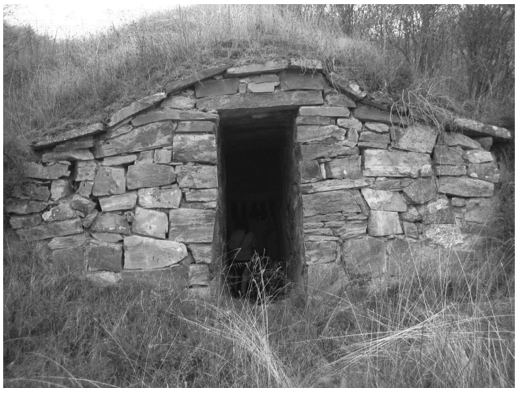


Figure 6. Entrance in a longitudinal winery.

of an inverted U.Typically, one of the sides was used for the placement of stairs, with the door at the corner of one end. The other side formed the main part of the cave, with the winepress at the bottom. With this geometry, it was impossible to insert the beam through the corridor. In this case, it was necessary to make a horizontal borehole a few metres below the ventilation shaft exit hole that is over the winepress,in order to insert the beam. This was only possible when the cave was dug into the side of a hill.

In some instances, two or three caves share the same entrance corridor. In the case of two caves, one beside the other, the beam was inserted through holesin both caves using the procedure described above. In still other cases, there is a second or third cave in front of the corridor, which was used to insert the beam into the cave on the left or right side of the corridor, making a provisional hole between the cave at the bottom and the lateral cave. The caves that share the same corridor at their origin probably belonged to the same family. This allowed them to save space and labour.

The façade of the entrance of all wineries as well as the first part of the corridor (walls and ceiling) were originally made from stones (Fig. 6). The remains of the oldest examples show stones from a local quarry that also provided materials for other constructions (such as churches, bridges, troughs, winery mechanisms, boundary stones to delimit properties, etc.)

In the caves in the shape of an inverted U, the upper part of the hole, over the winepress, usually ends with a window next to the door, as is shown in Fig.7.

Note that the geometry of the cave does not allow for the passage of materials that exceed the dimensions of the width of the entrance. For example, barrels must be constructed inside.



Figure 7. Entrance and hole in a winery with a U-plan.

The entrance doors of the wineries are traditionally made from wood, with holes at the top for ventilation. The boards are nailed together with large-headed nails. The typology of the locks is quite often very singular (Fig.8). Both the lock itself and the bolts are made of wood. The bolt is slotted and sits horizontally. When the lock is engaged, a small rectangular-shaped piece of wood slides into each slot. To open the door, an iron key, also slotted, is inserted horizontally in a hole over the bolt of the lock. When the key is moved upwards, the small pieces of wood free the bolt so that it can be pulled back and the door opened.

2.3 *Procedure for grape pressing*

When the grapes are put into the winepress, they are stacked under the beam. At this time, the beam should be raised as high as possible to allow sufficient space for the grapes below it. To do that, one alternately raises both left and right ends of the beam by rotating the screw (called *huso*) adequately and making use of vertical supports wooden blocks

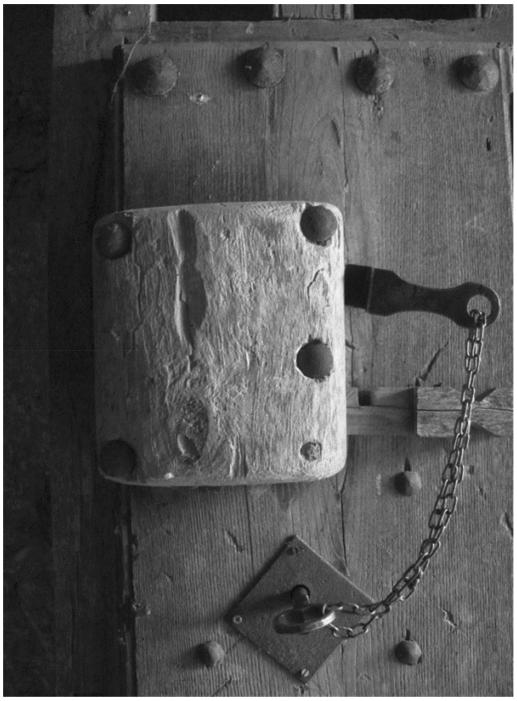


Figure 8. Traditional lock.

A (named *fitos*) (at the left end of the beam) and C (at the middle of the beam, see Fig. 9). At the end of the procedure, the wooden block C is freed.

Once the grapes are placed under the beam, a round board of about 1,50 m in diameter, called *compromiso*, is placed over the pile of grapes. To distribute the force that the beam is going to exert on the round board, several wooden logs of about 0,7-0,9 m length, forming a structure with transverse layers (termed *castillete*), are placed between them, as close as possible to the beam.

Then, another wooden block (B) is also placed between the beam at the left end and the structure over it, discharging beams, called *cargadero* (the lever pivot point or fulcrum of the system, which can be considered a second-order lever), to prevent the first one from moving upwards when the screw is rotated so that the counterweight (called *pienso*) hangs from the beam. At this time, the force exerted on the pile of grapes can be approximated by the expression

$$F = \frac{a}{b}\left(\frac{m}{2} + M\right)g$$

where a and b represent, approximately, the length of the beam (force arm) and the distance from the left end of the beam to the bearing point of

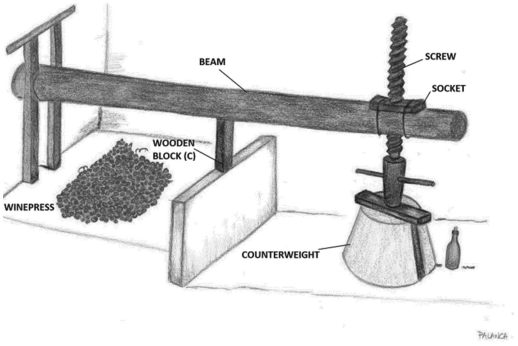


Figure 9. Grapes pressing system. Rest position.

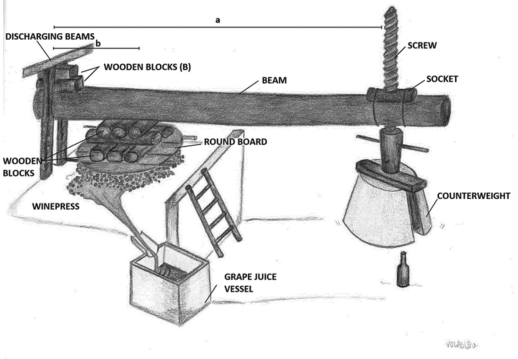


Figure 10. Grapes pressing system.Working position.

the beam on the wooden structure (resistance arm), respectively (Fig. 10); m and M represent the masses of the beam and the counterweight, respectively, and g ($\cong$9,8 m/s^2) is the gravitational acceleration constant. In this calculation, it is considered that the density of the beam and its section are constant. Typically, $m \cong 1000$ Kg, $M \cong 1500$ Kg, $a \cong 8$ m, $a/b \cong 4$ or 5, whereby the a/b factor strongly amplifies the effect of the weight of the beam and the counterweight on the grapes, imposing conditions on the beam and, therefore, on the geometry of the cellar. The points of the beam that support most of the stress are those over the wooden structure, which is why its widest part is placed to the left-hand side in Fig. 10.The pressure exerted by the force F on the pile of grapes causes them to be squeezed as the pile yields until the counterweight touches the ground. Usually, this process lasts less than a day. Normally, the grapes are piled up again and the pressing procedure is repeated once or twice more.

Typically, the counterweight is attached to the screw by a horizontal wooden plank, which is

then attached to two lateral wooden boards (fitted in two lateral grooves to the counterweight) which are wider at the bottom, so that the counterweight cannot slide down as the screw raises the counterweight.

2.4 *Construction aspects*

The way in which the wineries were built is characterised by their focus on savings: time, labour, earthworks, etc. The construction began at the entrance, determining which side would form the front of the cave. A vertical cut was made into the hill, through which a tunnel was dug for access. To prevent erosion and to reinforce the solidity of the entrance, the façade and the first metres of the excavated gallery were covered with stone slabs.

The next step was to dig out the cave. This excavation was done using vertical wells with a triple purpose: first, to allow the progress of the worker at the same time that excavated soil was removed; secondly, to helpmaintain the alignment of the horizontal underground passage (corridor); and thirdly, to serve as a ventilation chimney during the excavation, and when the winery was finished. These wells are called ventilation shafts or holes (*zarceros*). One part of the ventilation shaft is built directly into the clay but the upper part, which stands above the original hill, is reinforced with solid bricks baked from mud. They are placed on slabs to spread their weight across a larger base. (Fig. 11). The excavatedearth wasalso used as a material to protect the hill from exposure to rain.

The tools used in the excavation were quite common in the region. The most usual one was the pickaxe, called *pico de monte.* The traces observed on the inner walls show the marks have been chiseled using this tool. Wicker baskets, termed *talegas*, were used to extract the soil. They were raised using a very ancient device made of wood with a rotating cylinder (Fig. 12). Larger wicker baskets without handles, called *talegones*, were used to carry the grapes to the winery, where they were dumped into the winepress through the hole.

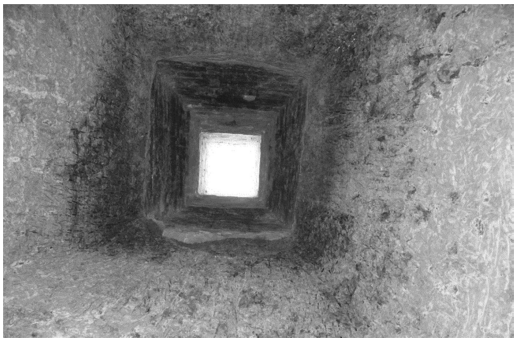


Figure 11. Ventilation shaft or hole.

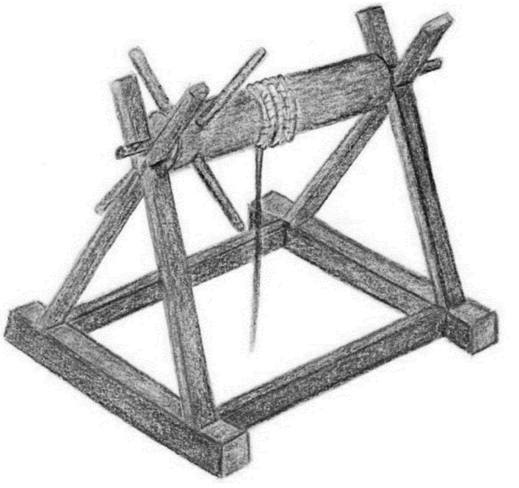


Figure 12. Local pulley system.

3 CONCLUSION

There are many examples of wineries in the Urz-Vidriales valley. They are functional constructions used for the production and preservation of wine. While they share many common elements, quite often the wineries also reveal specific features, sometimes due to terrain requirements, and so a rich variety can be observed. Judging by their simple external appearance it is not possible to imagine the structural wealth to be found within. As already indicated, the geometry of the caves is conditioned by the pressing mechanism. It was described in detail the most common features that are to be found in essentially all the wineries. However, it was observed significant differences, mainly in the union between the screw and the counterweight.

It is considered of great importance to preserve these caves in some way, at least on record. With this in mind, one initiative would be the preparation of a catalog, including at the very least, the accurate location, a description of both the construction and the equipment, and the state of preservation for each winery.

The wineries in the region studied here are examples of vernacular architecture, seeing as they include the defining features of this type of architecture: their rural character, their adaptation to the environment, their being designed for a specific productive activity, the use of native materials

and pre-industrial technology, and local building typologies, among others. All of these characteristics are in danger of becoming extinct. Therefore, it is quite urgent that a representative sample was preserved, at least.

Finally, it is regarded as essential an awareness of the great contribution the architecture of wineries has provided to the construction of the landscape, which can be appreciated both by means of cartography and in the environment itself.

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Scottish earth building materials

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ABSTRACT: While there is an extensive tradition of vernacular earthen built heritage in the UK, in Scotland these building types are not well recorded. As this type of construction was commonly used at least until the 18th and 19th centuries, there is an urgent need for research in order to document, preserve and maintain this part of Scottish vernacular history. Research on documentary and published material will increase our understanding of earth building materials throughout Scotland, including the various techniques of earth wall construction and the use of earth mortar. Whereas some sites are well known to the conservation and heritage community, it is anticipated that many others are not well known and some are unrecorded altogether and at risk from inappropriate repairs. This paper will demonstrate the need for recording all earth materials being used in Scotland, to ensure their future conservation. It also illustrates the need to maintain skills in the repair of vernacular buildings.

1 INTRODUCTION

Earth building in Scotland is not a well-studied topic and many conservators tend to think that this kind of construction is only possible and effective in hot and dry climates. The fact that earth building is less common than in many other countries does not mean that the materials are not suitable or appropriate in the Scottish environment.

In Scotland, although stone is considered the most common building material, earth construction played a prominent part in Scotland's built heritage. Earth used as a construction material would have been adapted to its environment, making it compatible with the local climate. Several earth building methodologies are found in Scotland which can be compared to those used elsewhere in the world.

2 THE HISTORIC USE OF EARTH IN CONSTRUCTION

Earth-based buildings are lived in by a third of the world's population (corresponding to 50% of the population in developing countries) and earth has been used as a main construction material for at least 10,000 years (Houben 1994). The oldest remains of an earth structure discovered so far date from 8000 BC at Jericho, a town made of mud bricks. Earth building has been undervalued in the last couple of centuries for its lack of resistance when affected by water ingress and earthquake damage. Earth is also considered to be a less important material, causing a general lack of interest in repair best practice. Earth built heritage, therefore is continuously being lost throughout the world, and this needs to be prevented by bringing information and education to the relevant communities assuring preservation of the world earthen heritage.

One of the most sophisticated examples of construction with earth it has been in Yemen, in the city of Shibam, where buildings of up to 11 storeys have been constructed with adobe bricks. In this design, the openings are bigger on upper floors so that the lower walls that have to support greater load bearing capacity. The most significant problem with these buildings began when people introduced water supply systems, as minor leak can be catastrophic.

In other parts of the world, earthquake is the greater risk to this type of buildings, as earth walls are strong in compression but weak in tension and therefore performs poorly when earthquakes occur. There where earthquake and flooding/water ingress are not a risk, lack of knowledge and interest it can still be an important risk to care of.

3 EARTH BUILDINGS IN SCOTLAND

Although Scotland is well known for its stone buildings, earth materials were once commonly used. In Scotland, the buildings that have been built with subsoil earth are the same type as for the rest of the UK. These are adobe/unfired brick, cob, clay dabbin, wattle and daub, stake and rice and mud and stud and these can be found throughout the UK.

The remains of earth buildings in which topsoil or turf has been used for building are also common in Scotland, as are buildings with an earth core and earth and clay mortared stone buildings. From all the traditional building methods listed in Table 1, two cases studies will be discussed for the purpose of this report. A clay dabbin and a cob wall building.

3.1 *Priorslynn, canonbie, dumfrieshire, clay dabbin*

The building at Priorslynn Farm, located within the area occupied by the Buccleuch Estate in the parish of Canonbie, is possibly one of the best earth wall examples in the county of Dumfries and Galloway in southern Scotland (Stell 1972).

Table 1. Traditional earth building methods in UK (HES Tan 6 1996).

Type	Location/Description
Adobe/Unfired earth brick	Earliest method and most common building type in the world. Not very popular in Scotland. Referred as clay lamp in the rest of UK. Great for conservation of massed earth walls.
Cob (slow no-formwork method)	Very popular in throughout UK.
Clay dabbin (quick method)	Solway Firth. Better remaining examples can be found in the south of the firth, due to historic tenancy agreements (Jennings 2003)
Wattle and daub (non-load bearing used in partitions)	Used in urban and rural areas, more popular in the south of England than in Scotland.
Stake and rice (structural or infill on timber-framed walls)	Stabs or poles interwoven with ropes or brush bush. Commonly used as structure for large canopy structures.
Mud and stud.	Very popular in center UK.
Blackhouses (earth core)	Scottish western islands mainly. Load bearing wall in most cases.
Excavated	Areas where peat was being extracted, and peat depth was enough for a wall (HES technical advice note 6, 1996)
Fale	Large fibrous block normally in form of parallelogram used for building purposes.
Fale and divet	Introduction of a layer of thin grass turf (divet) between layers of fale.
Turf	Rectangular blocks of soil of well-maintained pasture.
Stone and turf	Alternating layers of turf and boulders.
Earth/clay mortar (bedding mortar for masonry building)	Possibly the most extensive use of earth in urban areas and large construction, such as castles and tower houses.

Believed to belong to the second half of the 18th century and linked to the clay dabbin construction style of the Solway Plain (Messenger 2012), this single-storey gable ended building is currently in a very ruinous state. Despite being A-listed as a cruck frame byre, it has also been listed in the Buildings at Risk Register for Scotland in 1999 (BARR) for being in poor condition and at high risk of being lost if no intervention is made.

The byre, rectangular in plant, measures 17.30 m in length by 4.42 m in width overall. Gable ended, the roof structure is formed by 5 cruck trusses, forming 4 bays that vary in size. The cruck blades sit on stone footings as the earthen walls are not load-bearing.

Clay dabbin is a quick construction method, and involves layering between 5 and 20 cm of the mixture, without need of formwork, with a thick layer of straw in between. In this way it could be a non-stop building process as adding the straw layer between the mud layers accelerated drying of the clay and increased the compression and lateral strength. In addition the compressive strength of the wall increases as it starts drying, although earth materials require always a component of humidity to activate the clay that will keep aggregates together, so ideally a mud wall will never be completely dry.

In Priorslynn, the layers range from 8 to 23 cm with an average thickness of the wall of 51 cm except for the one surviving earth wall gable which has 61 cm thick and reaches 3.96 m from ground level.

There is an earth wall partition dividing the byre into two almost equal spaces (Guilford 1996). The original access on the east wall for each space is currently blocked with stone, and there is an entry to each partition through the west wall, opposite the blocked entries. Having opposite entrances within the same space creates cross ventilation,



Figure 1. Lift layers of 5–20 cm. Clay dabbin. Credit: Author.

making this a feature of fundamental importance in a chimneyless byre-dwelling (HES Tan 5 1996).

One room has an earth floor and a widened door which could indicate that this space has been used for carts in later use. There is no evidence that the building has been inhabited, and it most likely functioned as a detached building of a complex farm.

The walls have been built using massed earth above a plinth. This is a mix with local red clay mixed with pebbles naturally contained in the subsoil and straw, using the method that it is well known in the area as dabbin, or daubin as it was originally called in the past. In a description in the Old Statistical Account for Scotland in 1792, the minister of the parish of Dornock, not far from Canonbie, describes it as a singular way of erecting the walls. Firstly digging out the foundation and laying some rows of stones, then collecting straw and clay from a pit close by. Then as a community cooperative, the whole neighborhood gathers together to do the construction. Only the most experienced people make the walls, while the others mix the mud, or carry the materials. In this manner the walls could be finished in a few hours. This is what originally would have been called 'daubin' (Old statistical account for Scotland 1792).

The term 'daubin' is now more commonly known as 'clay dabbin', referring to the technique of construction that can be found on both sides of the Solway Firth. Clay dabbins were built until the end of 19th century in the area to provide shelter using locally available materials, providing houses for people and their livestock. They are one of the greenest historical building types known and according to the minister of Dornock 'exceeding warm and comfortable' (Old statistical account for Scotland 1792).

Under normal weather conditions the climate in Dumfrieshire county was described as 'variable and rather moist' by Joseph Duncan in the New Statistical Account of 1833.

3.2 *Cottown old schoolhouse, Parish of St maddoes, perth*

In an area of east Perthshire, due to its large expanse of clay, is one of the largest concentrations of mud wall structures in Scotland. One of these, Cottown Old Schoolhouse in Perthshire, is a mud wall thatched cottage, believed to have been built in between 1745 and 1770, the rubble plinth being from an earlier building destroyed by fire in 1766 (National Trust for Scotland 2015) with later alterations and additions, and used as private house until 1985.

What today is known as the 'Old Schoolhouse' was significantly transformed and by the time of the first ordnance survey map of 1861, it was a cottage with three bedrooms. The building is a single storey, rectangular in plan measuring 6 m by 18 m, earth built with cob. Divided into four spaces (three rooms and a hall entrance) and has a later brick extension on the east in which kitchen and bathroom are allocated. The earth walls are built on a stone plinth bedded with clay although the western wall has a larger percentage of stone in its construction. Most of the windows and doorways are timber framed and of different shapes and sizes, showing the continuous development of the building through the years.

Cob building is a slow building process, as every lift or layer needs to dry before another lift can be added. Compared to clay dabbins the building process is slower. The lifts are between 300 to 600 mm in height. In the interior the partitions are made of timber vertical posts infilled with clay and straw, which is commonly called 'mud and stud'. The hamlet of Cottown is surrounded by farmland of alluvial clay soils which was originally marshland drained for agricultural purposes as mentioned in The Old Statistical Account for Scotland 1792.

Prior to its restoration, the building was cement rendered. This render was retaining water causing damage to the earth walls. After removing the render to assess damage, day lifts (a day lift in cob building is the portion of wall that has been built up in a work day, then left it to dry to continue the day after) from the cob building could be identified in most parts of the building, as well as modifications in the openings (a window that was a door west of the porch and a blocked window in the west gable). The National Trust for Scotland acquired the property in 1993 in a very ruinous state and saved it from destruction in a restoration partnership with Historic Environment Scotland (then Historic Scotland). There is no current use assigned to the building, which remains empty and is slowly decaying through capillary damage (National Trust for Scotland 2015). The property is A-listed, and on the Buildings at Risk Registered for Scotland having been designated a building in poor condition but at low risk.

4 IMPORTANCE OF KEEPING VERNACULAR BUILDINGS TRADITIONS ALIVE

Preserving and protecting an old building is a matter that concerns social, economic and cultural value, which relies upon funding, the knowledge and engagement of proprietors and of professionals. Nowadays there are fewer remaining earthen heritage buildings due to the factors discussed

above and the fact that people have undervalued earth constructions (where other, new materials are available). In Scotland, improvement using new materials was introduced during the Industrial Revolution at the end of 19th century. At this time most of the traditional earth buildings were replaced (Naismith 1985).

At the 12th ICOMOS General Assembly in Mexico in 1999 the Charter on the Built Vernacular Heritage was created in which the general issues, principles of conservation and guidelines in practice are included. In this charter the best definition of why to preserve our vernacular or traditional heritage state:

'The built vernacular heritage occupies a central place in the affection and pride of all peoples (…) It is utilitarian but at the same time possesses interest and beauty (…) Although it is the work of a man it is also the creation of time. It would be unworthy of the heritage of man if care were not taken to conserve these traditional harmonies which constitute the core of man's own existence' (…) Vernacular building is the traditional and natural way by which communities house themselves…the survival of this traditions threatened world-wide by the forces of economic, cultural and architectural homogenization (…) Vernacular structures around the world are extremely vulnerable, facing serious problems of obsolescence (…) It is necessary, therefore, in addition to Venice Charter, to stablish principles for the care and protection of our built vernacular heritage' (ICOMOS 1999).

Earth materials have low embodied energy, are recyclable and have good fireproofing and soundproofing properties. They also have good thermal performance that appears to be related to wall thickness (Heathcote 2010). In this respect their use is associated with low energy usage and improved living conditions. Retaining knowledge of this branch of vernacular architecture, and equally important the skills associated with construction and repair is therefore of vital importance.



Figure 2. Priorslynn Byre, Cannonbie. Credit: HES.



Figure 3. Cottown Old Schoolhouse. Credit: HES.

5 CONCLUSIONS

In its various forms, there is evidence of earth structures being used to shelter humans and livestock for longer than any other building material. Global examples include the Great Wall of China and Hadrian's Wall, the Alhambra and the Great Mosque in Mali. In much of the world, earth buildings were the most popular because of the availability of material and basic level of construction.

Even considering the contrast in climate between the UK and countries to the south, it is remarkable how similar the traditional techniques are, using wood frames, walls reinforced with stones and building with cob. The way in which earth has been used for building has been adapted to different local climates. The fact that Dumfrieshire is a very rainy place in Scotland, makes a rapid building method (clay dabbin) the most suitable one. In clay dabbins, layers of earth mix from 5 to 20 cm in height are placed, with a layer of straw in between. The layer of straw makes the mix dry quicker while strengthening the earth mix laterally. This allows continuous construction and is called the quick process. When building in cob, the layers are up to 50 cm, and need to dry more slowly. The use of a stone plinth is common in almost all of the historic earth buildings to protect the lower part of the building against direct rain, splashing and dampness by capillarity.

After the Industrial Revolution, new materials were rapidly introduced and earth building has since been neglected. While new standards including earth building have been proposed by professionals in 55 countries (Mazarrón et al. 2010)

further standards and standardization of the conservation works is still required. General and regular maintenance of earth buildings, including the, the footings and the detailing is the key for survival of an earth building. This is usually less expensive when repairing an earth building compared to stone structures.

Traditional skills in this matter are crucial. As well as reaching and engaging with communities, maintaining skills in earth (and other) building is the only way for the survival of vernacular architecture.

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Thinking about historic resources: A proposed guidance document

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ABSTRACT: The ISCEAH Sub-committee on In-Use wishes to guide communities around the world in preserving, conserving and rehabilitating historic earthen resources worldwide. The Sub-committee seeks to guide through a comprehensive illustrated document that can be easily disseminated. The document will assemble an illustrated glossary of terminology as well as a methodology for approaching work on a historic resource, including documentation and evaluation, assessment of best treatment/levels of intervention, and assessment of attainable and sustainable results. The document will also use community case studies from around the world as illustrative examples.

1 INTRODUCTION

1.1 *The ISCEAH Sub-committee on in-use*

The ICOMOS International Scientific Committee on Earthen Architectural Heritage (ISCEAH) is tasked with carrying out specialized, scientific studies and sharing information that contributes to the protection and conservation of the world's earthen architectural, archaeological and cultural landscape heritage. The Sub-committee on In-Use (Scientific Theme 1) is concerned with conserving and studying extant, standing, and possibly in-use earthen architectural heritage of all kinds.

1.2 *Project introduction*

The ISCEAH Sub-committee on In-Use has noted a lack of basic guidance documents in the international cultural heritage community that could instruct the preservation, conservation, and rehabilitation of historic resources throughout the world and especially in those countries which lack their own guidance documents. In response, the Sub-committee drafted a table of contents for such a document in December 2016 and has recently begun the process of creating comprehensive guidelines for approaching a historic resource. While the Sub-committee's topical specialty is earthen architecture, the information in *Thinking About Historic Resources* could be applicable to many types of tangible, immovable cultural resources.

2 THE NEED FOR A GUIDANCE DOCUMENT

2.1 *Existing guidance document availability*

There are numerous existing resources for those who wish to learn how to approach historic cultural heritage. At the broadest level, there are numerous international charters and declarations which have outlined the cultural heritage field's approach to many aspects of the discipline, including authenticity, rehabilitation and replication, and the treatment of specific resource types such as wooden resources.

Expanding on the international community's broad declarations, individual countries and communities throughout the world have produced guidance and policy documents to guide cultural heritage work within their respective borders. For example, the United States first drafted its *Secretary of the Interior's Standards for the Treatment of Historic Properties* in 1966 and the Chinese published their *Principles for the Conservation of Heritage Sites* in 2000. The forthcoming "Guidelines of preservation and conservation of earthen architecture in Spain" (Fernando Vegas and Camila Mileto) is also an exemplary model for a country-wide guidance document.

On an even more specific level, treatment plans for individual sites or resources also provide examples of methodologies for identifying, evaluating, treating, and managing historic cultural resources.

The Sub-committee was particularly inspired by the recently-published "Conservation and Rehabilitation Plan (CRP) for one of Northern Africa's most significant earthen sites, Kasbah Taourirt in Ouarzazate, Morocco."

All three levels of guidance documents—international charters, country—or city-specific principles, and site-specific plans—may be readily available to those who wish to engage with a historic resource, with one major caveat: in order to find these documents, one must know that they exist elsewhere and know the correct key words to use to find them. Moreover, one must have the field-specific knowledge to interpret these documents and extrapolate how their recommendations may apply to the resource at hand.

The Sub-committee aims to create a document that can be used by cultural heritage professionals and laymen alike to protect, treat, and manage tangible, immovable historic resources around the world.

2.2 *The risks of insufficient guidance: Ribat Riyadh*

Ribat Riyadh is located in the city of Seyoun, in the Hadramaut Governorate of Yemen. It is the last remaining religious school of its historic shape in the wider region and an important monument of local architecture. Recent modernizations, however, show clear deficits in preservation techniques and awareness on different levels.

Ribat Riyadh was built in 1898 AD by the al-Habshi family as a religious learning institute connected with a mosque. It was erected in a time when wealthy families returning from overseas introduced Neoclassical, "colonial" architectural styles in the wadi. These new styles of architecture were still built in the autochthonous methods of Hadramaut, which was developed in the remote desert region relatively free from outside influences. The building was erected in the local mud brick technique, completely covered with white plaster, and accented with carved wooden elements of local hardwood. The complex consists of a main courtyard with two prayer halls, a portico, an ablution wing, open-roofed mosques that were used on summer nights (before the introduction of air ventilation), and a *madrasa* (school for Islamic instruction) building. The complex still serves its original purposes: the *madrasa* is used for religious teachings and the mosque by the surrounding quarter.

The owners began a wide-ranging renovation in 2007. According to the local mud-building technique, the upper layers have to be removed and redone. This includes the upper mud layer and several plaster layers. Since much of the building is maintained by this periodic removal and replacement of layers, any fine relief or other plaster decoration is going to be destroyed and has to be redone according to careful documentation. The replication of this decoration is not part of the traditional practice but is required by preservation standards; otherwise, the traditional architecture and knowledge of traditional techniques would be entirely lost.

In this case, the work was executed by a master builder of Tarim. This builder had no specific knowledge of the artistry of Seyoun and low awareness for the necessities of professional conservation. There are no legal restrictions or guidelines in place in the area except for a decree which forbids the destruction of historic mosques, which is not enforced by the authorities. Furthermore, the owners did not seek professional conservation experts on their own. Despite the lack of professional oversight, the owners' general awareness of the monument's value allowed for the preservation of some significant elements of the building, including *mihrab* (prayer niche) details and many carved, wooden doors and windows.

Other parts of the building, however, underwent larger transformations and even destruction. The old ceiling, constructed of mud vaults and wooden beams, was replaced with a concrete ceiling. Wooden window lintels were replaced with concrete ones, which destroyed triangular lamp niches above the windows which were vital to the design of the interior. The proportions of arches and columns were changed, causing the integrity of the prayer hall to be lost.

In the ablution wing, traditional cisterns were changed into modern ablution cells with ceramic tiles. On the exterior of the building, plaster decoration was replaced without an understanding of the logic and intent of the original design. This led to shapes which are similar to the historic ones but which don't reflect the essence of the historic design's geometrical harmony. Therefore, the new



Figure 1. Southern view of Ribat Riyadh before the renovation. Courtesy of T. Leiermann.



Figure 2. Southern view of Ribat Riyadh after the renovation. Courtesy of T. Leiermann.



Figure 3. Courtyard entrance before the renovation. Courtesy of T. Leiermann.



Figure 4. Courtyard entrance after the renovation. Courtesy of T. Leiermann.

exterior plaster cannot serve as documentation of or a model for the traditional craftsmanship which is so important to the building.

In addition to the alteration or destruction of many historic features, the renovation included the construction of a second minaret and domes in Egyptian and Turkish styles. These changes turned a building of an already unusually high level of ornamentation into a collection of historic and pseudo-historic details.

Even if the transformation of the many altered elements could have been justified by the needs of cyclical maintenance, careful documentation and professional supervision could have maintained most of their original dimensions, shapes, and materials. The lack of guidance in this situation ultimately led to unnecessary damage to a significant historic building. Even in the absence of official cultural heritage oversight, this regrettable result may have been avoided if a simple, easily-accessible, comprehensive guidance document like the one proposed by the Sub-committee had been accessible to the owners of Ribat Riyadh (all preceding from Leiermann 2017).

3 GUIDANCE DOCUMENT CONTENTS

3.1 *Introduction*

The guidance document has the working title of *Thinking About Historic Resources: Guidance for Identification, Documentation, Evaluation, Treatment, and Management.* The proposed contents of this document were developed through an extensive evaluation of existing guidance documents from around the world. ICOMOS and ICCROM charters such as the Venice Charter, Nara Document, and Riga Charter were referenced to identify major international themes. The way in which different countries translated these universal themes into policies, principles, and standards was explored through an evaluation of the national guidance documents of the United States, China, and the United Kingdom. Country-specific evaluations were further supplemented by specific practical and technical recommendations from site-specific documents, such as the Kasbah Taourirt plan.

Following this in-depth investigation—from the broadest context to the most specific—the Sub-committee identified the terms, concepts, methodologies, technologies, and case studies that are necessary to address the needs of those working on historic resources. This information was arranged in a logical manner that allows the reader to first gain a basic understanding of cultural heritage preservation concepts and terminology and then continue on to an evaluation of his or her specific resource. *Thinking About Historic Resources* will guide the reader through the steps of addressing a cultural resource in order and will attempt to provide guidance for most major considerations and treatment options; where guidance cannot be given, resources are suggested for further research.

3.2 *Visual glossary*

The inclusion of a glossary is crucial in a document which may be used by cultural heritage professionals and laymen from differing countries and educational backgrounds and who speak different languages. The Sub-committee determined that a

visual glossary—one which supplements textual definitions with photographs, diagrams, and other graphics—will be especially useful in creating a comprehensible guide.

3.3 *Extended discussions of conceptual issues*

In addition to the visual glossary, *Thinking About Historic Resources* will contain longer discussions of more complex or conceptual terms such as authenticity, significance, condition versus integrity, and the concept of minimal intervention. These terms, which are so critical to the understanding and practice of cultural heritage work and so ingrained into the minds of heritage professionals, must be thoroughly and clearly explored for the benefit of the layman or new professional.

3.4 *Methodologies*

Thinking About Historic Resources will guide the reader through five stages of interaction with their historic resource: identification, recordation and documentation, evaluation, treatment, and management. Within each of these stages, the document will address more specific methodologies. What is a survey and when might different survey types be applicable? What is the best way to document a particular resource? What tasks should be performed by a specialist and which can a generalist undertake?

The document will also include information on technical topics such as cleaning historic earthen architecture, materials testing, and documentary technologies. When should a building be tested for the presence of lead? Is pressure washing appropriate and, if so, how should it be done? What is a Building Information Model and why might one be helpful?

The Sub-committee acknowledges that it is not possible to cover every possible methodological and technological question and that the field is always evolving. In the interest of providing the most complete guidance, however, the Sub-committee will provide a robust appendix of recommended resources for further research and study.

3.5 *Case studies*

Case studies will be utilized throughout the document to illustrate specific methodological and technological concepts, potential challenges, successes, and failures. The 'story' of each case study will be supplemented by definitions and discussions of major concepts. Two examples of case study 'stories' can be found below, in Section 4.

4 CASE STUDY EXAMPLES

The following case studies are abbreviated examples of the types of case studies that will be utilized in *Thinking About Historic Resources*. The case of the Tumacácori National Monument illuminates the necessity for both minimal intervention and reversibility in treatment as well as the caution with which untried treatment technologies must be approached. The case of Arg-e Bam illustrates the dangers of an incomplete treatment plan and highlights the importance of assuring structural stability foremost amongst preservation concerns. In the final guidance document, these 'stories' would be followed by in-depth looks at the concepts identified within each example.

4.1 *Tumacácori national monument*

From the 16th to the 18th centuries, Spanish envoys from Mexico established hundreds of missions as far north as what is now San Francisco. These missions served as bases from which the Spanish colonized and converted surrounding native populations (Brocious 2010).

The site at Tumacácori had been part of the Spanish mission system since the 17th century, but it was not until the turn of the 19th century that the surviving adobe church was constructed. The new adobe church replaced an existing one that was in great disrepair and too small for the population's needs. The church was never quite completed and shows evidence of multiple alterations and repairs throughout its history (Crosby 1985).

The site was abandoned by 1850 and remained unused and deteriorating until 1918. Tumacácori was inscribed as a National Monument in 1908, but it was not until 1918 that the National Park Service (NPS) dedicated any significant funds to its preservation.

The NPS undertook multiple projects at the site beginning in 1918; the progression of these projects allows a glimpse into the technologies and preservation philosophies that were predominant in the field at their respective times. Preservation in the

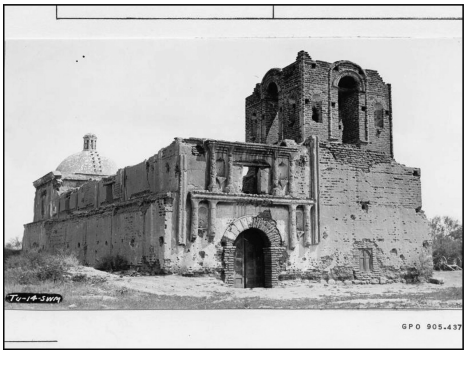


Figure 5. Tumacácori in 1919. Photograph in the public domain, courtesy of the NPS.

United States before the 1960s favored the reconstruction of ruins, as the predominant theory was that visitors would not be able to connect with an incomplete building, structure, or site. Work at Tumacácori prior to the National Historic Preservation Act and the *Secretary of the Interior's Standards for the Treatment of Historic Properties* (both dating to 1966) focused on reconstructing damaged or missing features of the church including the nave, dome, and perimeter wall. During this period, much more of the historic fabric was removed or altered than would be acceptable today.

In addition, Tumacácori became a lab for a number of experimental or relatively untried chemical consolidation techniques. Chemical consolidants were first utilized on the deteriorating adobe walls in 1935 and were used liberally throughout the 1950s and 1960s. According to a 1985 Historic Structure Report, "a silicone material, 'Daracone,' was used by Gordon Vivian in the mid-1950s and Roland Richert began to experiment with 'Daraweld' in 1960. Daraweld was apparently used periodically during the 1960s and perhaps into 1970–71" (Crosby 1985). A 2010 news article indicates that these experimental preservation methods were ultimately not compatible with the adobe bricks and lime plaster of the walls and resulted in internal erosion to "such a degree that they became little more than hollow shells" (Brocious 2010).

In the 1970s, the NPS took a more hands-off approach at Tumacácori (and indeed at most other sites). Further work at Tumacácori included "simply stabilizing [the] ruins with mostly natural materials" and attempting to reverse earlier inappropriate or harmful interventions (Brocious 2010).

The history of interventions at Tumacácori illustrate the necessity of a few key preservation concepts that apply to all architectural resources: reversibility, minimal intervention, and the use of tested and reliable treatment methods. The silicone-based consolidants used beginning in the 1930s did not allow the adobe to 'breathe' and, since the intervention was not reversible, caused severe and continued damage to the walls. The extensive reconstruction of non-extant features completed before the 1970s does not reflect the current preference for minimal intervention. And, finally, the widespread and repeated use of experimental methods of treatment is never advisable unless all other options have been deemed insufficient.

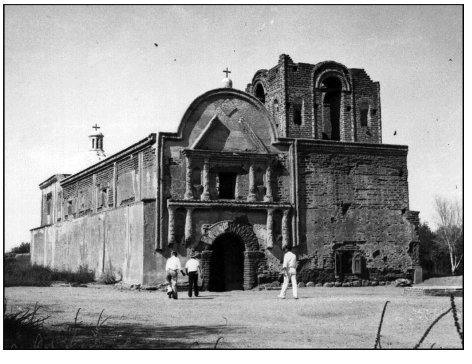


Figure 6. Tumacácori in 1938, following a major reconstruction effort. 1935 was the first year that an experimental chemical consolidant was used on the walls. Photograph in the public domain, courtesy of the NPS.

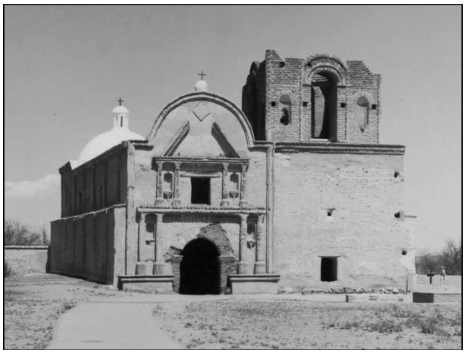


Figure 7. Tumacácori in 1970, following decades of reconstruction and chemical consolidation. Photograph in the public domain, courtesy of the NPSv.

4.2 *Arg-e Bam*

At 5:28 AM local time, an earthquake struck Bam, Iran. The earthquake measured between a 6.3 and 6.6 on the Richter scale and left about 70% of the city destroyed. Among the litany of damaged buildings was Arg-e Bam, the city's historic citadel and the world's largest mud brick complex (ICHO 6).

Arg-e Bam was constructed between the sixth and fourth centuries BC to serve as a center of trade for the Achaemenid Empire along the Silk Road.

The citadel has been occupied nearly continuously from its construction until the early 20th century. Despite its near complete abandonment, the compound survived intact to the point of the earthquake through the power of its religious and national symbolic elements (ICHO 6). However, without a residential population to complete the cyclical maintenance that is so crucial to the longevity of earthen architecture, Arg-e Bam began to disintegrate.

Its national and religious significance allowed Arg-e Bam to be listed on the National Heritage List of Iran in 1945 and the World Heritage List in 2004. The site's 1945 listing sparked a flurry of rehabilitation and restoration efforts within the compound. This work was guided by preservation professionals and respected the historic fabric and design of the structures; the efforts were considered a success (ICHO 30).



Figure 8. Arg-el-Bam before the earthquake. Photograph by Arad Mojtahedi (2000). Licensed under CC BY-SA 3.0.



Figure 9. Arg-el-Bam after the earthquake. Photograph by the US Federal Emergency Management Agency (public domain).

The 2003 earthquake illuminated a crucial flaw in the previous decades of otherwise successful restoration: the restorers did not have the foresight to seismically strengthen any structures that were restored. This oversight is especially egregious considering the region's long history of significant seismic activity, and as a result the city suffered the loss of nearly 70% of their mud brick buildings (Manafpour 7).

The unfortunate destruction of Arg-e Bam may not have been completely avoidable, but seismic retrofitting of historic buildings has been shown repeatedly to successfully protect earthen architecture against structural collapse in the event of an earthquake. In this case, an otherwise appropriate restoration effort was undercut by a failure to prioritize structural stability before undertaking any further interventions in the complex. Structural interventions are not always visible or exciting but can assure the survival of historic fabric and any additional interventions at the site. The case of Arg-e Bam also illustrates the necessity for a comprehensive evaluation of threats to a resource and the necessity of a treatment plan that mitigates as many of those threats as possible.

5 CONCLUSIONS

It is the Sub-committee's intent that *Thinking About Historic Resources* serve as a reference for the basic preservation and conservation of the world's earthen architectural heritage. Moreover, the document will be largely applicable to built heritage of other varieties; with this approach, the Sub-committee hopes to fill the larger need for comprehensive guidance in approaching any tangible, immovable historic resource.

The Sub-committee completed an outline of *Thinking About Historic Resources* in December 2016. A working draft of the full document may be forthcoming in 2017.

In the future, the Sub-committee will need to address the methods through which preservation professionals and interested non-professional parties will learn of this guidance document, to assure that it does not become yet another guidance document existing just out of reach of those who need it most.

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Historic cob structures in Moravia

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ABSTRACT: Cob has a long and continued history throughout many parts of the Danubian region, to which Moravia as a historic land of actual Czech Republic belongs. The traditional cob including two basic variants of stacked or coffered bread-shaped pieces—*války* was the predominant technique in Central and Southern Moravia especially in Haná and Znojmo regions. Besides, these two techniques with many regional variations, several examples of pitched-forked (tooled) cob were identified. Appreciated by generations of art historians and ethnologists for their significant aesthetic qualities *války* represent today perhaps the most vulnerable part of our earthen architectural heritage. The objective of this paper is to present our actual knowledge of cob in Moravia enriched (through surveys of the last decade) with a number of findings dating from 16th to 20th centuries.

1 INTRODUCTION

The building construction manifestations of Moravia as one of the historic Czech countries are similar to those of other Central European neighboring countries (Upper Austria, Slovakia, Hungary), with whom we share also the history of the Habsbourg monarchy and its interventions in construction since the half of 18th century.

We encounter here two basic groups of historic structures, that can be referred to as an "unburned clay masonry":

- structures of massive earthen material to which belong stacked or coffered bread-shaped pieces - *války*, pitched-forked (tooled) cob and rammed (moist fresh) earth
- structures of sun-dried bricks (adobes) shaped by hand or by using molds laid with mortar

These techniques were used for both loadbearing and non-loadbearing walls. While adobe bricks can be found practically all over the territory of actual Czech Republic, the first group of techniques is present practically only in central and southern Moravia.

The presented paper is mainly based on a systematic inventorial works of the Association of the village and small town (SOVAMM) and on series of historic structures analysis that were elaborated by its members, and the investigation of historic earthen materials carried out within the project conducted in 90th by Jan Kříž (Kříž & Vorel 1998). The earthen techniques were recently studied in the framework of several research projects, mainly the project *Technology of traditional clay architecture in Moravia and its relationship to the Central Danube region* focused on the possibilities of transfers and reconstructions in open-air museums, granted by the Czech Ministry of Culture (NAKI project DF11P01OVV015 2011–2015) and the *Zpátky na Zem / Down to Earth—Earth Building in Central Europe* (transnational cooperation Austria—Czech Republic project Nr. 7AMB16AT019 2016–2017).

2 EARTHEN BUILDING MATERIAL

Already the analysis of Moravian historic earthen constructions carried out by Jan Kříž (Kříž & Vorel 1998, Syrová et al. 2000) proved that the predominant earthen building material in Morava valley was loess, which, thanks to its properties was used for all traditional techniques with no need of additives. The work with loess is easy, which was probably its main advantage for the builders. Its negative aspects as chalking surface and water sensitivity were mitigated by structural details traditionally used as protection of the surface of the walls; i.e. clay or lime plaster or tilework. In practice, using only nondestructive historic structures analysis and inventories that means that it is difficult to identify the type of historic earthen technique used in the building.

3 HISTORIC MORAVIAN COB TECHNIQUES

Among the historic structures with massive earthen walls the stacked earth structures are, most archaic, if not most ancient. All variants of this technique have several common properties. The walls are built in successive technological layers from earthen material in its plastic state. The amount of vegetal fibres mixed with earth and water may be very low if loess is used in the construction. None or simple tools are used. No formwork is needed, but it can be used to simplify the construction.

3.1 *Pitched-forked (tooled) cob*

Earthen walls with pitchfork, which are for most of our ethnologists and historians of architecture the only representatives of staked earth construction in Danubian region, can be found mainly in neighboring lands. Known as *wellerbau* in Saxony, Saxony—Anhalt and Thuringia in Germany (the term *wellerbau* being used in German for stacked earth in general) (Ziegert 2003), *gesatzte mauern* (*g'satze mäuer*) in Lower Austria and Burgenland (Meingast 2014), *rakott sárfal* (*fecskerakásos sárfal*) in Hungary (Novotný 2014).

This technique came to the Czech literature through the work of architect and historian of art Václav Mencl (1905–1978), who uses for the technique the term *lepenice,* used from Middle Ages in Bohemia for daubded earth, or *nakládání*, derived from Slovak *vykladanie*. As a heritage curator in Slovakia he had in the 1950s on Žitný ostrov (Rye island in the Danube river) the opportunity to observe and document this techniques and traditional know-how by a series of photographs (Fig. 1). Thus he describes the construction: "*If one enters one of the Hungarian farms around Komárno and Nové Zámky at the moment when the construction is in progress, then the first thing, he sees, is the courtyard transformed in a great pool of mud: Its entire surface is covered with a thick layer of black earth, extracted out into the loess dunes and mixed with bullets and straw to reinforce the structure. The cattle are trotted on this earth, trample it and work with their hoofs; the wet mixture is then placed in a wheelbarrow and mounted with the aid of a pitched-fork. The walls stacked up to the top are covered with straw and left to dry for two years. Then the surface of the walls is cut with an ax and small openings are pierced (the large ones were built at the same time as the walls) and it is only afterwards that the roof is erected and the walls rendered. Thus formed wall is incredibly strong, warm and durable, if it is not threatened by water*" (Mencl 1980).

According to ethnological surveys, peasants in the southern regions of Slovakia considered the pitched-forked cob much better than *nabíjenice*. It is hard to say today which technique this comparison refers to as the literature very often confuses two techniques of construction characterized by the use of formwork: rammed (moist fresh) earth and coffered pressed bread-shaped pieces (*války*).

If the pitched-forked cob existed also in Moravia, the know-how had disappeared here before the first ethnological investigations of the 19th century. The hazards of conservation made us possible to observe on the wine cellars of the small market-town Šatov (distr. Znojmo), which had partially lost their coatings, the structure of the walls with rounded corners constructed in several layers with the traces of treatment of the surface by a sharp tool (Fig. 2). The earth used in these constructions seemed to be mixed with relatively large volume of straw (Syrová & Syrový 2007). These buildings could be dated in the middle of the 18th century. Inventoried in 1995, both of these cellars already disappeared. Martin Novotný interpreted as pitched-forked (?) cob the walls of the granary of the farmhouse no. 5 in Dobrčice (distr. Přerov) (Novotný 2013, 2014). In other cases of the walls of monolithic appearance that we know from Znojmo, but also from Haná



Figure 1. Pitched-forked cob construction in Žitný Ostrov (Rye island) in 1950s (Václav Mencl).



Figure 2. Wine cellar built with pitched-forked (?) cob in Šatov (dist. Znojmo) (Zuzana Syrová 1995).

region, it is often uncertain if it is not one of the variants of *války* techniques.

3.2 *Války*

The term *válek* (pl. *války*) designates a piece of building material fashioned from plastic earthen material to be used in cob walling. Traditional vernacular terms and therefore also the ethnological literature often confuses the two main *války* techniques: freshly stacked (piled) on top of one another and the constructive variant in which the formwork is used. Josef Kšír (1892–1978), heritage curator in Haná region in 1940–60, was the first who tried to distinguish them correctly. He speaks of *války hroudové* (lumps or clods) and *války válečkové* (rolls or rollers) (Kšír 1956). The two adjectives (*hroudové* and *válečkové*) were added and invented by Kšír.

In the Slavic languages of the Danube region the words used for the all construction variants are the same: *válek* or *vál* (in Moravian dialects also *kochval, krupec, šulec*) (Frolec & Vařeka 2007). From the point of view of etymology the word *válek* is derived from the verb "*váleti*", signifying here kneading and rolling of the earthen dough (Machek 1968, Mjartan 1970). The Hungarian word *valyog,* used for loam and adobe, according to some authors should have the same old Slavic roots and the nomadic Hungarians (or Magyars) who came to Pannonia at the end of the 9th century adopted this term as well as many other words related to the construction of the Slavic population of the Great Moravia (Mencl 1980, Mjartan 1970). In Hungarian literature (and we can only regret, that in the articles published in English, French or German by Hungarian experts the original terms are missing (Buzás 2011) term *csömpölyeg* for *války* and *gombóc, gömbölyeg* for their „ball" variant can be found. From Lower Austria we know terms *wuzel*/*wutzel* (also *wuzelmäuern* or *batzbau* in Austrian dialects) (Meingast 2014). German term *lehmbrote* is linked to the modern technique used in Westfalia during the interwar period (Ziegert 2003, Novotný 2014).

3.2.1 *Stacked cob structures*

According to contemporary descriptions that we have available primarily from the first half of the 20th century, the earthen material was usually kneaded and then shaped into a form of elongated bread or cylindrical roller with dimensions of 25–35 cm × 10–16 cm approximately. Their surface absorbed often straw and chaff sprinkled on the ground on which they were prepared. They were used directly or prepared one or two days before construction and then simply plunged into water to ensure their better adhesion. Typical practice was the diagonal laying with an angle of up to 45°. Direction could be alternated in next course (Fig. 3) or changed after five or six courses (the layer corresponding to the work of one day). The decorative value of this structure is not negligible and it naturally attracted the curiosity of ethnologists and art historians. One of the best known descriptions of the traditional *války* construction of the Vyškov region gives J. Zháněl, doctor and amateur ethnologist, cited by Václav Mencl:

"Shortly before the harvest in 1903 the wooden barn of the Přibilík family in Pačlavice no. 48 fell down. There was not time enough to make vepřovice (sun-dried bricks), used at the time for most constructions, and the barn had to be finished and prepared for harvested unthreshed cereals. So they decided to build with války. The earth was taken directly on site—still you can see a pit next to the barn. The surface black soil and the yellow clay soil is used without making the difference between the two, which gives the variety of colors of the courses. The water is added and they left the earth to rest until the morning of the next day, so that the water is absorbed slowly and the earth is not too



Figure 3. Garden façade of a barn with *války* left without plaster in Hruška (distr. Prostějov) (Zuzana Syrová 1994).



Figure 4. Války structure of the remains of cottage with partially conserved plastering of interior surface of the walls and visible piece of wood that served as reinforcement of its corner; Hruška (distr. Prostějov) (Zuzana Syrová 2000).

wet. In the morning the earth is trampled to a paste consistency; at the same time fibres are added, usually barley straw. It is mainly the work of women. The quantity of mud required for one válek is simply estimated from experience. It can be separated from the mass of earthen mixture by a large hoe (graca) or by both hands. People work on bended knees. The separated piece of mud is kneaded on the ground, sprinkled with balls, in the shape of a válek, in the same way as an elongated bread is kneaded. Válek is approximately 30 cm long and 15 cm thick. In general, a stone basement is used. Usually three války are laid side by side, giving a wall about 50 cm thick. First two external války are placed and the third then pressed in between the two. They are laid wet, without mortar, as they stick together themselves. The horizontality of the courses is controlled by means of a cord. It is especially difficult to keep the same inclination of války, which is an appreciated know-how. Usually one course is built per day. One day of drying is sufficient so that the wall is not deformed. The construction of the corners and the heads of the walls on the sides of the gate is interesting, because války are laid horizontally there. Any surface inequalities are cut after drying with an ax. The work can continue only when the weather is nice, in case of rain the crown of the wall covered with straw. The construction usually consists from 16 to 20 courses, which correspond to the working days" (Mencl 1980)

According to description of one of the observers of *války* construction in Němčice nad Hanou (distr. Prostějov) in 1920 the external *válek* was pressed by hand after been laid in the wall, so that its footprint became triangular. The intermediate *války* were prepared already as conical (Kšír 1961). Martin Novotný had the opportunity to disassemble similar structure during the demolition of a barn of the farmhouse no. 13 in Tištín (distr. Prostějov). According to his findings all *války* were shaped as triangular (Fig. 5). He presented an experimental reconstruction of this structure on the exhibition Earth Architecture in Moravia in Strážnice open-air museum (Novotný 2013, 2014).

The inclination of the rollers prevents their possible sliding, but they can even be arranged in horizontal layers. It is especially the case of the repairs and the raising of the walls by cylindrical „rollers". Several cases of the walls built entirely from such cylindrical *války,* when one course was laid lengthwise and the next in a transverse direction, were documented. We know them from our personal observation of barn walls in Hruška (distr. Prostějov) (Fig. 6).

Ball-shaped pieces known from Hungary (Buzás 2011, Mileto et al. 2013) seem not to have been used in Moravia.

Field work in recent years has brought a series of cases of *války* walling from ordinary lumps or clods in Haná and Znojmo region (Novotný 2014, Syrová 2014) which, according to the literary descriptions should be used only with formwork (Kšír 1961). The problem in their identification lies of course in fact, that we have rarely chance to document a surface of a wall, that is not degraded, and see the traces of treatment of the surface by a sharp tool.

It should "pointed out that, even if the bare surface appear to be beautiful to our aesthetic feelings, herringbone *války* structures used to be cut and plastered, at least in case of facades facing the public space or exposed to prevailing winds and rains.

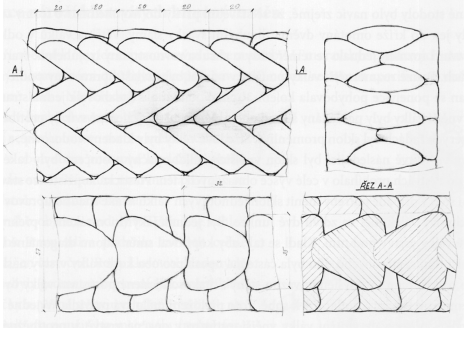


Figure 5. Documentation of triangular války structure of the barn in Tištín (distr. Prostějov) (Martin Novotný 2012).

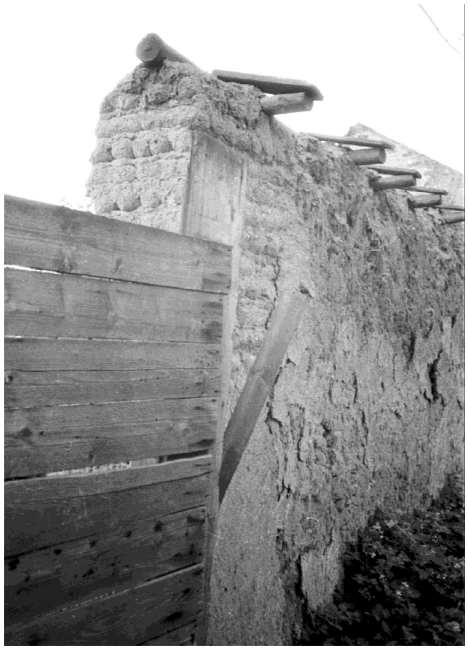


Figure 6. Remains of the barn built with cylindrical *války* in Hruška (distr. Prostějov) (Zuzana Syrová 1995).

3.2.2 *Coffered cob*

The technique coffered *války* was introduced in the Czech ethnographic literature by Antonín Václavík in his monography about the Slovak village of Chorvátský Grob (Václavík 1925). It was mentioned also in other sources like the village chronicle of Příkazy (distr. Olomouc). The detailed description of coffered války was brought by Josef Kšír from the Haná region in central Moravia (Kšír 1956). This technique, was widely used also in Znojmo region in south-western Moravia and in the neighboring regions of Slovakia, Lower Austria and Hungary (Syrová & Syrový 2007, Buzás 2011).

The hand made *války* were in plastic state thrown or simply put in the formwork and compressed to join together in a compact wall. The tools used for compacting and formworks were same as those used for rammed (fresh moist) earth (Syrová & Syrový 2012).

In the context of the use of formwork it must be emphasized that this construction variant can be faster and that the boards can simply prevent the deformation of the wall during construction and drying. If only one course of *války* is laid by hand per day, the height of the layer constructed with formwork corresponds to 6–8 courses (Figs. 7–8).

Války compacted in formwork show significant deformations. In several documented examples, mainly from Znojmo region (e.g. barns in Slup, Míšovice or Želetice) the effort to obtain a regular structure of inclinated courses on the surface of the wall can be shown. In these cases of v*álky* we can observe imprints of wooden boards against which they were pressed. If the interior surfaces indicate at the same time the technique of stacked *války* laid in the wall by hand, we can assume, that the wooden planks were used only in exterior to obtain faster a perfect flat surface, that did not need any additional treatment by cutting.

3.3 *Mixed structures*

Structural variants, in which *války* are used mainly as non-loadbearing are numerous in Danubian region and they were described recently with focus on Hungary (Buzás, Mileto). From south-eastern Moravia and adjacent parts of Slovakia we know combinations of *války* and adobe. Structural support of wooden watlle or wooden poles was documented mainly in Slovakia (Mencl 1980, Mjartan 1970). Josef Kšír gives a detailed description of the coffered války covered with "fur-coat" of thick earthen layer hung on wooden nails (*ježkování* – „hedgehog"), similar to earthen coating corner-timbered constructions (Kšír 1961, Syrová & Syrový 2013)

4 PRESERVED BUILDING STOCK

Cob structures can be traced back to the end of 16th century, which seems to be the period when the massive earthen structures start to replace previously dominant wooden structures even in vernacular architecture. Older archaeological findings in Moravia were practically all interpreted by archeologists as rammed earth as they knew them from ethnographic descriptions (Syrová & Syrový 2007). Pieces of clay clearly interpretable as *války* used as infilling of wooden structure of village house from 16th century were found in Slovak Chľaba (Ruttkay 1998). Without micromorfological analysis we are not able to identify if the massive earthen walls of the lower chamber of house no. 115 in the market-town Pouzdřany (distr. Břeclav) can be classified as cob or as rammed earth. The horizontal wooden pole used here as reinforcement of the wall is undatable by the means of dendrochronology, but the stratigraphy of the construction enables its relative datation before 1607. *Války* or *Wuzel* structure was discovered during the reconstruction of Brandlhof in Radlbrunn (Lower Austria) open as cultural cen-



Figure 7. Remains of barn built with coffered války in Míšovice (distr. Znojmo) (Zuzana Syrová 2016).



Figure 8. Detail of the cob structure of the Míšovice barn. (Zuzana Syrová 2016).

tre in 2005. Unfortunately the methods of building archeology were not applied during the reconstruction works, so that the age of cob walling may not correspond to the published date 1590.

In Moravia the oldest identified cob structures were built with coffered války. They were used for the construction of chamber-granaries of archaic houses with porch-*žudr* dating from 17th–18th centuries in Haná region and wine cellars dating from the same period in Znojmo region. The vast majority, hovewer, dates from the 19th century, which is as in the case of other traditional Moravian earthen building techniques also one of the consequences of construction regulations and interdictions of use of wood. (Syrová & Syrový 2014).

5 CONCLUSIONS

Our present knowledge is (through surveys of the last decade) enriched with a number of findings of variants of cob structures dating from 16th to 20th centuries. It is paradoxically neglected maintenance of farm buildings such as barns and also abandoned farmhouses, which lose their original plaster, that allows us to identify a significant number of cob structures. The exact specification of used construction method is often difficult; the need of use of the exact methods of building archeology seems to be more important than in the past as the preserved examples of cob structures represent perhaps the most vulnerable part of our earthen architectural heritage. There is a need of comparative studies and international and interdisciplinary cooperation with the disciplines of history of art, buildings and classical archaeology, structural analysis. We hope that we will be able to define these needs in transnational cooperation Austria—Czech Republic project whose aim is to become the basis for a wider Central European network. For now we try, in the framework of this project, to gather available information from this region.

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A study of pit houses with soil-covered roofs in a humid climate in Japan

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ABSTRACT: The pit houses with soil-covered roofs in Goshono in the northern Japanese prefecture of Iwate were first excavated in 1998 and restored. Research was carried out into adapting the problem of pit houses with soil-covered roofs to a humid continental climate. The indoor environment of pit houses with soil-covered roofs has very high humidity (90%). Moreover, given the heavy rain and snow the wooden timbers and trusses decay easily and are short lived. Given the annual mean snow depth of approximately 500 mm, snow has to be cleared from the roof several times each winter. In conclusion, it is necessary to use birch bark for roofing and drain below the frost line.

1 INTRODUCTION

1.1 *Background*

Rammed earth buildings are found in warm dry climates, while buildings with soil-covered roofs and walls similar to rammed earth building can be found in in some cold climates, for example, the Buryat tribe near Lake Baikal in central Siberia builds log houses with roofs covered with grass and soil.

Three sets of remains from the middle Jomon period (2500–2000 BC) have been excavated in northern Japan. The pit houses with soil-covered roofs found in Goshono (Iwate Prefecture) and dating to the middle Jomon period were excavated for the first time about 20 years ago.

1.2 *Subject of this study*

As regards Japanese pit houses with soil-covered roofs from the Jomon period, thatched roofs were also considered suitable for the damp rainy climate. The climate of northern Japan is classified as a humid continental climate according to Koppen's climate classification, but the rainfall in this area is more than double that of the European humid continental climate area.

This paper analyzes the problems of pit houses with soil-covered roofs similar to rammed earth houses in humid continental climate areas.

2 HISTORY AND CLIMATE OF THE GOSHONO REMAINS

2.1 *Location of Goshono remains*

The Goshono remains in the town of Ichinohe (Iwate prefecture, Japan) are found at lat 40.13 N and long 141.18 E and at an altitude of 442 m. The Goshono remains, where the pit houses with soil-covered roofs were excavated, date back to the middle Jomon period.

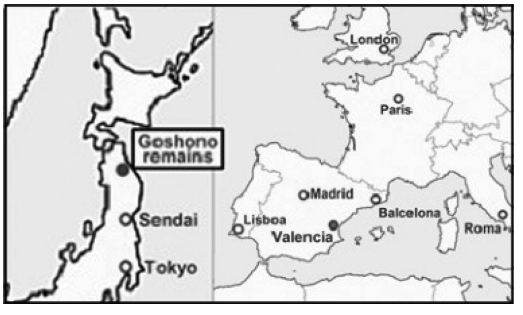


Figure 1. Location of the Goshono remains.

2.2 *Climate*

The Goshono site is located in a cold and snowy area, in a humid continental climate (Dfb) similar to Prague or Oslo according to the Koppen climate zones. The annual mean temperature in Goshono is 8.1°C, and annual rainfall is 1372 mm. Although it has about the same annual mean temperature as that of Prague, Goshono has about 2.5 times as much rainfall.

It is presumed that in Japan in the middle Jomon period the annual mean temperature was about 1°C higher than the present climate. In fact, in Goshono the rainfall is more than double that of a humid continental climate. The vegetation in this area is mixed forest with pine trees, Japanese cedar, Japanese chestnut, oak etc. Maximum snowfalls are about 500 mm and occur between late December

Table 1. Geographical and climate characteristics of Goshono site (2500–2000BC).

Characteristics of Goshono remains	Ichinohe town, Iwate pref. Japan Middle Jomon period (2500–2000BCE) Pit house with soil-covered roof Mixed wood frame structure
Location	Lat 41.13 North Long 141.18 East
Altitude	442 m
Climate	Dfb (Humid continental climate, Koppen climate classification) Annual average temperature 8.1°C Monthly average temperature Maximum 21.3°C/Minimum –4.1°C Annual rainfall 1372 mm Maximum snowfall about 500 mm
Vegetation	Pine, Japanese cedar, Oak, Japanese chestnut etc.

and March. The highest monthly mean temperature is 21.3°C, and the lowest monthly mean temperature is –4.1°C.

3 RESTORATION OF REMAINS OF GOSHONO PIT HOUSES

Excavation of the Goshono remains began in 1990. Seven burned-down pit houses were excavated in 1998. Pieces of carbonized wood were preserved in the burned-down pit dwellings. After excavating two pit houses, analysis of the soil and sediment strongly suggests that the roof was soil. Most of the wood from the excavated house was Japanese chestnut.

The minimum size of excavated pit houses is 2.5 m × 4.5 m with six pillars, and the maximum size is 4.8 m × 9.9 m with seven pillars. The floorplans are oval, elliptical, or irregular hexagons. The excavated pit houses in Goshono have been restored with soil-covered roofs. An example of a pit house with a soil-covered roof is shown in Figure 2.

4 THE INFLUENCE OF HUMID CONTINENTAL CLIMATE ON PIT HOUSES WITH SOIL-COVERED ROOFS

This study investigates the influence of a humid continental climate on rammed earth houses in a cold, snowy, and rainy area in a humid continental climate, specifically on these pit houses restored in 2001. Although maximum summer temperatures may exceed 30°C, the interior temperature in pit houses with soil-covered roofs remains constant at



Image 1. Restored pit house in Goshono, Japan (Middle Jomon period, 2500–2000BCE).



Image 2. Restored pit houses with soil-covered roofs in Goshono.

about 20°C. Humidity inside pit houses with soil-covered roofs, soil floors, and spandrel earthen walls is 90 percent or over. Humidity falls to about 70 percent when a fire is lit in the sunken hearth. Given the heavy summer rainfall, the roofing soil and the timber of the roof trusses of the pit house are permanently wet in summer. The interiors, floors, and spandrel walls of the restored pit houses freeze in winter.

Frost appears on the earthen spandrel wall and the timber surfaces of the roof trusses, etc. The soil in the roof also remains wet until spring as snow lies on it all winter.

Over a two-week period the interior temperature of the Goshono pit house is kept at about 0°C by the thermal effect of the soil-covered roof.

Timber and other wood elements deteriorate rapidly as rafters and roofing boards are wet all year round.

The deterioration of timber rafters and roofing boards, soaked by the soil-covered roof, also continues in other seasons of the year.



Image 3. Interior of restored pit house with soil-covered roof (as indoor humidity is very high, roof trusses, timbers, and roofing boards are blackened and deteriorated).



Image 4. Snow is removed from roofs two or three times every winter as Goshono is under about 500 mm of snow. Source: Ichinohe town educational committee (2004), Report on environmental development planning of Goshono remains, p 106.

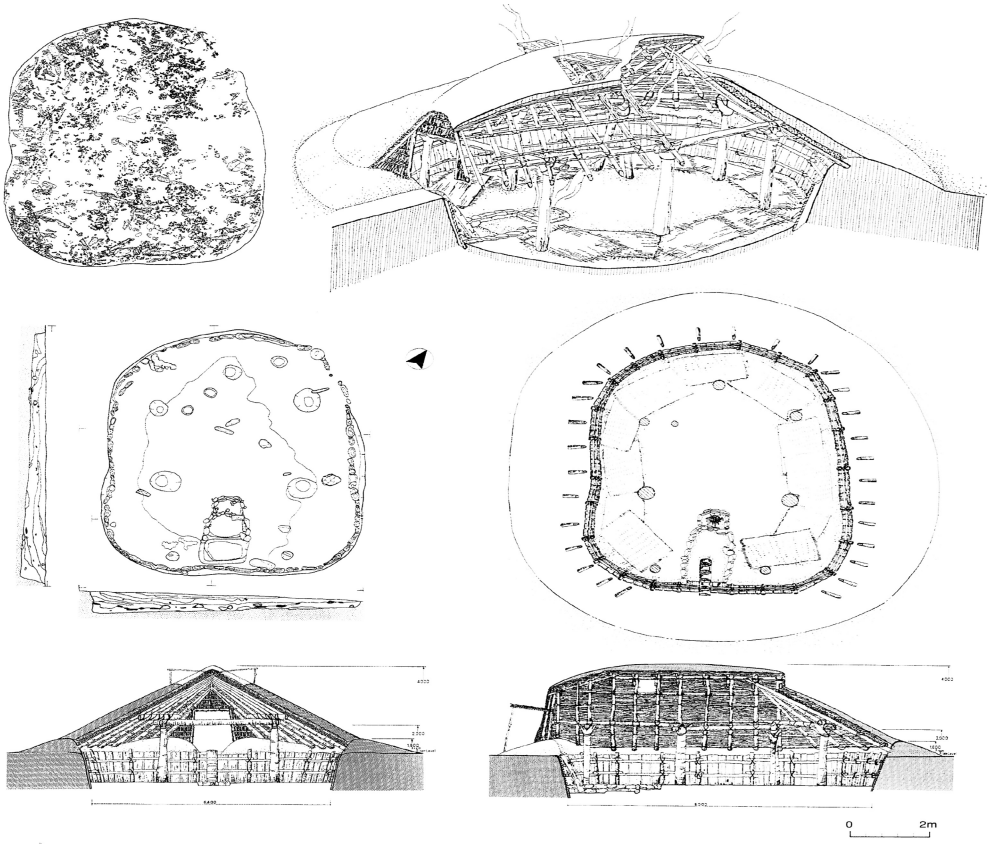


Figure 2. Plan and section of restored pit house with soil-covered roof.

When winter comes, the temperature goes down to –10°C, and indoor water vapor and wet soil begin to freeze. In addition, the heavy snow on the soil-covered roof causes roof rafters, timber, and trusses to warp, so that it is essential to use sturdy pieces of wood and remove snow from the roofs.

Table 2. Comparison table of performance between soil-covered roof and thatched roof.

	Soil-covered roof of pit house	Thatched roof of pit house
Roof building materials	Soil, grass, wood	Thatch, wood
Building technique	Complex and difficult	Simple and easy
Indoor environment	Mild air temperature change	Severe air temperature change
	High humidity all year round	Relatively dry
	Smoke remains inside house	Smoke escapes through thatch
Measures for rain	High humidity from roofing soil	Leaking rain through thatched roof
	Add drain around the pit house roof	Steepen roof slope
Measures for snow	Remove snow from roof	Snow slides off steep roof
	Use large timbers and truss and complex frame	Add thick thatch
Maintenance	Complex and difficult	Easy to rethatch
	Rebuilding 15–20 years	Replace roof thatch every 30 years
To increase lifespan	Drain ground around soil roof	Important to replace damaged thatch
	Use birch bark for roofing	Make a gutter around the roof

5 RESULTS OBSERVED IN GOSHONO PIT HOUSE

A series of problems became clear when adapting the restored pit house with a soil-covered roof to a humid continental climate, given the high rainfall in Goshono, and these are shown below.

Japanese pit houses have been restored with thatched roofs given the humidity of the climate.

As water runs down off a thatched roof, the thatched pit houses are relatively dry inside.

Since pit houses with soil-covered roofs provide considerable insulation from external air temperatures, the indoor air temperatures of pit houses with soil-covered roofs are more stable than those of thatched ones.

As the soil-covered roof is equally wet all year round due to the heavy summer rain and is continuously covered by snow in winter, the timbers of the roof truss are also always wet.

The deterioration of the timber of the restored pit house with a soil-covered roof in Goshono is accelerated by high humidity, so that the restored pit house with a soil-covered roof will have to be rebuilt after fifteen years.

Since the soil-covered roof is about five times as heavy as the thatched roof, roof trusses and large elements are needed to bear this heavy load. It is also more complicated and difficult to build a soil-covered roof than a thatched one.

As roofing soil is easily washed away by torrential rain or thawing snow, maintenance requires time and effort.

Under snow, the roof load may increase by 300 kgf/sqm, so that the roof truss buckles under the heavy weight and snow may have to be removed.

6 CONCLUSION

One of the main effects of a soil-covered roof on the pit house is the steady internal temperature despite the high external air temperatures found in humid continental climates.

The roof timbers in pit houses with soil-covered roofs deteriorate, given that the roofing soil is moist all year round, so that rebuilding will be necessary after fifteen years.

Birch bark is suitable roofing in a climate with heavy rain, snow, and high humidity.

Compared with thatched roofs, roof trusses supporting heavy soil roofs are necessarily complicated, since sturdy timbers are needed, while construction and maintenance, such as removing snow from the roof, is also difficult.

In order to lessen the indoor humidity of a pit house with a soil-covered roof, and to maintain and lengthen its life in a humid climate it is necessary to dig a drain around pit houses with soil-covered roofs below the frost line to dry out the subsoil, and to solve the roofing problems with different wooden building materials.

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Traditional earthen architecture in Aragon, Spain

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ABSTRACT: Traditional earthen architecture is highly vulnerable to globalization and adaptation to current requirements and uses. The main aim of this article is to establish the characteristics of different earthen constructive techniques, their state of conservation, and their presence in different points of the Spanish autonomous community of Aragon. This territory has a very heterogeneous geography and climate and the physical, material, structural, and implementation techniques are the response to the optimization of resources in each location. The literature on the different earthen techniques in the region of Aragon was reviewed. In addition, the assessment and reference mappings in the area under study made it possible to establish relationships and comparisons between architecture and specific locations.

1 INTRODUCTION

Earthen architecture is present throughout most of the traditional architecture found in the Iberian Peninsula. This research is part of a wider project which aims to highlight the importance of this architecture throughout the entire territory given its cultural, constructive, and material value, studying and proposing different options for compatible intervention and restoration to adapt traditional buildings.

This study is part of a doctoral thesis following the global guidelines of this project and currently focuses on the Autonomous Community of Aragon.

1.1 *Research location and context*

Aragon, in the northeast half of the Iberian Peninsula, is a region of great geographical contrasts which allow three areas to be defined from north to south (Fig. 1). Firstly, in the north, the Pyrenean region (in the province of Huesca) is a mountainous area with very high mountains and considerable changes in level. Secondly, the valley of the River Ebro (mostly occupying the province of Zaragoza, as well as the south of Huesca and the northeast of Teruel), is an area with wide plains mostly devoted to agriculture and has an average altitude of approximately 400 m. Finally, the Iberian System (province of Teruel and west of Zaragoza) is a dry region full of valleys forming plains at a considerable altitude (approximately 1000 m) and mountain systems reaching great altitudes (up to 2000 m) (Allanegui Burriel 1979).

The different characteristics of the territory mean that the architecture is also heterogeneous, adapting to the needs and resources available for each of the areas, with a great variety of constructive and technical variants and solutions. Traditional architecture is understood as that which uses local materials and techniques by local



Figure 1. Physical map of Aragon. Source: www.comarcas.es. Edition: Authors.

builders and craftspeople who apply traditional knowledge and optimize resources that are suited to each place. Earthen architecture has been present in Aragon for many centuries and is part of the area's constructive culture. It dates back to the Middle Bronze Age, specifically in the remains of *manteado de barro* (clay daub) or formwork in the Castle of Frías de Albarracín, Teruel, in 1520 BCE (Burillo Mozota, 1985). There are also remains of adobe pieces in the Celtiberian-Roman city of Contrebia Belaisca in Botorrita, Zaragoza, which date from the fifth-fourth centuries BCE and are part of the old town walls (Figols González 2006).

1.2 *Aims*

The main aims of this research are as follows:

a. To identify traditional earthen architecture in Aragon, to verify its presence throughout most of the territory, and to recognize specific aspects of different areas of the studied territory, establishing classifications and relationships between them.
b. To highlight earthen architecture as a cultural element characteristic of the region given that it uses local materials and techniques, is sustainable, and respects the environment. The valorization of this architecture constitutes a first step toward local residents recognizing it as their own, to conserve or restore it in the most suitable and sustainable manner.
c. To ascertain the general state of conservation of earthen architecture in the area studied, as well as its general characteristics, and the adaptation of interventions to maintain or restore it.

2 METHODOLOGY

Prior to this research the literature on earthen architecture (AAVV 2011) and its techniques, specifically earthen architecture in the area studied, was reviewed. However, the specific bibliography found for Aragon is rather general (Abad Alegría 1997), although there are more detailed studies on the earthen architecture of particular areas (Figols Gonzalez 2006); as well as those on traditional architecture in general which simply mention certain earthen techniques as characteristic to a given area.

Therefore, in order to use information and data as objectively as possible, extensive fieldwork was carried out through visits to a large number of population nuclei (approximately 100) spread out over Aragon. These visits consisted primarily in direct data collection for buildings through measurements, photographs, and sample collection, as well as direct accounts from residents of the different localities with data on specific buildings or characteristic local constructive techniques. These visits therefore sought to analyze the presence of these techniques as well as their characteristics for individual areas and cases.

2.1 *Classification fiches*

In order to facilitate rigorous, clear, and objective data collection a study fiche was created to analyze specific cases, forming a database from which general conclusions could be extracted (Fig. 2).

This fiche is made up of three distinct parts (Villacampa et al. 2016): a first part analyzing the location and general aspects of the surroundings and the building itself (province, region, locality, number of inhabitants, building typology, constructive techniques, and state of intervention); a second part with an in-depth analysis of constructive techniques present in the building—rammed earth, adobe or formwork—and main problems currently observed as a result of natural actions or prior interventions (situation inside the building, element size, color, constructive variant and pathologies). The third part analyzes interventions carried out in the building (when applicable) studying their main characteristics, including any affected zones or types of material used to implement them (aim of the intervention, previous consideration, type of intervention and technique, and materials used), together with photographs which help understand the building and its parts (García Soriano 2015)

3 MAIN RESULTS OBTAINED

3.1 *Constructive techniques used*

Three earthen techniques analyzed through the fiche are found in the region of Aragon with a wide number of constructive variants which are adapted and optimized depending on the materials available and the geography and climate of each location at each point in time. Among these techniques it is worth noting the presence of adobe and rammed earth all over the region, with wooden formwork occurring less frequently and found mainly in wooded areas where wood was abundantly available.

On the one hand, according to the data collected, rammed earth is one of the most common techniques. Although measurements tend to vary, they are generally within the following ranges: width of form between 120 and 170 cm, height between 60 and 80 cm (the most common measurement is 75 cm), and wall width between 40 and 70 cm. This technique has the most constructive



Figure 2. First and second part of the fiche for studying and cataloging cases. Example of a specific case.

variants, divided into two major groups: those with structural supplements (corners, buttresses, layers of different materials) and those with supplementary material in the rammed earth itself or in the joints, with the option of combining these with any of the supplements named in the first group. When analyzing the variants from the second group it is worth noting the following:

a. Simple rammed earth only contains earth, sand, and gravel in its mix and is usually rendered, although in secondary buildings it is often left bare.
b. Rammed earth reinforced in its joints. Many different forms and materials are used, but it is worth noting the use of gypsum following vertical and horizontal joints between the formwork, or *brenca* or crescent shaped gypsum reinforcements at the side of the form. This type of rammed earth appears in all sorts of buildings and in many cases is left bare. (Vegas et al. 2009)
c. Lime-crusted rammed earth: this type is rendered in lime or gypsum added during the construction of the wall. This type of rammed earth wall is very common as it has greater protection and the wall and rendering are done at the same time
d. Faced rammed earth: although this type of rammed earth wall is less common quite a few cases were found. It has elements in different materials in one or both of its faces. This facing is usually in stone or brick and helps to prevent the wall surface from eroding. This type of rammed earth wall is not usually rendered.
e. Gypsum-reinforced rammed earth: this type is built differently to the other rammed earth walls as a mix of pebbles, rubble, earth, and gypsum is added. It is slightly compacted but its resistance is due mostly to the gypsum setting. (Vegas et al. 2014)

As for adobe, its presence is widespread. However, the number of constructive variants is very limited given the construction method. Most of the pieces are stabilized with straw, with gravel, or with both. Two types of pieces with notable variations in measurements can be identified: the adobe bricks used in structural walls (approximately $20 \times 40 \times 9$ cm) and the adobe bricks used in surrounding walls or inner partition walls with smaller measurements (approximately $13 \times 28 \times 9$ cm).

There are also variations in the type of mortar used for the execution of joints. These can either be in clay mortar, which results in a homogeneous wall with a barely noticeable joint, where the entire wall washes off equally in erosion, or else with reinforced joints (usually in gypsum) which can be made out because the joint is in a different color and when it erodes it tends to overhang the adobe brick. Some more unusual and less common solutions were identified, such as joints reinforced on corners or buttresses of rammed earth or masonry walls.

Finally, wooden formwork is a lesser known technique in the area under study. However, examples of interest include small units of shuttered cob, using reeds and earth between wood screens. This type of technique usually appears from the first floor upwards and it is common for it to

appear only on the last floor or inside as separation elements or partition walls and is much more difficult to locate given the inaccessibility to most buildings.

It should be noted that, despite what is generally understood, these constructive techniques do not only appear in the most "popular" buildings or more productive buildings mostly associated with agriculture and stockbreeding, but rather are present in most of the most important or noteworthy buildings of population centers visited, including Camarillas in Teruel, Monterde in Zaragoza, and Graus in Huesca (Fig. 3).



Figure 3. Examples of noteworthy building in Graus (Huesca), Monerde (Zaragoza) and Camarillas (Teruel). Source: authors.

3.2 *Relationship with the environment*

As described earlier, the geography of Aragon is highly varied and this affects traditional architecture, given that this is directly connected to material and natural resources and climate (figure 4).

The presence of earth in the Pyrenees is limited or non-existent, although techniques such as adobe are abundant in areas near these mountains such as Besians.

To the south of the mountains and in the Ebro valley adobe is frequently found in all types of buildings (residential and production), while rammed earth is also found in the region, but much less frequently. Most of the buildings in the area are rammed earth, locally known as *tierra de barro* or mud earth (Allanegue Burriel 1979).

To the south of the Ebro valley (lower area of the Iberian System, northeast Teruel, and south Zaragoza) both techniques have equal presence and are often found combined in the same buildings, where the lower parts are usually rammed earth while the upper parts are adobe.

In the Iberian System, which covers almost all of the province of Teruel, except for the northwest or Lower Aragon, it is particularly worth noting the

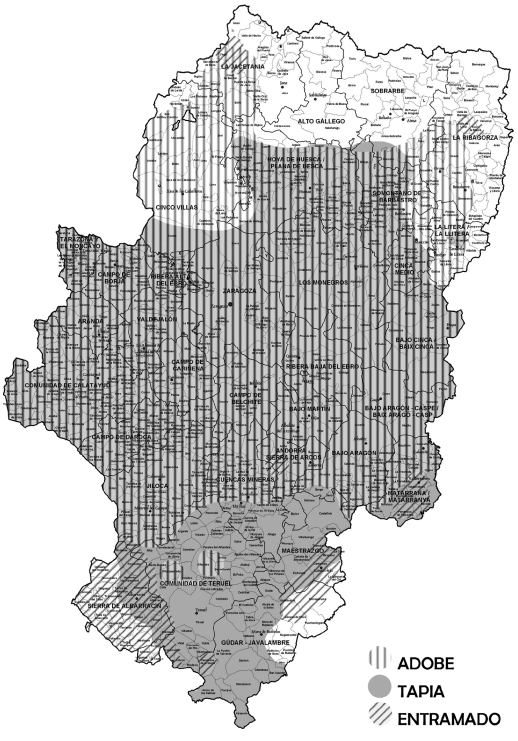


Figure 4. Technique mapping according to data collected and bibliography. Source of basic map: www.comarcas.es, edition: authors.

presence of rammed earth, with fewer instances of adobe. In the mountain areas or higher parts of this region formwork is found, encouraged by the presence of forests and the wood used in their construction. These are particularly abundant in Albarracín and Gea de Albarracín, where the system is used in almost all the buildings. Gypsum is also abundantly used in the different constructive solutions throughout the province of Teruel and part of Zaragoza, (Vegas et al. 2009), where it is used as a supplement in different ways in most buildings or as a rendering. This is the case of gypsum brencas, gypsum- and lime-crusted rammed earth, gypsum-reinforced rammed earth, gypsum fillings in formwork, gypsum joints in rammed earth and adobe, etc. (Fig. 5)

3.3 *State of conservation and intervention*

In order to study the conservation and intervention of earthen architecture the data compiled on different field visits was analyzed using the study fiche. On the one hand, a large number of buildings have not been subject to interventions, which makes it possible to carry out detailed studies of the characteristics of traditional techniques. These cases are mostly in nuclei or areas where population has decreased drastically and many buildings are often in ruins. On the other hand, buildings still in use, of which there are many throughout Aragon, have mostly undergone interventions, sporadically or on separate constructive elements. The interventions carried out are usually immediate spontaneous responses to maintenance or repair issues for parts at times without foresight, the quickest way using available materials and usually in the easiest and cheapest manner possible.

The most common cases include: filling gaps with cement in rammed earth walls, repairing adobe walls with hollow bricks and cement or concrete blocks, and replacing entire stretches between the uprights of formwork (Figure 6). In most cases these interventions are executed with no knowledge of the subsequent damage produced

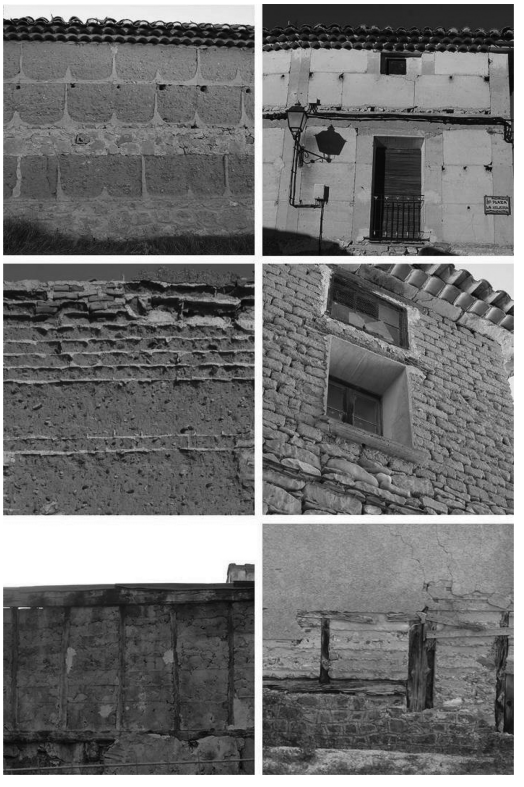


Figure 5. Examples of techniques and variants. From top to bottom and left to right: Orrios, Teruel; Aguatón, Teruel; Belchite, Zaragoza; Perarrúa, Huesca; Moscardón, Teruel and Ansó, Huesca. Source: Villacampa, L., Vegas, F. and Mileto, C.



Figure 6. Examples of interventions. From top to bottom and left to right: Grañen, Huesca; Perarrúa, Huesca; Gea de Albarracín, Teruel; Calcena, Zaragoza; Muniesa, Teruel, before and after the intervention. Source: Villacampa Crespo, L. and Gómez Patrocinio, J.

by incompatible materials, mainly cement mortar which can cause considerable damage (damp, salts, detachment affecting part of the old wall, etc.), and also noticeably alter the traditional view of the building or construction it is part of.

4 CONCLUSIONS

This study aims to present a general overview of the considerable presence of traditional earthen architecture all over Aragon in order to present its assessment and encourage its conservation. This architecture is highly varied throughout the territory and constitutes an extremely rich cultural heritage illustrating constructive customs and the resources used in each place.

Finally, although earthen architecture is mistakenly understood as being of poor quality, it is important to note the existence of important major buildings in this material. Despite their abandonment, they are in an acceptable state of conservation. In addition, in many cases, either as a result of severe depopulation or local interest and affection toward traditional housing, many of these buildings are still conserved or have had minor interventions. However, these interventions have not been appropriately executed, due mainly to a lack of knowledge of original techniques or of potential damage to the structures caused by new materials.

NOTE

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The use of natural materials and ancient building techniques: The case for rammed earth construction

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ABSTRACT: The construction industry is one of the largest contributors to the world's carbon footprint. One way to dramatically reduce this is to go back to use natural building materials and implementing modern applications of ancient and historic building techniques. A system showing promise in modern applications is rammed earth. In this paper brief historical background examples will be presented followed by a modern analysis of the embodied energy expended in the construction rammed earth methods will be explored. Followed by pointing out the positive results of using massive exterior walls as strategy to reduce the impact of outside temperatures on interior space. Finally modern examples rammed earth buildings and techniques will be presented.

1 HISTORICAL BACKGROUND

Taking a look at our ancestors and more primitive societies can be useful for some valuable lessons on how to minimize the impact of our building practices. Combined with energy efficient, high tech solutions and hardware, a symbiotic relationship between old and new technologies can forge a promising strategy for a more sustainable building industry for the future.

Limited by technological advances, our ancestors and existing primitive groups were by necessity forced to use the available natural building materials of the regions they inhabited to create shelter. Each region has a unique response to solving their building needs by using the natural materials available in the region. Each inhabited area of the world devised a unique response to create the built environment. These singular solutions, in turn, produce their own vernacular architecture.

2 RAMMED EARTH

Generally speaking, earthen materials are arguably the most common natural, unprocessed building materials available worldwide. Utilized from prehistoric times to the present, on all five continents, there are many ways to use earth in construction: cob, adobe brick, compressed soil block, waddle & daub; and rammed earth are just a few ways to utilize soil as the principal building material.

Rammed earth techniques have been used around the world and throughout the ages (Easton, 1996). Some of the most outstanding examples, many of them still standing, can be found in Asia, Africa and the Middle East. Europe has many examples as well, Here in Spain there are many examples of centuries old rammed earth forts built by Moors (Gil-Crespo 2006). As a sample of ancient and historic rammed earth buildings in the Continent of America, Prehispanic sites of Pakime and Xaaga located in Mexico (Fig. 1).

Even older than the examples found in Mexico, Peru has a vast pre historic and historic tradition of both residential and monumental earthen construction: Pachacamac and Chan Chan are merely two pre-Hispanic grand cities in South America built with earthen materials (Fig. 2).

2.1 *Embodied energy*

Modern construction, although replete with artificially created materials and state of the art technologies do indeed enhance the performance of the built environment. However, these modern materials and technologies create a high content of embodied energy. A proposal is suggested here based on



Figure 1. Hacienda Xaaga, Oaxaca,Mexico.

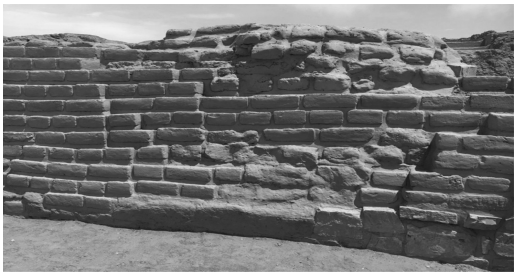


Figure 2. Pachacamac, Peru.

the use of historic and ancient building techniques using lightly processed natural materials in combination with some modern technologies to minimize the impact of environmental damage caused by modern construction processes and materials.

According to a recent study, as an industry, modern construction practices cause at least 50% of the fossil fuel consumption in the USA (Strain 2017). This industry involves architects and engineers; builders and contractors; manufacturers and fabricators; shippers and erectors; to name just a few of the actors. Together, all of us involved in this industry, directly or indirectly, are responsible for this most damaging impact on the environment.

Modern technology has created a cornucopia of new artificial materials and innovative building techniques pushing the envelope of structural capabilities, thermal efficiency, automation, artificial lighting and many other, constantly changing and improved materials and technologies.

One aspect that perhaps is not getting sufficient attention, but awareness is slowly advancing, is to reduce what is known in certain circles as embodied energy. Calculating the embodied energy of a particular building is a complicated process at best, but there are heroic investigators who have engaged in the task of doing so. In one such study investigators in India have calculated that a CSRE (cement stabilized rammed earth) walls consume in the range of only 15% to 25% of embodied energy needed for burnt clay brick masonry (Strain 2017).

This presentation will concentrate on modern rammed earth projects in the Continent of America in general and Central Texas, USA in particular.

Each area will have different soil characteristics and to consider your project to be sustainable the closer you can locate suitable soil for rammed earth walls to your site the better. In the Central Texas area, as in many parts around the world, abounds with soils with high lime content. This type of soil works very well as rammed earth material. There are several tests that can be undertaken do depict the composition of local soils (Easton 1997).

Locally known for its Mexican Spanish term caliche, this is a soil commonly used as a road base. The cal in caliche is the Spanish word for lime (CaCO3).

Central Texas is also an area with large deposits of pink granite. Decomposed granite, is a term to describe the almost pulverized granite. Commonly used to aesthetically enhance gardens and patios decomposed granite is also as surface for hike and bike trails. Although technically cannot be considered a soil, decomposed granite makes for an excellent rammed earth material. As a stabilizer and soil binding agent, dry Portland Cement is often utilized, these are known as CSRE, as noted above as CSRE walls (Venkataram 2009); other stabilizers include lime (CaCO3); asphalt and prickly pear cactus (OPUNTIA) sap have also been utilized with generally good results.

2.2 *Thermal mass*

In addition to lowering the embodied energy of buildings by taking advantage of thermal mass inherent in rammed earth walls and developing passive solar strategies both for heating and cooling needs, there is the potential for vastly reducing the need of fossil fuels to achieve desired comfort levels in the interior spaces of low rise buildings.

Thermal mass is the ability of a material to store heat. Heat energy also travels from hot to cold and heavy or dense materials provide a time lag, from exterior surface to interior space. There is a time lag of 10.3 hours for 250 mm of rammed earth exterior wall (Baggs 2017). Scientifically controlled testing have elicited bold statements such as "Thermal mass, when used together with passive solar design techniques and natural ventilation can effectively eliminate the requirement for air-conditioning".

All these factors and some, not accounted for here, contribute to the total embodied energy needed to create the built environment. A further testing of soil mixtures that also would be a good indication if it will work in a full blown application is to tamp by hand samples into small wooden boxes, as shown here in workshops undertaken by architecture students at Texas A & M University. Students also tested potential rammed earth material by constructing scaled sized structures (Fig. 3).

Rammed Earth techniques can also be used as structural load bearing columns. Fig. 4 illustrates two test columns one made by using "caliche" dirt; the other using decomposed granite (Fig. 4). It is important to note here, that these samples columns were built in 2009 and are still standing, unprotected in 2017.

After complimenting your available soil mixture into a workable solution, and have made tests, you are ready to begin building your full scale rammed earth structure. Walls are constructed by first building forms. Basically 10 to 20 feet long and 18 to 24 inches wide, although one can build wider forms



Figure 3. Sample wall by student Whitney Altenhoff.



Figure 4. Granite and Caliche columns built by Texas A & M students.

if needed or desired. The minimum width however is dependent on the width necessary for one or two persons to be working, tamping the soil inside the form. Although forms can be constructed in different ways, the architectural design- build firm ALARIFE, based in Austin, Texas utilizes 8 x 4 foot x 5/8 inch plywood panels secured by bolted threaded bar. Threaded bars usually come in 8 foot lengths which you can cut to the desired width. Modern rammed earth buildings the author has seen in Mexico used metal panels secured by thick wire. One of the advantages of this method is that metal form work, as opposed to wood boards or plywood panels, is that metal panels can be utilized many times.

Even though in historical times and even in modern times, tampers consisted of heavy flat stones on a wood handle, in modern times, pneumatic tampers speeds up compacting the earthen material within the form work (Fig. 5).

2.3 *Contemporary projects*

The following projects are recently constructed examples of rammed earth structures in Central Texas.



Figure 5. Tamping a rammed earth wall using pneumatic tampers.



Figure 6. Star studio.

2.3.1 *Star studios*

This is a studio for a ceramic artist. Located in downtown Austin, this rammed earth structure replaced an existing carport. The 18 inch rammed earth walls here are built out of decomposed granite.

Other sustainable features such as radiant slab heating; photovoltaic panels; re use of salvaged wood from the existing carport structure; cross current and convective loop ventilation; use of lime-cactus natural stucco; hand carved local limestone; contributed to Star Studio receiving a coveted energy conservation award by the City of Austin (Fig. 6).

2.3.2 *Tweedy Ranch house*

The Tweedy Ranch is located in the Western part of Texas, not far from the Mexican border. Most of

the soils in this area are lime based or caliche soils. In this project the rammed earth walls, using caliche soils, are also 18" thick. Door and window lintels are made from locally quarried limestone; roof is supported by heavy timber Texas cedar; many of the antique doors were made with Mesquite. Both Cedar and mesquite are common local trees (Fig. 7).

2.3.3 *Hacienda Dos Arroyos*

This is a private residential complex, located some twenty miles West of Austin, Texas. The structure depicted was originally destined to function as a barn. The high quality and durability of the construction of this structure however, justified it into becoming, a two family residence. The rammed earth walls of the Dos Arroyos Hacienda are 24 inches thick made from locally acquired decomposed granite. The door and window lintels are massive granite slabs. Cactus stucco and hand carved stone niches were integrated into the walls. Roofing is hand-made, wood fired clay tile (Fig. 8)

2.3.4 *Hood residence*

Built in a suburb West of Austin, the Hood residence is another award winning project. Built with decomposed granite rammed earth, load bearing walls, solar panels and a wetland system the Hood residence is already more than fifteen years old.

One of the walls, separate from the main structure however, was exposed to the elements and had created a serious leak into an underground space.



Figure 7. Tweedy Ranch.



Figure 8. Hacienda Dos Arroyos under construction.

The wall had substantial water damage and moisture content, the surface had eroded.

2.3.5 *Solution*

The first step was to stop the source of leak, and allow the existing moisture within the rammed earth wall by removing the ill-conceived, non-breathable Portland Cement layer and allow the moisture that had penetrated the wall to to evaporate. Then, a stone slant was carved and placed at the base of the wall to divert all moisture away from the building in general and from the rammed earth wall in particular. Next a stone cap, with a slight slope, was carved and placed on the top of the wall thus also diverting rainwater away from the rammed earth wall. Finally, to cover up the eroded wall, a scratch coat of lime stucco was applied, followed by a finish coat of cactus (*opuntia*) burnished stucco.

The leaking has now ceased and the exposed rammed earth wall has been restored to a new luster.

3 CONCLUSION

The building industry in our modern world is arguably the single most damaging activity humans have on our natural environment. By minimizing the embodied energy inherent in modern building materials and construction techniques, the impact caused by modern building practices can substantially be reduced. Rammed earth load bearing walls offer a simple and sustainable solution to our building needs. Although this technique has been used around the world since prehistoric times, it is still very applicable today and its source, is virtually without limits. Modern wireless technologies and state of the art plumbing and mechanical systems are even easier to implement within rammed earth structures than conventional modern day building techniques. So even though rammed earth technology is ancient and primitive, its extremely high potential to provide for humanity's sustainable modern construction needs is monumental.

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Wind and dwellings in the villages of Rincón de Ademuz, Valencia (Spain)

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ABSTRACT: In order to analyze wind, invisible to the eye, it is first necessary to examine the openings and furniture characteristic of dwellings, as these dictate the wind-path. There are multiple ways in which the layout of a dwelling can be influenced by the wind, both negative—for example when carrying the odors of domestic animals—and positive like controlling the smoke release of chimneys. Thus, occupants need to find a way to control the intake of wind. Thermal environment is a factor in the passive design of dwellings, with natural air convection working well in vernacular architecture. This analysis provides a clear picture of dwellings in Rincón de Ademuz and how the lifestyle of local inhabitants is adapted to the wind.

1 AIM OF THE STUDY

This section aims to establish how occupants control wind in order to create a comfortable living environment in dwellings. Wind, viewed in the context of dwellings and lifestyle, has distinct properties.

This study examines the research method followed and the composition of the dwellings, analyzing the plans of the different types of dwelling existing in each village. The following section also examines the wind-paths in these dwellings, which have been remodeled to accommodate the current demands of occupants. The analysis of wind is mostly carried out in relation to the openings and furniture characteristic of a given dwelling. Openings allow the entry of the wind-path of a specific dwelling, as do fireplaces, prompting a need to eliminate smoke. For this reason occupants need to find a way to drive the wind air flow in their dwelling.

2 METHOD OF RESEARCH

This study focuses on research carried out in Torrebaja, Casas Bajas, Castielfabib, Torrealta, Cuesta del Rato and Casas Altas in Rincón de Ademuz. Thirty-one housing units in total were considered for the analysis.

The research method includes interviews and documentation tasks, with entire dwelling plans drawn up by hand and pictures taken. The dwellings were visited on several occasions and occupants were interviewed in order to get a clearer picture of their lifestyle and how they used the places and furniture.

3 TYPES OF DWELLINGS

Due to the risk of flooding and cold air drainage, dwellings are not usually built at the foot of valleys. Equally, mountain ridges present difficulties given the presence of strong winds, and arable land is needed in order to ensure that the population can be fed. However, mountainous terrain presents limitations when it comes to creating farmland, and dwellings in mountainous areas need to be compact and high density. Dwellings at higher altitudes are always built as multi-story houses with farm facilities and living quarters under the same roof. (1)

The dwellings in Rincón de Ademuz are three stories high. The ground level has traditionally been used as for farming, although at present only two of the families taking part in this study keep animals. The effect of agricultural mechanization on planning led to most families remodeling the farming facilities to transform them into storerooms or garages. The living quarters are located on the second floor, although it is generally the first floor that is used for this purpose. However, in some dwellings, the living room and farm accommodation coexist on the ground floor. The most important characteristic of the living quarters is the fireplace, always found in the living room. These living rooms traditionally also served as kitchens, which meant inhabitants used the fireplace to both heat the dwellings and to cook. Now that gas use in dwellings is widespread, inhabitants have started to remodel their dwellings in order to transform these kitchen and living room spaces. At the same time, fireplaces are no longer a necessity thanks to gas and electric heating systems in use. However, in some dwellings fireplaces are still in

use, with some families even choosing to install a second fireplace in another room. The remaining attic level is now used for storage or transformed into bedrooms. Traditionally, attics were workspaces, spaces where grain and cereals were dried for bread or chickens were raised. Even now, some of these rural dwellings still use dovecots.

While three-story dwellings are commonly found, floorplans can vary depending on their location. There are two characteristic locations in mountainous terrain: flatland or sloping land. Torrebaja is located on the flat terrain near the river, Casas Bajas is on mountainous ground, while Castielfabib is also on mountainous ground but at a higher altitude. These differences in terrain and location are important details to be noted. For instance, although almost all of the dwellings in Castielfabib are on sloping ground, some are found on flatlands on the mountaintop. On occasion, various types of terrain can be found in a single village.

The different types of dwelling can be classified based on their corridor. Without fail, the dwellings on flatland have interior corridors, connected to all rooms. For the purposes of this study this type of dwelling is defined as 'flatland-type'. In contrast, high-density dwellings built on sloping ground do not incorporate corridors, given the limited footprint of the small sites. The compact rooms tend to be concentrated in smaller spaces, connecting directly to stairs. These dwellings are defined as 'slope-type'.

Flatland-type dwellings are built on large sites, and usually incorporate an entrance hall, a corridor and stair hall. Thirteen of the thirty-one dwellings considered fall into this category. These dwellings are usually composed of three or four floors with many rooms, more than in the 'slope-type'. In contrast, the remaining eighteen fall into the slope-type category, with no corridor, entrance hall or stair hall. These dwellings are composed of four or five floors in different shapes. These dwellings have two entrances, one gives onto the street that passes below the dwelling and the other is above street level. The height of the dwelling is controlled until the second floor, counting from street level, as it is stipulated that these dwellings should not cast shade over their backyards. These dwellings are considered typical in the region of Rincón de Ademuz.

4 WIND-PATHS IN DWELLINGS

4.1 *The type of interior doors as factors in wind visualization*

Doors are elements designed to act as separation to spaces. In addition to providing inhabitants with privacy, doors also separate indoor environment elements such as air, light, sound, smell, and atmosphere inside the dwelling. Figure 1 shows the distribution of five types of interior doors. In general, the corridor is nestled inside the dwelling to connect each room. Sunlight does not always reach these corridors, and in these cases interior doors with glass panels and transom windows are used to provide illumination, along with ceiling lights in the corridor. In cases where sunlight does not reach some of the rooms, the corridor and stair hall are used to provide indirect light, effectively functioning like courtyards would. This explains the presence of interior doors with glass panels and transom windows in the corridor and stair hall.

Other types of doors were also found during the research. Doors with holes were used in storerooms to protect food from mold, while in other cases the dwelling occupants had added multiple holes to doors elsewhere. In view of the fact that doors are intended as elements of separation for spaces, the presence of these perforations in the wooden panel door does prompt questions. According to occupants, these holes allow wind to enter through the doors, which are commonly found on ground and first floors whenever fireplaces are present.

In some cases a small window was also added to the entrance door, allowing both the entry of wind and a view of any visitors arriving. Further research of front doors showed that entrances often incorporated bead curtains with plastic strips or tubes, designed as protection against flies and often found in these rural areas. These antifly blinds allow residents to keep the entrance door open in the summer, ensuring an intake of wind while also acting as a deterrent to flies. Just like the bead curtains, these interior doors with holes could be used to allow wind into the dwelling, while keeping insects out.

In ten of the cases examined, these curtains are used as room separation, most often, on stairs and corridors.

These curtains and interior door with holes function in a similar way, dividing spaces when necessary but allowing the passage of environmental elements. In addition, these curtains can serve as blinds, with occupants even using them in the bedroom on occasion. This kind of room division is particularly prevalent in the sloped constructions of Castielfabib, where they help small rooms feel less oppressive. Differences in the distribution of interior doors should be noted. Flatland-type dwellings favor the use of interior doors with glass panels and transom windows for their long corridors, while slope-type dwellings have interior doors with perforations, with curtains occasionally used as room separation, allowing the environment into the dwellings.

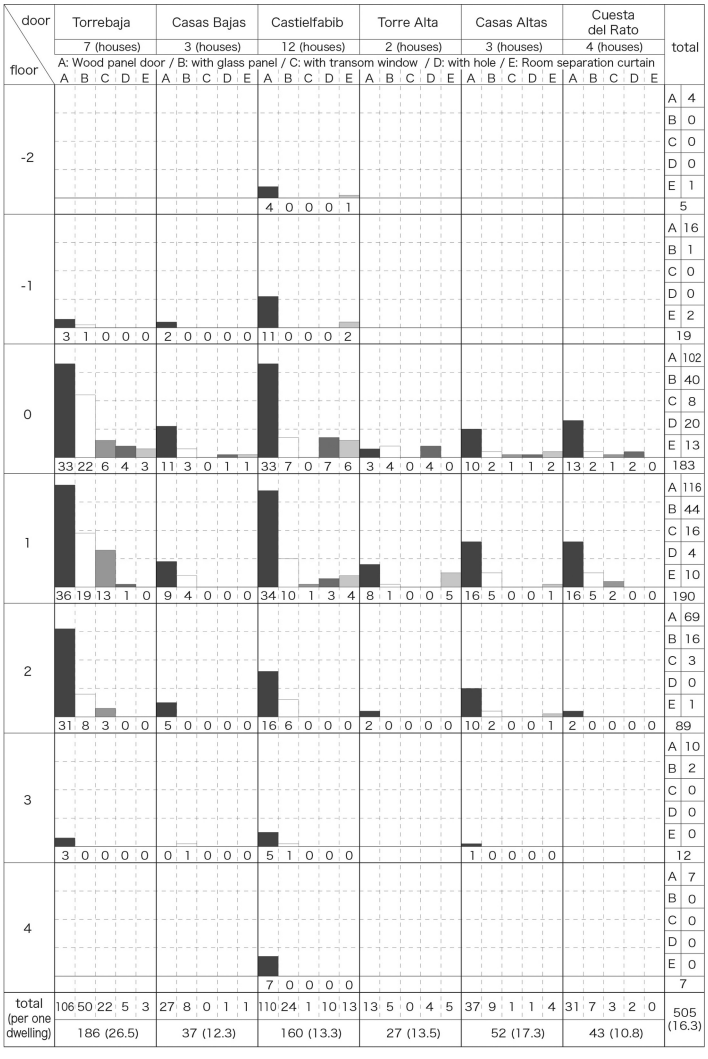


Figure 1. The distribution of interior doors.

4.2 *The direction of fireplaces and the wind-path in living rooms*

Fireplaces are an essential factor to consider when examining the relationship between wind and dwelling, especially given the need to eliminate smoke. In the past, fireplaces were used for cooking, in addition to being the only source of heat in dwellings. They were considered a symbol of family and were carved and decorated with ceramic tiles when installed in the communal space. Also used as a place to welcome visitors and eat together, fireplaces were often gathering spot for the family and represented a happy home. They were a reflection of the lifestyle.

But nowadays the circumstances of fireplaces have changed, with some of them rendered obsolete by the new kitchens and heating systems installed by most residents. Some inhabitants have also incorporated steel stoves, adapting the chimney so that smoke is led directly outside. This makes it possible to warm the living room, without having to worry about wind and smoke elimination. Furthermore, in some cases the fireplaces have been completely eliminated from living rooms, which are transforming due to new lifestyle. However, the purpose of this study is to establish how inhabitants adapt to the climate and live in the village. Although new technologies are certainly helpful to these dwellings,

the climate remains the same. This analysis therefore focuses on the original fireplaces, as used traditionally in the villages. Information provided by local residents confirmed the original locations and uses of fireplaces. As the original location of fireplaces could not be confirmed for four of the thirty-one dwellings considered, only twenty-seven dwellings are suited to analysis in this section.

Each chimney has a cowl as protection from rainfalls. Traditionally inhabitants join two ceramic tiles in an inverted V-shape for cover, leaving a single inlet for wind, as explained in the first section. In order to ensure that the wind is conducive to smoke elimination, the chimney cowl should have a large opening which allows wind to flow without obstruction. In order to ensure better smoke extraction, the cover opening must face the direction of the wind.

In contrast, windows and doors in the living room are also important factors which greatly affect ventilation. The best possible condition is when two openings are set at either end of the living room. However, since the dwellings analyzed are in different locations and the fireplaces need to be in a specific part of the wall area, this limits the options of spaces for openings. In short, the space available for openings is reduced by the mere presence of the fireplace. While it is clearly preferable to ensure the wind air flow through the living room, openings are needed for smoke to exit the living room.

The living room wind-paths are analyzed based on the location of the openings (Fig. 2). The most important characteristic for wind is to ensure that the space has inlets and outlets. The best possible scenario is that with openings at both ends of a space, and therefore a living room with openings at both ends of a wall is defined as 'good wind-path'.

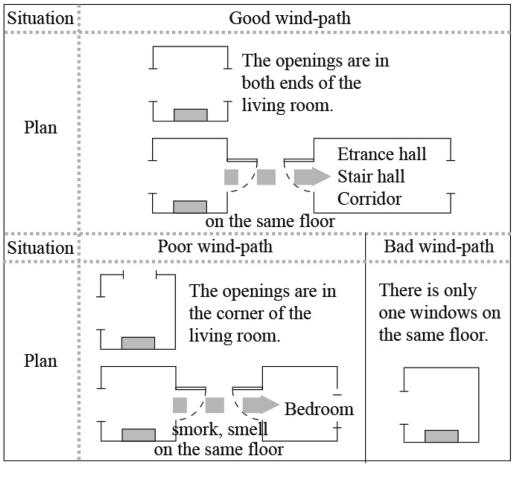


Figure 2. Definition of wind-path in the living room.

There are also cases where windows are set on the same floor at both ends of the dwelling and the wind flow spreads into the living room aided by the interior doors, especially when windows are set in a common space, such as entrance halls, stair halls and corridors.

Cases in which windows in the other rooms support good ventilation in the living room are also defined as 'good wind-paths'. However, when the living room has openings on only one side of the wall or in one corner, it is defined as 'poor wind-path', also taking into consideration that interior doors are not directly connected to the street. Although there are instances when there are windows in different rooms—which are beneficial to the wind-path—other windows are located in bedrooms and most people are not keen on smoke or the smell of smoke in their bedroom. Finally, a 'bad wind-path' is considered to occur when the openings are only on one side of the wall and there are no interior doors to support the ventilation on the same floor.

Based on these distinctions defined above, the following figure shows the relationship between the fireplace and the condition of openings in the living room (Fig. 3). This figure categorizes the direction of the wind-path in the living room. Fifteen of the twenty-seven living rooms analyzed are seen to have 'good wind-path' conditions and eight of these fifteen fireplaces face north-south. These are the best rational conditions for smoke elimination. The remaining seven fireplaces face east-west and do not have to face the direction of the wind, as the living room wind-path supports smoke elimination. A good dwelling wind-path can follow many different types of direction, yet treatment of the living room remains the main priority. However, eight of the twenty-seven dwellings analyzed experience poor wind-path conditions due to their locations. Seven of these eight fireplaces face north-south, with only one facing east-west. Finally, four of the twenty-seven dwellings analyzed present poor wind-paths. As all of these dwellings are located on sloping ground it is impossible to create two openings at opposing ends of the living room given that one of these wall is carved out of rock. These living rooms are therefore considered to be in an unsuitable location, with two of them facing north-south and the other two facing east-west.

According to the above, seventeen of the twenty-seven fireplaces facing north-south, and six of the ten fireplaces facing east-west are in good wind-path conditions. Only four fireplaces facing east-west are in poor or bad wind-path condition. This clearly suggests that occupants, although aware of the importance of the direction of the fireplace, were not able to incorporate the action of the wind.

Therefore, it can be stated that the orientation of fireplaces explains the relationship between the dominant wind and orientation of the dwellings. One of these is when the fireplace 'catches the wind', as is the case when the fireplace is facing north-south. As the fireplace faces the direction of the wind the smoke is let out more smoothly. When the fireplace faces east-west, it is considered that it 'dodges the wind'. In this case, the fireplace does not face the direction of the wind direction, but the living room presents good wind-path conditions. Thus, greater importance is attached to the passage of the wind through the living room. Both cases illustrate the same idea adapted to different locations. The orientation of the fireplace and the type of interior doors are also closely linked. The bottom part of Figure 3 shows the characteristics of the interiors. Dwellings CF2 and CF7 have interior doors with a hole, set in the living room. In the case of CF7, the living room has a poor wind-path due to the location of the dwelling, and this prompted inhabitants to make a hole in the door to let in the wind from different floors. In contrast, given that CF2 has a good wind-path location it seems strange that a hole was added to the interior door. CF2 was remodeled in 1965, when the owners bought the neighboring dwelling, and joined the two properties. The hole was made prior to 1965 for the purposes of ventilation, given that the original dwelling had no opposing openings. There are an additional

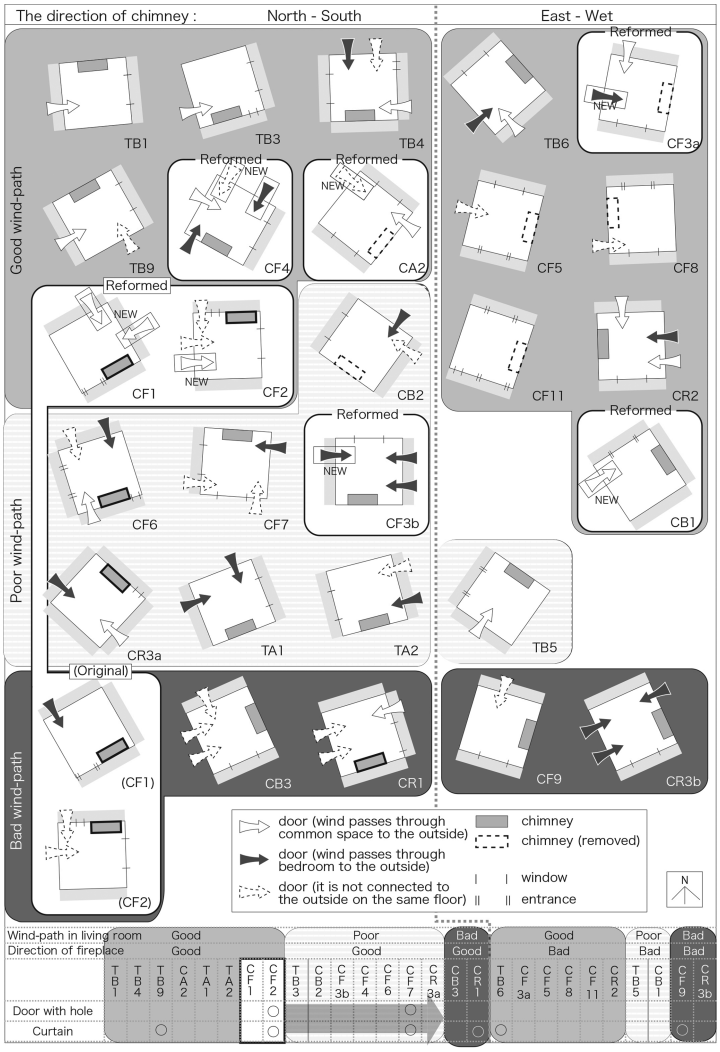


Figure 3. The relation between the direction of fireplace and wind-path in living room.

six dwellings where curtains—functioning only as blinds—are used as a separation in the stair hall and corridor. Five of the six curtains are found in dwellings with poor or bad wind-path conditions to support the ventilation in the living room.

Given that these dwellings are not necessarily found in good locations, it is essential that those living there know of different control mechanisms to allow wind to pass through the living room.

5 CONCLUSION

Inhabitants control the indoor environment in the living room to create a comfortable life there. This is why on occasion, to ensure better smoke elimination, fireplaces in living rooms need to be turned in order to avoid the wind, to create a good wind-path or to catch the wind. In addition, stairs and the hole in the door also are ideas to let pass the wind from different floors. The common factor of these issues is the fact that inhabitants are adapting to the environment. They know how to live in their dwelling and they create some ideas to control the wind in dwelling to overcome the bad wind-path conditions in the living room.

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Rehabilitation of vernacular earthen architecture



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Thermal insulation for a sustainable rehabilitation of traditional buildings

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ABSTRACT: Experiences and testing made in the course of 15 years at the DICAAR—Dipartimento di Ingegneria Civile, Ambientale e Architettura at the University of Cagliari, highlighted that the major interventions for the conservation and rehabilitation of traditional buildings are generally to be made on openings and roofs. Walls are, in fact, almost always in a pretty good condition, as are the horizontal timber frames between floors. Some recent researches offered the possibility to experiment new solutions for roof and wall insulation. Starting from the need to put together natural and very performing materials, and the need to limit the transportation of building elements for economic and ecological reasons, some tests were made on new panels made with locally produced fibers, waste product from other artisanal production, and clay. Panels made with clay and straw, loofah or hemp wood have been manufactured and tested both in restoration sites and in the climatic chamber. The results obtained are very promising.

1 INTRODUCTION

In the course of the last 15 years the DICAAR of the University of Cagliari, Italy has focused its research and testing on the techniques of interventions for the conservation and rehabilitation of traditional Sardinian architecture. Results have been collected through the edition of the *Manuals for the conservation of Sardinian popular buildings*, a set of volumes focusing on the state of Sardinian ancient construction and the historical building technologies. In all cases, whether it was stone or earthen architecture, mountain or coastal buildings, results have been very comparable. Walls, even earthen walls, are in general in a very good conservation state, they show no concerning structural failure, but they almost all show external erosion, especially at the base of the wall and where plaster is missing.

More frequently common building pathologies are to be found on openings and roofs, due most frequently to lack of maintenance or original errors in the choice of the materials or the dimensioning of the building elements. In these cases windows and doors lintels are too short or thin, trusses are placed too far out on the outer walls exposing the heads to humidity, causing their deterioration.

Roofs were generally covering an upper floor that was commonly used to store food and other goods, never for residential purposes. Nevertheless, as its surface is identical to the downstairs floor, the tendency in restoration is to convert it to a residential space by raising the height of its springer (generally too low for residential purposes) and increasing the thickness of the roof in order to achieve thermal protection.

As a result, restoration interventions on ancient buildings commonly foresee the complete substitution of window sets and the complete remake of the roof.

This type of intervention is also influencing and solving a very important issue regarding the actual regulation for energy saving, which compliance is nowadays mandatory in almost all Mediterranean countries. These regulations represent quite a problem for almost all countries in the south of Europe, as they were originated in central European countries with different climate and different needs. These regulations work in fact very well for cold climates and in winter condition, but they strongly penalize historical buildings that have been conceived to comply with hot climate and long summer conditions through the year.

On the one side they oblige the use of a consistent thermal insulation even on traditional buildings if restored, but on the other side they give no indication on the characteristics that these insulation should have. More specifically, they give no indication on how to manage the danger represented by opposing no transpiring/synthetic elements (as most of the products sold on the current market) on natural supports.

Some researches projects that the DICAAR is carrying out since 2016 lead to the development and testing of new solutions for wall and especially roof insulation.

The challenge concerned several issues: the need to put together natural materials in order to better adapt the new elements to the natural supports (stone and earthen walls), the goal to obtain very performing panels for the hot local climate,

the need to limit the importation of building elements for economic reasons and at the same time sustain the development of a local micro-economy in the sector. Some tests were made on new panels made with fibers produced locally, almost always waste products from other artisanal production, and earth. Three types of panels, (earth and straw, earth and loofah and earth and hemp wood), have been produced and tested both in real restorations and in the climatic chamber.

These panels have been inspired by the ancient tradition of using vegetable fibers as insulation, and thanks to their hygroscopic nature, adapt well to the use on natural surfaces. In addition to this it is important to underline that, unlike other natural insulation materials produced in Sardinia, as cork and sheep wool, their production cost is much lower, as the main material used is not a prime material.

2 THE EARTH BINDER

For the three tests the soil used as binder was excavated in the area of Serrenti, 35 km away from the capital, Cagliari. The soil was empirically characterized with the methodology followed by CRAterre (Houben & Guillaud, 2006), through tests of sedimentation, mechanical resistance and absorption. The tests gave the result of a homogenous soil in granulometry, with clay content of about 25%.

Even such a little quantity of clay guaranteed a good binding action. The soil was previously sieved with a 2 mm mesh sieve, and then brought mechanically to a viscose/fluid state with the addition of 50% of water in order to reach the consistence of a fluid grout (*barbottina*).

3 STRAW-EARTH PANELS

Straw and earth have been used together as building material in many ways since ever and worldwide. The addition of straw allows creating light earth construction with different techniques: light adobe, cob, straw-earth fillings, among others. In Sardinia straw was mixed to earth only to prevent adobe and plasters from cracking. Today, its use for thermal insulation is still almost unknown. In Sardinia, due to the mild climate, thermal insulation has been historically not an issue, and houses were actually never insulated, relying on the massive earth walls for a protection against the weather. Nevertheless, it gets more and more necessary nowadays to provide an effective insulation in summer condition, as temperatures can become very high for long periods. Thermal retrofitting is furthermore obliged by law, in case of renovation with major changes also of historical building.

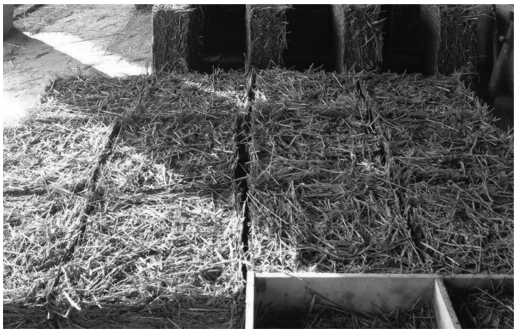


Figure 1. Straw-clay panels.

Straw-earth panels test samples were produced manually using local wheat straw and earth. Straw is intensively grown on the island for alimentary purposes; the resulting straw is generally sold in the livestock sector.

Wheat straw was incorporated to the grout, mixed in a basin built for this purpose and covered with more grout. Afterwards, the mix was pressed by hand into $50 \times 50 \times 18$ cm molds. The grout cover, in addition to binding the straw fibers, assures a light protection from insect and fire events.

The press action was empirically measured with multiple tests in order to achieve a density of around 300 Kg/m^3. The panels were left to dry naturally during a period of one month (September) until completely exsiccated. At the end of the process each panel weighed 16 kg, had a fairly regular form and was compact enough to be safely manipulated.

In a second phase the straw panels were tested in the climatic chamber. The test was made on a panel $50 \times 50 \times 12$ cm size. The imposed temperature setting was 2°C for the outdoor chamber and 22°C for the indoor chamber. The relative humidity value was set at R.H. 50%. Internal Air Velocity was set at 0.5 m/s, the external at 1.0 m/s. The test lasted 4 days.

The result determined a thermal conductivity $\lambda = 0.06$ W/mK, which qualifies the product as a good performing insulation natural material, comparable to mineralized wood fiber and reed mats (Marti 2001).

Considering the cost of the raw materials used and the costs of man/working hours needed for the entire production process, the straw-earth insulation panels ultimately cost 15 €/m^2.

The same panels were used as thermal insulation on a ventilated roof in the restoration of a private residential building. In this case, the panels had a

dimension of 50 × 25 × 18 cm and were mounted between the wooden planking and a ventilation chamber. At the bottom and on top of it a steam barrier was positioned.

The calculation to design the dimensions of the roof were made according to the instructions of the Italian Ministerial Decree D.M. 06/2015 that states that the maximal thermal transmittance for horizontal or tilted opaque structures, in winter condition for the climatic area "C" has to be equal to 0.34 W/m^{2}k.

In the case of the straw-earth panel tested, their thickness of 18 cm corresponds to a thermal transmittance (U-Value) U = 0.29 W/m^{2}k.

In the calculation the building elements beyond the ventilated space have been ignored.

The periodic thermal transmittance was equal to Yie = 0.064. As for thermal transmittance in the calculation the building elements beyond the ventilated space have been ignored.

The calculated time lag, i.e. the time delay due to the thermal mass, is equal to φ = 12,56 (h), the decrement factor fd = 0.216.



Figure 2. Straw-clay panel ready for the climatic chamber test.

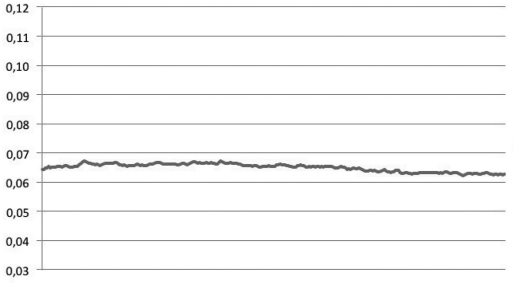


Figure 3. Thermal conductivity during the last 24 h of the test.



Figure 4. Straw-clay panels mounted on the ventilated roof.

4 LOOFAH-EARTH PANELS

The cylindrical loofah that was used for the experiment comes from the Campidano plain.

The 2 hectares of cultivation give an annual production of about 50,000 loofah used for the production of sponges for personal care. Several tens of thousands pieces are sold throughout the island of Sardinia and the Italian Peninsula yearly. "The advantage of cultivating loofah—explains the producer Marcello Mancosu—is that it does not require special terrains. It can easily grow on various types of soils".

The product is collected once it is completely exsiccated, that is when the squash has fully lost both pulp and seeds. Later it gets washed in special laundries and prepared for further processing.

With a similar procedure to the one used for the straw-earth panels, loofah panels have been produced using the same earth as a binder.

There have been many attempts to test mixtures, to find the best solution to obtain a regular and well resistant sample.

The loofah used was the waste material derived by the sponge production, further cut in pieces of maximum 1 cm in size. The shredded loofah becomes easy to handle and gives a smooth and regular surface to the panels once unmolded. Being the waste material of the sponge production its cost is very low, around 20 € per cubic meter.

Loofah panels offer an interesting new application for the building sector. The ease of processing the panels allows their adaptable use for different purposes: for thermal or acoustic insulation, or as filling for bearing structures. It is possible to vary the percentages of the materials mixed, in order to obtain more porous or more compact panels. It is also possible to change their size and thickness, depending on the final use. Finally it is possible to measure the compression force to get the panel to a precise density and repeat it for the entire production, to obtain a standardized product.

Panels were produced in the size $20 \times 20 \times 5$ cm, and mounted in the climatic chamber in order to reach a module $50 \times 50 \times 10$. The temperature setting was 2°C for the outdoor chamber and 22°C for the indoor chamber. The relative humidity value was set at R.H. 50%. Internal Air Velocity was set at 0.5 m/s, the external at 1,0 m/s. The test lasted 4 days.

The values determined in the climatic chamber, thermal conductivity $\lambda = 0.05$ W/mK, indicate that the tested panels have insulation values comparable to other high-efficiency insulating natural materials as wood chips, cork granules, expanded perlite and cellular glass.

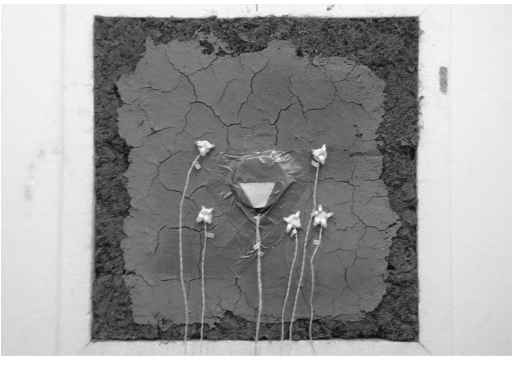


Figure 5. Loofah-clay panel ready for the climatic chamber test.

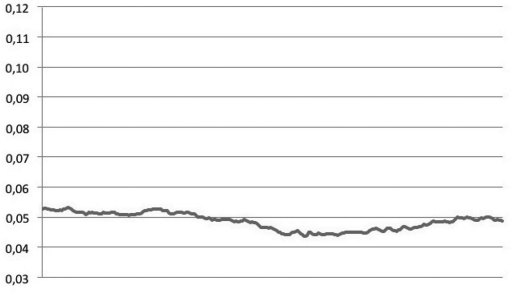


Figure 6. Thermal conductivity during the last 24 h of the test.

5 HEMP SHIVE–EARTH PANELS

The *Cannabis Sativa* is becoming a new business in Sardinia. The plant is easy to cultivate and does not need irrigation, herbicides or pesticides, furthermore, not containing proteins it does not get attacked by rodents and insects. The seed produced represents the prime product and is used in the food chain, for the production of flour and oil. The outside of the hemp stalk is covered with a skin (epidermis), underneath it there are bast fibres whereas in the centre of the stem there is a wood-pulp core (shive), the proportion of which is between 60 to 80% of the total mass of the stem. Hemp shive is the secondary product and is used in textile and building industry as building and insulation material. The shives and fiber obtained from the hemp stalks, with the addition of water and clay can give very regular and resistant panels. Test panels have been produced in the initial size $20 \times 20 \times 5$ cm, but they had a little shrinkage in the exsiccation phase.

Panels have been mounted in the climatic chamber in order to reach a module $50 \times 50 \times 12$. The imposed temperature setting was 2°C for the outdoor chamber and 22°C for the indoor chamber. The relative humidity value was set at R.H. 50%. Internal Air Velocity was set at 0.5 m/s, the external at 1.0 m/s. The test lasted 5 days.

The average value determined in the climatic chamber for the thermal conductivity of hemp-earth panels is $\lambda = 0{,}110$ W/mK.

Compared to the straw–earth and loofah–earth panels, the thermal conductivity results fairly weaker. This can be attributed to the increased density of the material. The shives in fact present a surface offering a more difficult grip for the clay, which must be added in higher amounts, consequently increasing the specific weight of the product.

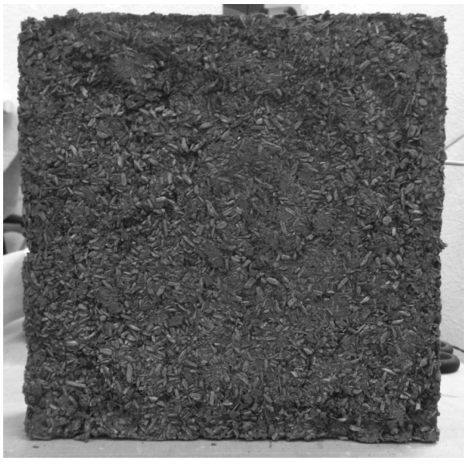


Figure 7. Hemp shive panel.

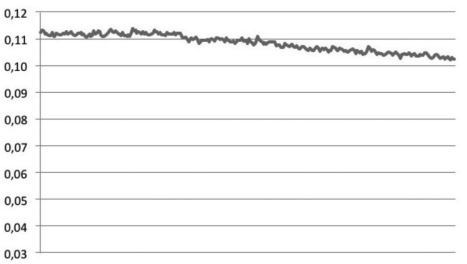


Figure 8. Thermal conductivity during the last 24 h of the test.

This result can certainly be improved by carrying out further tests on the percentages of the components and the quality of the binder chosen.

6 CONCLUSIONS

From the dawn of human settlements stems of fiber plants have been mixed with earth or lime to build shelters, housing and infrastructure so commonly that even today, after more than a millennium, they continue are extremely common. Vegetable fibers are revalued today for the performance they offer in the field of building insulation.

They give an exceptional contribution to sustainable building considered in terms of quality and quality/price ratio, healthiness of dwellings and the effective protection of the environment, starting with a drastic reduction of CO^2 emissions.

Their local availability, their being often waste product, the ease of transformation and use, make them an appealing resource for building purposes.

Fibers are commonly used in building generally mixed with cement or lime bonds, but they do not really represent in Italy a true alternative to commercial synthetic products, which are still more performing and cheaper.

The experimentation done by the DICAAR on the mentioned products bonded with earth aim to verify the possible use of local resources for the building sector that can support the local microeconomy, decrease the loads of waste production and introduce in the building market energy-efficient elements for the renovation of historic buildings and new sustainable construction.

The calculation made for the application of straw-earth panels on an ongoing restoration work have given very positive results, suggesting a valid contribution to the use of this kind of insulation for ancient buildings in all countries with hot Mediterranean climate.

The investigation just started will be extended in the near future towards the characterization of the materials used and their possible standardization in the thermal insulation sector, in view of a future industrial production. At a later time, other parameters of the behavior of materials, such as the acoustic insulation capacity and the durability will be verified.

ACKNOWLEDGEMENTS

Giuseppe Desogus coordinated the thermal investigation done at the DICAAR with the climatic chamber by Lorenza di Pilla and myself.

Alessandro Mereu elaborated the thermal calculation for the design of the ventilated roof insulated with straw-clay panels; he used the calculation sheet by Andrea Ursini Casalena, according to the Italian Standard UNI 13789/2008.

NOTE

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Thermal assessment of the behavior of retrofitted rammed earth in central Catalonia

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ABSTRACT: Compliance with the Spanish Basic Document on Energy Efficiency (DBHE) in some cases contributes to highlighting the deficient thermal resistivity of rammed earth walls, despite the thermal gains resulting from their great inertia. The conductivity values for walls between 30 and 60 cm thick range from 0.6 to 1.6 W/mK (Bauluz & Bárcena), depending on density, amount of clay, and type of soil. This research carries out an in situ analysis of the indoor ambient parameters of a restored rammed earth rural home in central Catalonia. A dynamic analysis is carried out of the different real thermal values, which are contrasted in different positions in order to take into consideration its good diffusivity, inertia and thermal accumulation capacity over extended sequential periods to apply the theory and practice according to HE1. Seven dataloggers were used to measure the different variables of the facade with the most solar exposure in the summer every half hour. Finally, the thermal transmittance values obtained for the rammed earth wall differed greatly from those suggested in the theory and short-term laboratory tests.

1 LOCATION

Can Gramunt is an old medieval *masía* (traditional Catalan rural construction) dating from the sixteenth century. The building is located – 382 meters above sea level—in the central Catalonian region of Anoia, in Torre de Claramunt in the province of Barcelona. A comprehensive retrofitting carried out from 2010 to 2014 divided it into three large holiday apartments. The use of bare rammed earth is predominant in this area and major nearby buildings include the famously tall Paper Mill Museum in Capellades, which is currently rendered (1).

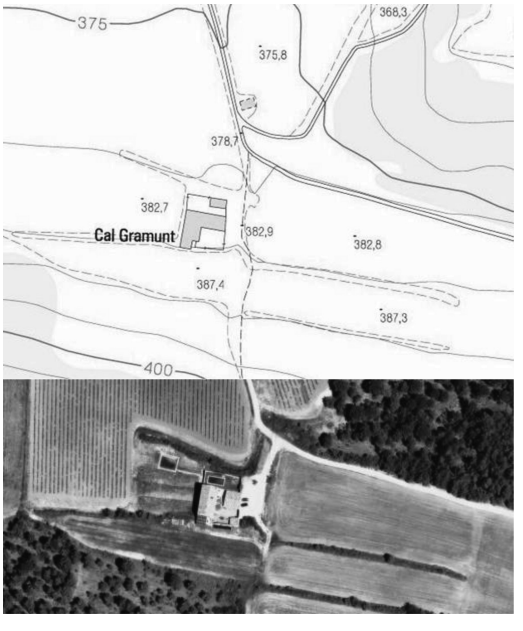


Figure 1. Topographical and orthophoto map, with north-south direction, provided by the Cartographic Institute of Catalonia (ICC).



Figure 2. Can Gramunt from the west.

2 CLIMATE

According to the Koppen classification the climate in the area is Mediterranean. The building is located in climate zone D2 according to the classification of the Iberian Peninsula found in DB HE1 of the Spanish Technical Building Code (CTE).

3 GEOLOGY

According to the geological map of Catalonia, the earth used for the rammed earth is almost



Figure 3. ICC geological map.

certainly local, from the Q layer. These Quaternary sediments contain traces which suggest they were very close to a lower topographic point, Qtr Pleistocene Travertine. Density is approximately 1.8 gr/cm^3 due to manual compacting and light composition. The surrounding areas provided allochtonous materials which eventually settled in this basin. These include materials from the Paleogene: PEag clay and stone with presence of gypsum from the Lutetian; PPec limestone and dolomites from the Ilerdian; and PEm Fossiliferous blue loam with red siltstone from the Bartonian age.

4 PROCEDURE

UNE ISO 6946, UNE EN 6940, and UNE EN ISO10077-1, which describe methods for the calculation of thermal resistance and thermal transmittance of building components and elements, were followed. The methodology was applied to components and elements with thermally homogeneous layers.

The first phase was used to obtain readings for surface temperatures and humidity on one of the rammed earth facades. Measurement devices were placed on the west facade from June to August. The dataloggers recorded readings every thirty minutes. In total, seven dataloggers were installed: on the ground floor (cellar); on the first floor, in the (room) and in its window, plus another one for measuring the indoor environment. The dataloggers installed outside under direct solar radiation incorporated aluminum, a cool reflective material used as protection, to prevent error due to overheating.

The moving average process was used to assess the data obtained, based on the idea that the mean of instantaneous relationships between heat flux and temperature differences in specific time scales increases progressively toward a steady state of thermal transmittance. In compliance with the ISO and for the purposes of comparison a dynamic analysis was applied to quantify the contribution from the heat capacity of the wall in the total transfer of exterior heat to the interior.



Figure 4. Dataloggers incorporated to measure the surface temperatures of the different elements.

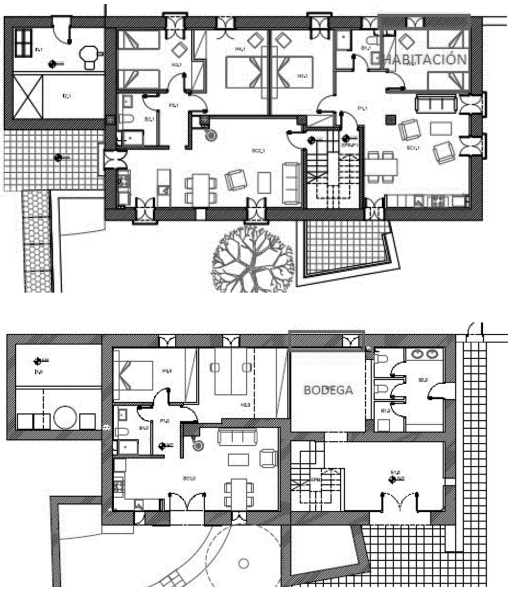


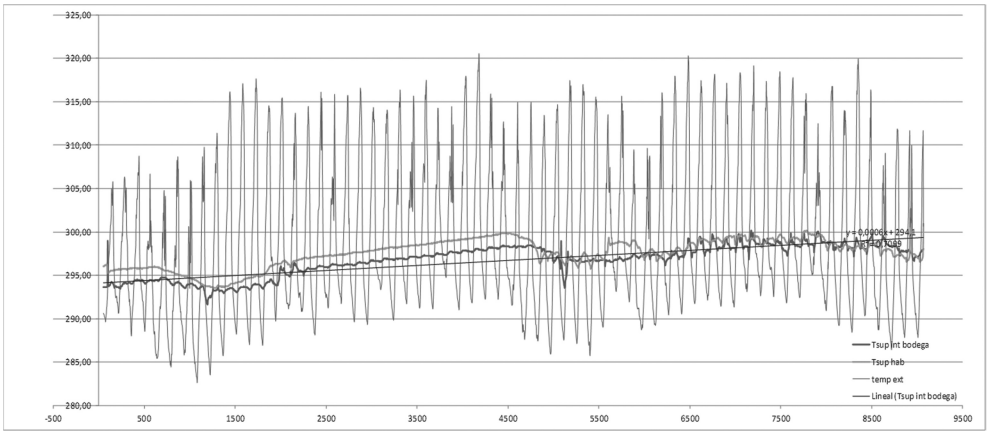
Figure 5. Areas under study on both floors appear highlighted.

The three main variables are:

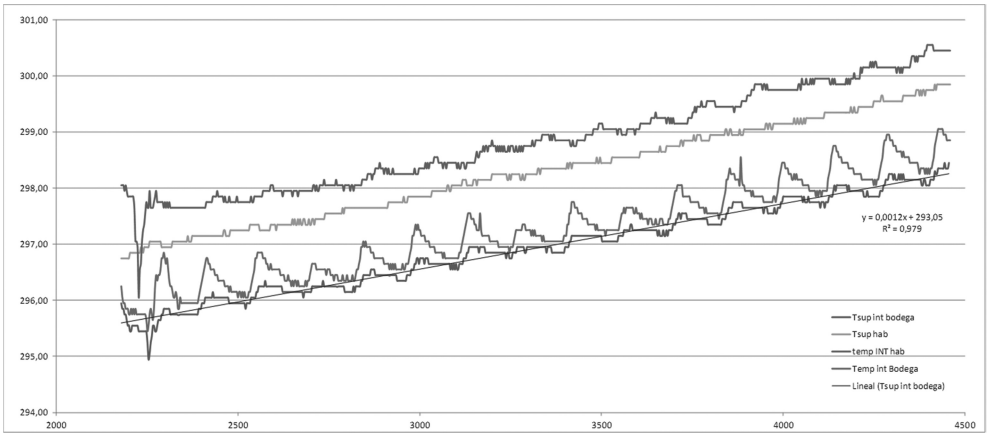
- t_{se} = interior surface temperature of the cellar.
- t_{si} interior surface temperature of the room.
- t_{amb} exterior ambient temperature.

The y-axis shows the temperatures with an interval of 5 ºK while the x-axis represents the 3,006 thirty-minute-long periods assessed.

Firstly the result for t_{se} is observed, with a high frequency of variation between maximum and



Graph 1. Superimposition of room temperatures and ambient temperatures. The black line is the increasing trend due to the thermal mass heating.



Graph 2. Partial study for the period 26/6 - 11/7. The gradient of the line is the first derivative of the differential equation and is associated with the thermal inertia of the rammed earth.

minimum temperatures. In contrast, t_{si} and t_{amb} remain in parallel and constant between 20ºC and 25ºC. t_{amb} is always higher than t_{si}, until late August, when both temperatures are at similar levels, occasionally intersecting when peaking, and with t_{si} higher than t_{amb}. The maximum outdoor surface temperatures of the rammed earth wall reach 40ºC while minimum temperatures do not go below 10ºC. Maximum interior temperatures reach 26ºC and minimum ones do not fall below 18ºC. Secondly, the proportion of exterior and interior temperatures does not remain constant.

When studying the period from June 26th to July 18th in detail a decrease is observed in exterior maximum surface temperatures. Temperatures only increase from July 18th and stabilize at 40ºC. In the case of t_{si} and t_{amb}, this proportional increase is first observed on July 24th from which point there is a progressive increase. The graph shows an increase in interior temperatures from June 24th 2016, six days after the increase in exterior temperatures. This increase is always gradual, following a uniform curve.

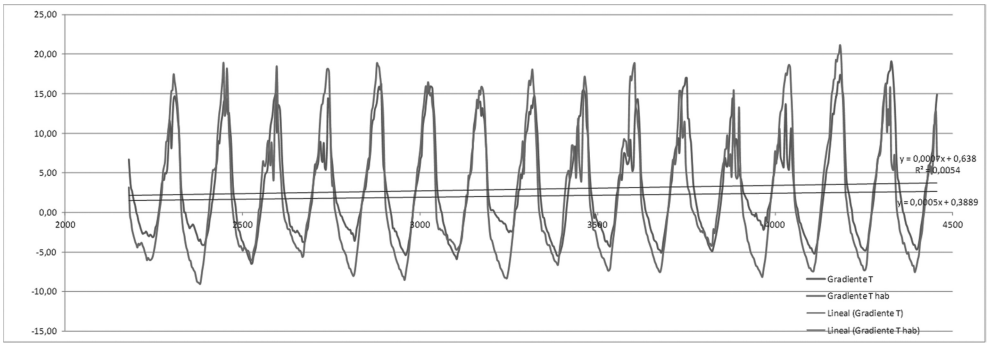
This table shows a summary of data for the period studied, as well as calculations for thermal resistance values and transmittance U [W/m² K] following (Walsh & Delsante and ISO 13786). This incorporates both surface heat resistance and the level of thermal inertia available within an element.

$$\lambda.\frac{\partial^2 T}{\partial^2 t} = c_e.\delta.\frac{\partial T}{\partial t}\frac{d}{\lambda} = R_{cyclic} \quad \frac{\partial^2 T}{\partial^2 t} = \Delta^2 T$$

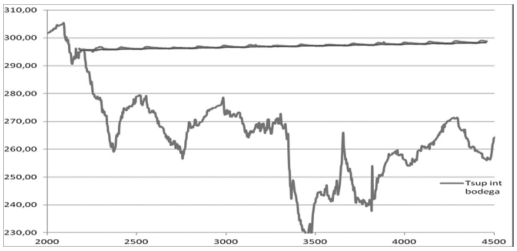
$$I = \sqrt{c_e.\delta.\lambda}$$

Table 1. Summary of total values and results.

				Tse	Tsi	Tse-Tsi	Ti	W	Hri	Rse	Rsi	R	R ciclica	U ciclica
				Temp. Ext. Pared	Temp. Int. Pared		Temp. Ambient	Emitancia		m/s viento me	1/Hri + Hci			
Date Set	Date	Time		TEMPER-ATURE	TEMPERA-TURE		Temper-ature:	Superficie tapia	UNE 6946	5,40				
								Factor emisividad	ε = 0,92					
4459	del 26/06 a 11/07	16:39:04	BODEGA	313,75	298,35	2,99	298,85	4,56	5,54	0,04	0,12	–3,85	2,829	0,33
4459	del 26/06 a 11/07	16:39:05	HABIT-ACIÓN	311,95	299,85	2,16	300,45	4,56	5,63	0,04	0,12	–2,52	2,041	0,45
9070	del 11/07 16:39 al	12/08 17:09	BODEGA	308,55	298,05	1,41	301,35	411,65	5,52	0,04	0,12	–0,58	1,334	0,67
9070	del 11/06 2:09 al	12/08 17:10	HABIT-ACIÓN	300,65	300,95	0,93	299,65	427,91	5,69	0,04	0,12	–0,04	0,881	0,96
9070	del 11/07 16:39 al	12/08 17:11	BODEGA	308,55	298,05	1,99	301,35	411,65	5,52	0,04	0,12	–0.58	1,887	0,49
9070	del 11/07 16:39 al	12/08 17:11	HABIT-ACIÓN	300,65	300,95	1,37	299,65	427,91	5,69	0,04	0,12	–0.04	1,299	0,68
													U media medida	0,59



Graph 3. Thermal gradient from 26/6 to 15/7.



Graph 4. Variability of enthalpy in the cellar.

where: λ = Thermal Conductivity (W/m.K); δ = Density 1850 (kg/m^3); c_e = Specific Heat Capacity (According to Heathcote and Barbeta the specific heat capacity of rammed earth walls can be assumed to be 820 kJ/kg.K. 1 kJ/kg.K = 0.28 W/hKgr.K); T = Temperature (°K); t = time; Δt = thermal gradient (Te-Ti); I = Thermal inertia, square root of the product between thermal conductivity and volumetric heat capacity, where the latter is the product of density and specific heat. $I = \sqrt{C.D.\lambda}$

Values obtained for average transmittance are U = 0.87 w/m^2 K in the room and U = 0.64 w/m^2 K applying a Fourier equation to obtain thermal resistance for stabilized temperature:

$$R = 1/((8*(Tsi - Tamb))/(Tse - Tsi))$$

When analyzing the thermal gradient it should be noted that the trend equation has a slope of 0.0005 (cellar) and 0.0007 (room). The effect is

Table 2. Calculation of enthalpy based the variations in interior humidity.

NO.	DATE	TIME	TEMPERATURE	RELATIVE-HUMIDITY	DEW-POIN	ta 0%HR	PVs	PV	Ha	HAH	Hs	
DATOS TEMPERATURA HUMEDAD—BODEGA									Kgr	Kcal/kg. °C	Entalpia vapo	Dif. Promedio
52	06/11/2016	2:09:38	20,5	77,7	16.4	49,86	20,39	15,85	0,01	11,97	7,05	7,05
53	06/11/2016	2:19:38	20,5	77,8	16.4	49,89	20,39	15,87	0,01	11,97	7,05	0,01
54	06/11/2016	2:29:38	20,5	77,8	16.4	49,89	20,39	15,87	0,01	11,97	7,05	0,00
55	06/11/2016	2:39:38	20,5	77,8	16.4	49,89	20,39	15,87	0,01	11,97	7,05	0,00
56	06/11/2016	2:49:38	20,5	77,8	16.4	49,89	20,39	15,87	0,01	11,97	7,05	0,00
57	06/11/2016	2:59:38	20,5	77,9	16.5	49,93	20,39	15,89	0,01	11,98	7,06	0,01
58	06/11/2016	3:09:38	20,5	78	16.5	49,97	20,39	15,91	0,01	11,99	7,07	0,01
59	06/11/2016	3:19:38	20,5	78,1	16.5	50,01	20,39	15,93	0,01	12,00	7,08	0,01
60	06/11/2016	3:29:38	20,5	78,2	16.5	50,04	20,39	15,95	0,01	12,01	7,09	0,01

Table 3. Comparison of theoretical calculations of transmittance.

TAPIAL REHABILITADO de 60 cm	e spesor (m)	Resistencia R (m^2k/W)	Conductividad (W/mk)	Trasmitancia U (W/m^2K)	U lim
Resistencia interna superficial		0,13			CTE
Revestimiento arcilla interior	0,085	0,129	0,660		
TAIPAL	0,495	0,450	1,1		
acabaado mortero cal exterior	0,020	0,020	1		
Resistencia external superficial		0,040			
TOTAL	0,600	0,77		1,30	0,95
Valor real medido en test				0,59	
				55%	

25% greater in the cellar due to the inertia of the space.

When considering a fifteen-day dynamic cycle U reaches values of 0.45 w/m^2 K, and when considering the summer as a whole, U = 0.68 w/m^2 K. Table 1 shows a summary of results with a final average of 0.59 w/m^2 K. Data were rectified depending on the variations in ambient relative humidity, as enthalpy must be constant. The difference is energy which has dissipated into recirculated air or the earth in the walls due to the surface absorption of ambient humidity. An internal convection coefficient hci of 2.5 W/m^{2o}K is adopted in compliance with UNE6946.

Humid air enthalpy (Hah), where x = kg vapor /kg air, is calculated after establishing vapor pressure and absolute and relative humidity:

$$Hah = 0.24*T + x*(595 + 0.46*T)$$

5 FINAL CALCULATIONS AND CONCLUSIONS

When comparing these results to the theory established in the CTE, with values adopted for earth conductivity based on density and previous laboratory tests, the resulting difference in values is over 55 percent. This is due to long-term thermal inertia. Thermal waves generated fluctuations after 6 days, but on occasion this period has been known to last for months. The differences in U values were contrasted with multiple studies monitoring in situ and it was concluded that the transmittance values of rammed earth may need to be revised to almost half of what is applied within the current regulatory framework.

This work is due to be completed shortly with a complementary study on cold weather periods, and with greater control of the enthalpy based on the rammed earth absorption of ambient humidity.

It should be remembered that the different classes of clays and their different kind of crystallization generate structures of different densities, with more hygroscopic capacity, cation exchange or anisotropy. For this reason the current reductionism in the thermal behavior of the walls generates a depreciation of this noble, millennial, and sustainable material.

NOTE

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Using machine-dismantled cotton seed hulls in the making of light earth blocks

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ABSTRACT: This report describes the making of Light Earth Blocks (LEB) using the waste from cotton ginning waste and slip (a mix of clay and water) in different proportions. Bearing capacity and thermal insulation of obtained blocks was then assessed. As today there is a wide array of experience in slip binding from different vegetable fibers, the aim of this work is to analize comparatively the physical properties of cotton ginning waste light earth and the ones of their widely studied analogues, such as light earth with straw and wood chips (Volhard, 2016). Results show the possibility of getting a very low density and easy to manufacture material which, despite its limited compression resistance, has a very good thermal insulation capacity that is entirely compatible with the required provisions to solve the housing deficit of the cotton production region in Argentina.

1 INTRODUCTION

According to the International Cotton Advisory Committee (ICAC 2012), during the 2012/2013 season 25,1 million tons of cotton were produced around the world. The largest producing countries in that season were China 6,42 million t, India 5,43 million tons, the USA 3,73 million t, Pakistan 2,1 million t and Australia 1,07 million t.

Argentina produced approximately 1 million tons of gross cotton in the last seasons which left 300,000 t of waste ("cascarilla" in Spanish) (35% of cotton production) composed by fibres, carpels, impurities, etc. These wastes had no intended destination. It is important to highlight that, due to mechanical cotton harvesting, which improves the profitability of cotton growing, a larger amount of cotton gin waste is produced (MINAGRI 2014).

In many cases the choice is to calcine this waste because many ginning machines are located in urban areas and provoke serious pollution problems, discomfort and chances of respiratory disorders (IOMC 2005). The open air storage of the wastes needs extensive lands for ginning machines and equipment to be moved. They are also exposed to unintentional fires and vermin proliferation (Carrasco 2015).

Results from the 2010 Census show that in Argentina 17.5% of houses have inadequate and incomplete external enclosures. The following materials identified were brick, stone masonry, unplastered blocks and concrete walls, wooden, metal or fibre cement, *chorizo* (clay strip), cardboard, palm, only straw or waste material. However, in the cotton production region the percentages rise to 25.3% in the province of Corrientes, 29.1% in the province of Santiago del Estero, 31.6% in the province of Chaco and 33.8% in the province of Formosa (INDEC 2010).

These situations differ from the standing recommendations for house building. They state the need of using insulating materials that reduce heat transmission through casings and light roofing (Carrasco 2015). Improvement in insulation can be achieved by the use of natural or industrialised materials, the difference between them being their evironmental effects. Industrialised materials need considerable amounts of power to be produced and transported from the plant to a final destination. Recycling wastes from industrialised materials after their lifespan in a house also becomes a drawback. Natural materials show an advantage. If they are near the place where they will be used (which should be a must criterion for their use), reduce power consumption and have minor negative environmental consequences (Placitelli 2012).

Developing these building materials with cotton seed hulls and using them would allow to approach simultaneously the environmental problems of this agro-industrial sector and the need to respond to the regional housing deficit with low cost and easy-to-produce technologies.

Although in previous research the possibility of producing building material using earth and local agricultural wastes (rice straw and cotton seed hulls) as raw materials (Cabrera 2016) was presented, a more detail analysis of the relationship between the dosage of light earth and its physical

properties with an emphasis on density, compression resistance and the thermal conductivity coefficient becomes necessary.

This paper firstly shows the specific methodology used in the making of light earth blocks and the tests made upon them. Secondly, a comparative analysis between the physical properties of light earth made with cotton ginning waste and the ones of their widely studied analogues, such as light earth with straw and wood chips is shown. Finally, some conclusions are drawn as to this study.

2 MATERIALS AND METHODS

2.1 *Moulding methodology*

The materials used for the current study were cotton seed hulls, clay and water. The cotton seed hulls were provided by ACRIBA S.A. from Villa Minetti, Santa Fe (Fig. 1), a cotton ginning company; whereas the clay came from Cerro Negro quarry, in Córdoba. After being tested, the soil was categorised as a "high plasticity CLAY CH" according to the USCS classification system.

With the help of previous research (Cabrera 2016) three dosages were proposed according to the dry materials weight (see Table 1).

Unlike previous experiences in which density variation was obtained modifying compaction energy given during moulding, this time each dosage was devised varying significantly the slip's clay/water ratio in order to obtain well-defined density ranges, being dosage the only variable.

Whereas the clay/water ratio was imposed for each dosage (independent variables) the amount of waste to be incorporated in each of them was previously studied in an attempt to acomplish the following premise: adding the maximum waste possible not to alter mixing and a final homogeneous material.



Figure 1. Cotton seed waste (cotton seed hull).

Table 1. Dosages.

Dosage	Water/clay ratio	Percentage content %			Waste/clay ratio
		Water	Clay	Waste	
1	1.22	46.9	38.4	14.7	0.38
2	1.00	42.5	42.5	15.0	0.35
3	0.67	35.0	52.4	12.6	0.24

In previous experiences, it was determined that the higher the clay/water ratio of the mix is the higher the clay/waste ratio becomes, which implicitly lowers light earth density. This is consistent with Franz Volhard's who used straw and wood chips as aggregates.

Finally, Table 1 shows the three proposed dosages and the clay/water and waste/clay ratios for each of them.

Eight prismatic blocks of 45 × 25 × 15 cm for each of the dosages were moulded, observing the following procedure: firstly, slip was made by mixing clay and the necessary water inside a mechanical mixer. Mixing time required to get a homogeneous slip without lumps was 3 minutes. After that, the mix was transfered into a plastic bowl to let it rest for 24 hours.This process helps clay particles hydration and improves slip's consistency.

Finally, after the 24 hours, slip was reintroduced inside the mixer on, cotton gin waste was then poured gradually. Once incorporated the agreed amount of waste, everything was mixed at a constant speed for 2 minutes.It is of utmost importance that all particles from the agricultural waste are soaked in slip to avoid direct exposure of the waste to the environment. Once soaked, decay and insect nesting inside it are prevented. This coating is evidenced by the colour of the mix which must be completely homogeneous.

Block moulding was done manually and no compaction energy was given due to the fact that density variation in each of the series aimed to be achieved only modifying dosage and not compaction energy as in previous experiences (Cabrera 2016). The material was "manually placed" inside the mould so as to leave no room in it and to avoid empty spaces and hollows. Because they presented high dimensional stability during their wet stage, block dismoulding was done immediately.

According to previous research, it has been stated that normal lab conditions for drying this material are between 3 to 5 weeks depending on the water/clay ratio with which the blocks are made and on their size mainly. This is the reason why, during this current research, moulded blocks were

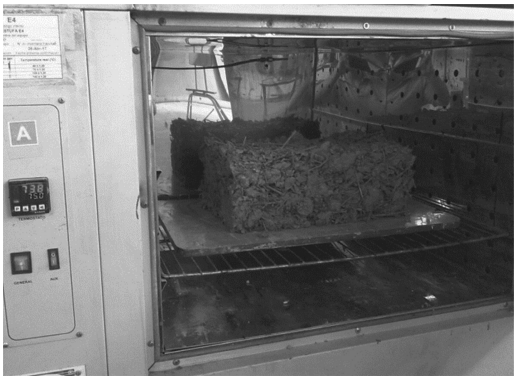


Figure 2. Drying of an light earth block (LEB) with a stove in 75°C.

taken to a stove to be dried at a controlled temperature (75ºC). Drying time was reduced to 2, 3 and 3,5 days according to the water/clay ratio used, it was the only incidence variable due to the fact that all blocks were the same size. This procedure aimed at minimising drying time and also preventing mould formation around the block walls during that time.

2.2 *Bulk density determination*

Each moulded block's density (ρ) was determined through equation 1, where mass (m) was obtained weighing each dry block on a digital scale with a 0.05 kg sensitivity. Volume determination was done

$$\rho = \frac{m}{vol} \tag{1}$$

using geometrical methods, each block considered as a perfect prism. In order to do this, the four longitudinal (L), the four vertical (H) and the four transverse (E) edges of each block were measured using a steel ruler with a tolerance of 0.5 mm. Finally, the length, height and thickness of each block were calculated from these measures (Lprom, Hprom and Eprom) with which the apparent volume was determined by using formula 2.

$$vol = Lprom * Hprom * Eprom \tag{2}$$

2.3 *Compression resistance*

In order to determine the bearing capacity of the blocks and find a correlation between this and their density, resistance to simple compression (σ) was tested in all of them by means of equation 2, where N is the maximum shear load borne by the block in *Kg* and A is the block's upper face (in cm^2) upon which the load will be applied.

$$\sigma = \frac{N}{A} \tag{2}$$

Given that the material used can be considered "non conventional", there is not a standard to describe the testing procedure to follow in order to determine compression resistance yet.

Likewise, these blocks rigidity is significantly lower than that of conventional concrete blocks or ordinary clay bricks, which will make their "failure" not easily noticeable. On these grounds, for resistance determination, as a shear load N, the load value associated to a 10% deformity related to the original block's height was adopted.

For the test, a gantry crane with a hydraulic press (20 t top capacity) and a Sipel load cell with 5 kg accuracy were used. Collapse deformation was measured using a centesimal comparator gauge with 0.01 mm tolerance (Fig. 3).

2.4 *Thermal conductivity coefficient (λ)*

The Lees and Charlton method was used to determine the thermal conductivity coefficient of the blocks. This test was done on three test tubes of different densities (a test tube for each initially stated dosage) to explore the relationship between the material density and its thermal insulation

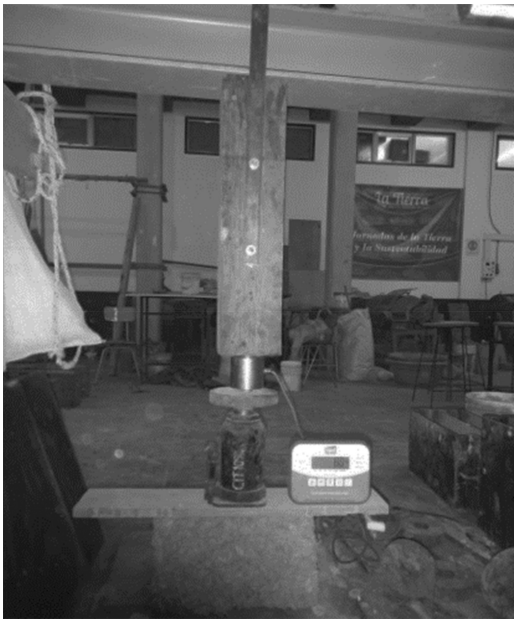


Figure 3. Compression test on a Light Earth Block (LEB).

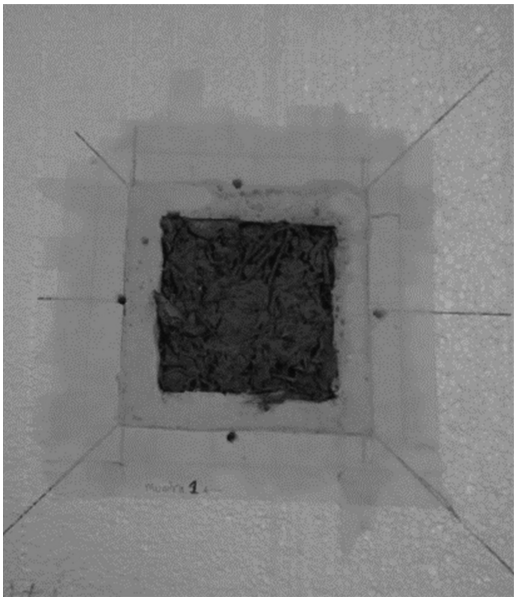


Figure 4. 13 × 13 × 5 cm test tube for thermal conductivity test.

capacity. Each test tube was molded following the procedure explained in 2.1, only the size was changed (13 × 13 × 5 cm). At the same time, given that the test was considered as "non destructive", two determinations of the thermal conductivity coefficient were done on each test tube, rotating them 180° between every test. Figure 4 shows one of the molded test tubes.

For the apparatus used to determine the thermal conductivity coefficient has been slightly modified compared to the Lees and Charlton original one, the figures obtained should be affected by a correction index to be compared to the thermal conductivity coefficients of the materials stated in the IRAM 11601 standard. This index has not been accurately determined yet. In spite of that, this apparatus proved extremely useful to compare each test tube figure when the relationship between light earth thermal conductivity and its density were tested.

3 RESULTS

Table 2 shows the results obtained in the compression density and resistance determination of each block, whereas Table 3 shows the compression density mean and resistance determination mean of each dosage and its corresponding SD (*st*).

Table 4 shows the results obtained after doing the Lees and Charlton test in order to determine

Table 2. Density and compression resistance in each block.

Block		ρ	σ
Dosage	Identification	Kg/m^3	Kg/cm^2
1	I1	490	0.55
1	I2	475	0.58
1	J1	390	0.40
1	J2	481	0.46
1	J3	373	0.31
1	J4	467	0.44
1	J5	477	0.48
1	J6	408	0,39
2	D1	488	0,55
2	E1	548	0,94
2	E2	587	1,02
2	E3	680	1,31
2	F1	579	1,02
2	F2	545	0,87
2	F3	614	0,66
2	F4	555	0,75
3	G1	868	2,95
3	G2	644	1,49
3	G3	816	2,39
3	H1	660	1,68
3	H2	763	2,58
3	H3	809	2,05
3	H4	751	1,92
3	H5	702	1,49

Table 3. Density and compression resistance mean in each dosage.

	ρ		σ	
	Kg/m^3		Kg/cm^2	
Dosage	Mean ρ	St	Mean σ	St
1	445	44	0.45	0.08
2	574	53	0.89	0.22
3	752	74	2.07	0.50

Table 4. Thermal conductivity coefficient.

	λ	Mean λ	ρ
Test tube	W/C°m	W/C°m	Kg/cm^3
Dosage 1 – 1st. Test	0.508	0.492	420
Dosage 1 – 2nd. Test	0.476		
Dosage 2 – 1st. Test	0.553	0.515	550
Dosage 2 – 2nd. Test	0.490		
Dosage 3 – 1st. Test	0.547	0.553	648
Dosage 3 – 2nd. Test	0.56		

the thermal conductivity coefficient (λ) corresponding to each dosage. Table 4 also shows each tested test tube's density which resemble the block's mean density corresponding to each dosage.

4 DISCUSSION

4.1 *Dosage correlation vs. density, and density vs. compression resistance. statistical analysis*

In order to test the stated hypotheses results were subjected to an analysis of variance (ANOVA) for determining if the arithmetic density and compression mean of each dosage differed between them. This analysis allowed the comparison of variance between the means of the groups and the variance in each group. This analysis finally determined if the study groups (each dosage) belonged to the same bigger population or if they belonged to different groups with different characteristics (Tellez Piñerez & Lemus 2003). RStudio software was used to process data as shown in Figures 5 and 6.

After the analysis it can be stated that the light earth dosage (water/clay ratio and the amount of agricultural waste) influences its density and compression resistance, something that proves a correlation between the light earth density and its simple compression strength: *the denser the material, the higher its compression strength*.

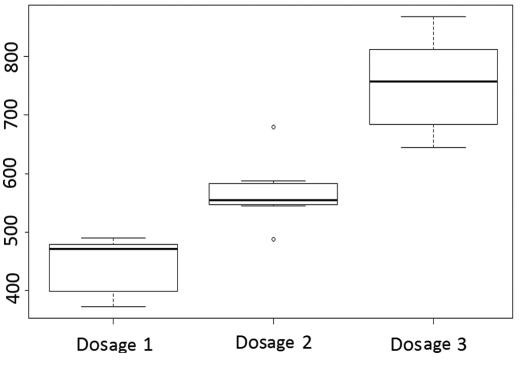


Figure 5. Analysis of variance. Dosage vs. Density.

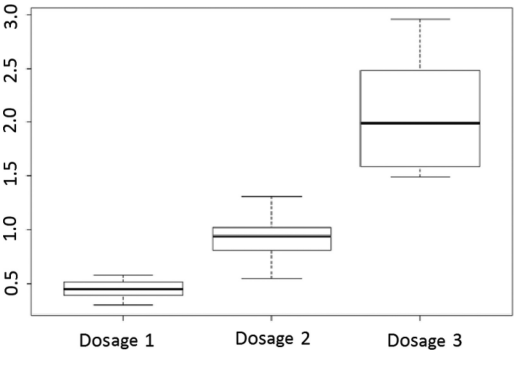


Figure 6. Analysis of variance. dosage vs. compression resistance.

It is relevant to highlight that these results are consistent with the results published by Franz Volhard in his book entitled "Construire en terre allégée." Volhard stated that by using staw and wood chips as aggregate materials to light earth, a range of 450 y 900 Kg/m^3 density is achieved by only varying the amount of earth, water and aggregates and without varying the compaction energy given.

It is worth highlighting that, despite the promising data obtained from the analysis of variance, the differences between the maximum and minimum density of each dosage were 24%, 29% and 26% respectively. This variation can be attributed either to the moulding procedure used –particularly to the light earth manually filled into the moulds- or to the applied methodology to determine each block's volume, considering the blocks as regular prisms and using geometry formulas.

4.2 *Bearing capacity*

As it was explained in 2.3, nowadays there is not a standard that determines a minimum compression resistance value to be reached in order to consider that light earth blocks are "bearing" or "non bearing". However, the values stated in the following standards can be taken as reference:

- Peruvian Standard E.080: Sets minimum compression resistance for adobe: 1.2 MPa;
- Spanish Standard UNE-EN 772-1:2002: It states that for a LEB to be apt for enclosures (non bearing) its resistance should be greater than 1.3 MPa;
- IRAM Standard 12566-1*: It states that for common bricks and blocks the value of compression strength should be the same or greater than 4 MPa;
- IRAM Standard 12566-2*: It states that for non bearing hollow bricks and blocks the value of compression strength should be the same or greater than 1.5 MPa;
- IRAM Standard 11561-2*: It states that for non bearing concrete blocks the value of compression strength should be the same or greater than 2 MPa.

It can be confirmed that either for the bearing capacity of light earth blocks manufactured with cotton seed hulls aggregates or for light earth with straw and wood chips the sampled density ranges (Volhard 2016), are insufficient when comparing compression resistance of the tested light earth blocks (in all cases

Table 5. Thermal conductivity coefficient for earth materials according to standard DIN 4108-4 2014: Thermal insulation and energy saving in buildings. Hygrothermal design values.

Density ρ	Thermal conductivity coefficient λ
Kg/m^3	W/m °K
300	0.1
400	0.12
600	0.17
800	0.25
1000	0.35
1200	0.47
1400	0.59
1600	0.73

lower than 0.3 MPa) with the minimum values set in the standards referred to above.

4.3 *Thermal insulation*

From Table 4, it can be concluded that, the higher the density of light earth the sensitively higher its thermal conductance coefficient (λ). This allows us to say that the lower the density of the manufactured material, the higher its thermal insulation capacity, which can be attributed to the increase in the amount of ocluded air in the interstices of the light earth. This last statement is consistent with what is set in the German standard DIN 4108-4: 2014 (see Table 5), and with Volhard's results when he studied the hygrothermal properties of light earth with straw and wood chips.

5 CONCLUSIONS

The results of the research suggest that it is possible to make building materials using earth and cotton seed hulls as raw materials by using easy-to-apply technology.

The manufacturing of "bearing" elements is not possible due to low compression resistence of this material. However, its low density and low thermal conductivity coefficient pose the possibility of making housing materials for enclosures to improve thermal insulation in houses.

Even when the initial hypotheses are tested, further research is needed to validate the material's coefficient of thermal transmittance. If inconsistencies are found, the reasons between thermal insulation values and those stated for earth-made materials from rammed earth in the German standard (DIN 4108-4) would also need to be checked.

The findings of this study suggest that the use of cotton seed hulls mixed with rammed earth as building materials could contribute to alleviate the environmental issues of this agribusiness sector and the housing deficit of the country's cotton productive region and be at the same time a labour alternative for the population.

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The *systemic approach* in the intervention on earthen architecture

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ABSTRACT: The application of the systemic approach in the field of monumental architecture heritage has led to a Systemic Method, which allows us to structure and to integrate, without repetitions, the cadence of all the necessary operations in order to carry out a proper intervention in a building, from its knowledge until the selection of criteria on the architectural project. But earthen architecture has a different history. The main point is that the restoration of monumental architecture has a tradition of over four centuries, which brings endless ideas about applicable experiences and intervention in earthen architecture does not exceed three or four decades. The previous scheme is not useful and it is necessary to design another one, albeit following the same principles. The purpose of this paper is to propose a new systemic method for the earthen architecture which operates in a similar way to what is explained about monumental architecture.

1 INTRODUCTION

At the beginning of our professional activity in heritage intervention, we verified the absence in our environment of a theoretical approach adapted to the right way of practising the profession. The search for suitable methods to teach and the epistemological development of the subject matter found in the *systemic approach*—although alien to heritage restoration—a set of powerful conceptual instruments.

Several authors have dealt with systemic philosophy throughout its long history, but it is Mario Bunge (Bunge 2003, 2004) who has best developed it in an operative way, at least in terms of our interests.

One of his simple phrases helps differentiating Systemism from concepts with which it has certain concomitances: *Individualism sees trees but misses the forest, whereas holism sees the forest but overlooks the trees. Only the systemic approach facilitates our noticing both the trees (and heir components) and the forest (and its larger environment)*. It is possible to add the next statement: *Systemism is the view that everything is a system or a component of one* (Bunge 2003).

A system requires: a *composition*, or collection of all components of the system; an *environment*, or selection of elements outside the composition but acting on its components or vice versa; a *structure*, or the collection of relations or links, which occur among the components of the system (endostructure) or between them and the elements of the environment (exostructure); and a *mechanism*, or collection of system processes that make it behave the way it does. Besides, in general, any system has a *purpose*; for example, the cardiovascular one carries oxygen to the cellular tissues, or the system formed by a newspaper company generates information.

Its application in teaching activities (Dossier MSIEH 2016) in the field of monumental architectural heritage has led to make explicit and to analyse two systems that are implicit in this field: in the first one, the components of the system are the existing buildings; and the second one includes all ideas about actual ways of intervening in existing monumental buildings. From the interconnection between the two approaches or systems we achieve the method, called the Systemic Method, which allows us to structure and to integrate, without repetitions or absences, the cadence of all the necessary operations in order to do a proper intervention in a building, from its complete knowledge up to the selection of criteria for the architectural project of the different elements of the monument and its realization.

But we are talking about SOStierra and because of the multiple and a deeply differential characteristic of earthen architecture, the previous scheme is not useful and it is necessary to design another one, although following the same principles.

The main difference is that the restoration of monumental architecture has a tradition of over four centuries that brings endless ideas about applicable experiences and the intervention in earthen architecture does not exceed three or four decades; although we already have recent contributions of a very important qualitative and quantitative level (Mileto, Vegas, García Soriano, Cristini 2015).

After several trials the following scheme is proposed for discussion.

2 PROPOSED SCHEME

The proposed scheme also consists of two systems interrelated with each other, being the particular purpose of each generating information that flows from the first to the second and vice versa; and being the overall purpose to solve the basic problem of the SOStierra project, that is to develop a systemic approach that operates in a similar way to what is said about monumental architecture. In other words, to structure and to integrate, without repetitions or absences, the cadence of all the operations required for the intervention, in this case, in a building of earthen architecture. And it can be done for both the individual case as well as the global case studies.

As we will see in the following lines, the first system– the one about the buildings– is sufficiently elaborated, taking into account the experience of the method in monumental architecture. The same does not happen with the second system, because the experience from the equivalent in the monumental system is not fully applicable. In order to increase its degree of elaboration we propose to develop this task here during the sessions of SOStierra.

3 THE FIRST SYSTEM: THE EARTHEN BUILDINGS

Components. The existing earthen buildings that, for one reason or another, should all be studied.

Environment. The natural environment, the land and the climatic action. The anthropic environment: individual people or groups of people who have created or currently transform earthen buildings.

Exostructure: links between the buildings and the anthropic environment

The initial promoters of the building, or its subsequent interventions, who can be the legal owner or even a public entity; the direct user of the building, for two reasons; for being the potential promoter of changes and because of the use that tends to degrade the building; the professionals of the construction/intervention who, at the request of a promoter and/or users, carry out their work in a certain way.

Exostructure: links to the natural environment. The buildings are clearly linked to the climate that surrounds them and to the land where they settle; both cause their degradation.

Endostructure: links between the buildings themselves. There can be of many kinds; for example, one can be the party walls. Another useful feature is the function, which makes possible to classify buildings (e.g. housing, schools, churches, theatres, hospitals, etc.). However, now is about classifying buildings according to the different characteristics which, in some way, can influence how they have to be refurbished.

The year of construction, it is not the same a building built 20 years ago than another built 200 years ago; its initial use.

If a refurbishment has already been made, it is important to know when, its magnitude and if it has led to a new use. The location of the building, which includes the regional geographical area and the immediate surroundings.

The type of building, which can be of different scales; the one of the building, according to its original function—castle, palace, house, etc. –and the one of its structural-constructive configuration –rammed earth technique, adobe, etc.

The sum of all these characteristics orders the set of buildings in an operative way, because each building will be clearly identified, characterised and differentiated.

Mechanism. The action mechanism of the natural environment is well-known and needs no additional explanation.

On the action mechanism of the anthropic environment, it can be:

- negative: behaviours which destroy buildings, for example wars, and—to a lesser or greater extent –wear and tear.
- positive: the restoration or rehabilitation, which is the mechanism that interests us, and particularly the reason why.

Experience allows us to draft an initial list of reasons or causes, from avoiding wear and tear or a

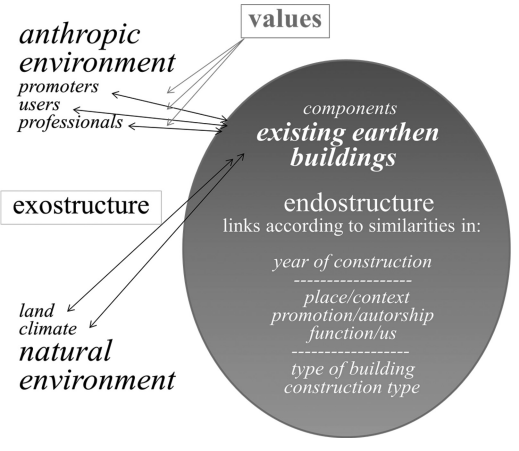


Figure 1. The first system.

collapse, to recovering a colour, a texture, an image lost by the passing of time, or improving habitability conditions, etc.

These are the objectives of the intervention, some of which, as mentioned above, do not represent a change of use of the building. Obviously, in many cases the intervention project is a change of the use of the building, in some cases already decided, like a library or a museum, but in other cases it will be decided once the buildings are thoroughly known. In any case, the objective of all these decisions is the concept, in its broadest sense, of the *increase in value.*

Purpose of the system. Obtaining information about the existing earthen buildings to know them better, in order to restore or rehabilitate them, or to extract experiences about their behaviour before and after a possible intervention. As it was said earlier, this information will be transferred to the second system. Undoubtedly, all the above data is essential to make a good intervention and, therefore, it is important to structure it in the best possible way. In order to do so, the experience gathered has proved that the so-called characterization is useful.

4 RESULTS OF THE FIRST SYSTEM

4.1 *Characterization*

It collects in a single document the history of the building including the mentioned attributes which characterise the building in future historical phases.

It is necessary to add that only the interventions that have meant a major transformation must be mentioned in the history and also the reasons why. All this will allow us to understand the current state of the building.

With regards to the constructive type, it is important mentioning that we define it as each of the particular combinations established by the constructive tradition of the variants that are given in the constituent parts of a constructive element, the whole structure, the walls, the floors, plasters, tiles etc.

Table 1. A representative scheme.

	History (in years)			
CHARACTERIZATION	Original	Phase 1	...	Current
Place/context				
Promotion/authorship				
Function/use				
Type of building				
Construction Types				

The knowledge of the different types allows us to simplify the studies, since buildings of the same type present many common characteristics.

A remarkable feature of the earthen architecture in our country is the existence of an extraordinary exhaustive list of constructive types on earth (Mileto, C. et al. 2011 & 2014), something thatdoes not happen in the field of monumental architecture.

4.2 *Valuation as a mechanism*

The purpose of a valuation is to establish the values of the building, as well as of any of its parts or some of its constructive elements to use, retain and transmit them. But, even though with the previous explanations is possible to characterise the buildings, finding the values of a building is not an easy task.

So as not to make this paper longer, we will use, without justification, the evaluation criteria obtained by the historical study derived from the second systemic approach made on the monumental buildings, which give us, as it has already been mentioned, a whole experience of four centuries. The study was developed by Albert Casals. The valuation procedure is based on key authors in this field, such as Riegl (1998) and A. González (1998), who are given more practical operation.

However, the list must add values that are specific to the earthen architecture and not found in monumental buildings.

For all these values, we propose the following definitions, many of them original ones:

- *Use values.* In rough outlines they are objective.
- *Architectural value of the performance of the building.* It is formed by the set of material qualities of the building in relation to its potential use nowadays. This is obtained through the evaluation according to the CTE of 2013 and other regulations which must be met with additional assessments, since not all the desired results have requirements established by the CTE or other standards. One of them, for example, is the possible durability, or even more importantly, an overall view on the conservation status, which covers everything related to pathological statuses. The definitive version of the Technical Code of 2013 includes the Flexibility Principle, which makes it easier to comply with the works on heritage buildings, even if the earthen architecture is not contemplated in it. It seems essential to redraft a new document similar to the one that led to the transformation of the CTE (González 2009). SOStierra could be an opportunity to give it a new push.

The aesthetic component of architectural value, totally subjective, has been placed in the significant category.

In any case, architectural value can also be considered without further qualification, provided that its two facets meet in an essential and inseparable way.

- *Location value*. *Immaterial*. Set of intangible links between the building and the land where it is located, identifies and, for certain people, it turns it into a place. *Material*. A set of material qualities in relation to its environment—topological, accessibility—as well as its compliance with current legal regulations (classification, qualification, suitability for building, affectations, etc.).
- *Economic value.* The economic value is based on the qualities defined by the economic value of the building, according to the laws of the market, being the cadastral and urban values the first ones.
- *Green value.* Any building has an ecological value because in terms of energetic cost, the refurbishment of the building is less expensive than its demolition and new built. Any earthen building, obviously, has the previous value, and other because earthen buildings are a palpable demonstration of a total adaptation to the natural and economic environment.
- *Documentary values.* Architectural value and/or historical building. Any building is an extraordinary document of the architecture and construction of its building time.

We need to add the historical and anthropological values of which the building also represent.

Significant values

Aesthetic architectural value. It relates to the *Kuntswollen* (feeling or will of the art) nowadays.

Identity value. Qualities of the building that suggest or establish a relation of belonging to the social environment where it is located. Sometimes, the disappearance of a building, or one of its parts, carries a feeling of deep regret for a certain group.

Iconic value. Set of semiotic qualities that confer a character of sign in the physical and social environment where it is located.

Antiquity value. Quality of aesthetic order derived from the contemplation of the cycle life—death—destruction caused by the passing of time.

Meeting or adding some of these values can contribute to the building with an added value that we can define as singularity.

It should be noted that the first two types of values, use and documentary, may be considered as quite objective. The third type is purely subjective and must be determined by some kind of contact or consultation with the communities related to the building or monument.

In conclusion, all the reasons that promote intervention processes in existing buildings have in common either preserving a proper value of the building or set of buildings or increasing some of its values that can be practical, documentary or significant.

The usual name of the procedures by which we can objectively characterise and evaluate the building is previous studies as it is well-known in the professional field, it does not need to be detailed now.

Interrelation between objectives, characterisation and valuation

Once the buildings has been characterised and valued, it is possible to find, among many others, the following cases:

1. The presumed use values are initially inferior and insufficient for the uses and it means a transformation of the building that clearly diminishes the documentary or significant values.
2. Documentary values are so high that any intervention can destroy them
3. Significant values are of such a level to prevail over the other two
4. All the possible combinations that would oblige to vary the objectives and to restart the process on any building or on any of its parts.
5. There is no apparent contradiction between the initial objectives, the values of the building and the possibilities it offers. In this case, it is necessary to organise all the results obtained so that the information is clear and valuable to be used after its passed through the flow of information.

Information flow. It arises from the first system to the second and contains the characterisation and evaluation of the buildings of the system studied.

Once they reach the second system, the second phase of the process must commence, as it has been mentioned; it must structure and integrate the cadence of all necessary operations for the intervention without repetitions or absences. In turn, it must generate a new flow of information that will return to the first system to apply to the building or buildings from which the previous data was obtained.

5 THE SECOND SYSTEM: IDEAS AND CRITERIA FOR INTERVENING

As it seems more explanatory, we will start with the purpose.

Purpose. Taking into account the information provided by the first system, the second system must generate the general criteria for intervention and the necessary and sufficient performance of building criteria in order to designing and carrying out the restoration or rehabilitation of earthen architecture buildings. These criteria will constitute the informa-

tion flow from the second system to the first system. More precise definitions are given below.

Components. Ideas about modes, manners, criteria and procedures about how to do an intervention in earthen buildings. (In order to avoid a constant repetition whenever the word "ideas" appears it must be understood that it is about modes, manners, etc.)

Environment. Natural-anthropic indirect. Ideas arising from experiences on the behaviour of existing buildings in which changes have occurred through mechanisms of intervention and/or mechanisms of natural action.

Anthropic Direct: disciplinary, professional, legal, social, economic, cultural. (See mechanisms)

Exostructure

Links between ideas or ways of doing with the natural and anthropic environment. (See mechanisms)

Endostructure

If all ideas were deposited in texts, a possible structure would be the decimal classification of a specialized library. However, experience shows us that reality is not well captured in that classification; there are many ideas that we cannot find in libraries but they can appear in the exchange of experiences between people who share experiences in buildings or processes; it could happen in seminars or meetings like this one. This structure has to be elaborated.

Since the engine of the intervention is to increase the values, as a proposal to be tested, the structure can be given by ideas that seek to improve use values, those that seek documentaries and those that do it with significant ones, and obviously all the subcategories already mentioned and their possible combinations. In addition, the internal structure, together with the mechanisms, should facilitate the results indicated below

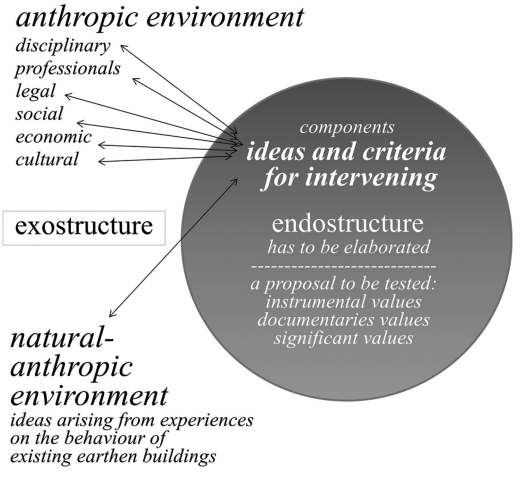


Figure 2. The second system.

Mechanisms. They drive the transformation of ideas:

- Through links of the natural-anthropic exterior structure; the experience of the behaviour of existing buildings without intervention or just the intervention subjected to natural degradation factors.
- Through links of the direct anthropic external structure, which can be:
- *Disciplinary* (*theoretical*, theory developed by architects, *applications*, incorporating new theoretical approaches to real activity)
- *Professionals*, opinions on any intervention, etc.
- *Legal and political*: legal provisions on restoration, public expectations about the role of restoration as a vehicle for social cohesion, as a show of prestige, etc.
- *Economic*: the monument as a local or supralocal economic engine, as a dynamist, as a generator of resources.
- *Cultural*: aesthetic social and environmental assessment of the monument: pedagogical object, way of knowledge, individual and social identification motivation, object of cultural tourism.

6 RESULTS OF THE SECOND SYSTEM

The interconnection amongst all ideas operated by the internal structure and the mechanisms must be such as to give rise to the following results.

General criteria for intervention

The criterion of intervention is understood as a set of rules, norms, evaluations or judgments according to which the building is to be intervened in order to increase its architectural, documentary or significant global values. And the criterion of performance of building is understood as a set of the same type but applied to the improvement of the performance of building values of the constructive elements.

If, in order to elaborate these criteria, we have to start from scratch, let us imagine, that because it is an activity with no past, the uncertainties about the effectiveness of the contributions offered by the direct anthropic environment would be unbeatable. But the building refurbishment is an activity with a very dense past and the links of the natural anthropic natural structure in the field of the monumental heritage give us almost extensive information, not so much in the field of earthen architecture, although some of them extremely valuable (Mileto, Vegas 2014).

As an example to be completed during the course of the SOStierra, it is proposed to merge the previous valuable contributions with those of the teachers of the mentioned Master, which

Table 2. General criteria of intervention.

PROCEDURES		
Generals	Particulars	MODE
RESTORATION (Subtraction and addition)	All valuable elements are maintained and their initial state is fully recovered	
ADDITION	Completion of original	Analogy
	General	
	Partial	Contrast
	Reintegration	
	of image	
	of lacuna	Harmonic diachrony
	Anastylosis	
	Functional addition	
	Above	
	New elem.	Integration
	Facilities	
	Next to	
	Protection	Mimesis
	From the weather	
	Of the land	
	From anthropic ac.	
	Consolidation Structural	Likeness typological
	Of material	
	Structural reinforcement	Simplification.
SUBSTRACTION	Release of excrescences Total cleanliness	Solid
	Cleaning with patina conservation	capable
RECONSTRUCTION. Of a monument or fragment of great size destroyed or missing	*Dov'era e com'era*	
	Virtual	
	Physical	
	By computer	
NEW COSTRUCTION Of a monument or a part that has never existed	Deferred execution	
	In style	
	Philological	
	Virtual	

concludes that the general criteria of intervention are formed by the sum of general and particular procedures, formal ways of definingthem and principles that all of them have to meet.

The principles are: minimal intervention, reversibility, compatibility, discern, conservation of strata of history, environmental conservation, integration in the environment, integration in the monument of functional additions, durability, maintainability and, the most difficult to define but the most important one, authenticity.

Performance of building criteria. The performance of building evaluation of the building will have defined the main deficiencies. The performance of building criteria of intervention will be part of establish those procedures rules or general criteria to solve those deficiencies.

Information flow. It will comprise the general criteria of intervention, the performance of building criteria and some initial proposal of a specific technique; all of them are the most appropriate for the building of the first system (or set of similar buildings) that has started the whole process, which has the intention of finding a way of common intervention. In the case of the specific building, this information must be assumed by the competent technician who carries out the final project as an activity with its own rules and outside the systemic approach, but taking into account that it is possible to find new data at the beginning of the work impossible to detect by these first previous studies. In that case, it will be necessary to re-apply the systemic approach, perhaps by repeating some of the initial studies and re-elaborating everything said through the process of the second system.

7 ACHIEVABLE GLOBAL RESULTS

The successive application of the two flows of information will allow us to feed back what we have called the natural-anthropic environment of the

second system, from the experiences of the interventions following the two systemic approaches. The components of the second system, i.e. ideas about modes, manners, criteria and procedures on how to refurbish earthen buildings, undoubtedly will be increasing and will be organised through a structure, of which only a small proposal has been made previously, and which will be elaborated definitively in this symposium or in the next one.

NOTE

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Kasbah Taourirt: Conserving earthen heritage in Morocco

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ABSTRACT: Southern Morocco is home to thousands of earthen *kasbahs* and *ksour,* or fortified earthen settlements. In 2011 the Getty Conservation Institute (GCI) partnered with the *Centre de Conservation et de Réhabilitation du Patrimoine Architectural Atlasiques et Subatlasiques* (CERKAS) to develop a Conservation and Rehabilitation Plan (CRP) for the Kasbah of Taourirt in Ouarzazate. The CRP developed a methodology for preserving this large earthen complex as a model for similar sites in the region. This paper describes the project with a focus on the planning process and the development of conservation policies that guided physical interventions on the site. The important role of these policies in the rehabilitation process is explored and recommendations are made for applying the methodology at earthen sites in Morocco and the wider region.

1 INTRODUCTION

1.1 *Background*

Kasbah Taourirt (Fig. 1) is located in the city of Ouarzazate at an elevation of 1,160 meters south of the High Atlas Mountains. The kasbah is a large complex covering over 12,000 square meters and is composed of various interlinked earthen structures including the Caïd Residence; the Médiathèque and offices of CERKAS; and the Stara, a large area with several residences enclosed by defensive walls. The buildings and defensive walls of the kasbah were built primarily in rammed earth, with adobe bricks used for the construction of the upper parts of towers and cornices, particularly where decorative patterns enrich the facades. Once the center of life in Taourirt, the kasbah is now surrounded by the vast urban development of modern Ouarzazate.

Kasbah Taourirt was occupied by the powerful Glaoui family, who ruled all of southern Morocco until the end of the French protectorate in the mid-1950s. In 1954, the kasbah was added to the Moroccan National Heritage List and in 1956, control of the property passed to the Moroccan state. In the early 1960s, the state returned ownership to the Glaoui and in 1972 the kasbah was sold by the Glaoui heirs to the municipality of Ouarzazate (GCI & CERKAS, 2016). With no inhabitants or maintenance in this period, the kasbah fell into ruin and was abandoned until the late 1980s, when CERKAS was established to study and protect the kasbahs of southern Morocco. While parts of the Kasbah were subsequently rehabilitated for use as offices, a museum, and a public library, large areas of the complex including the Stara and much of the Caïd Residence remained abandoned or were occupied by squatters (Fig. 2).



Figure 1. Overall view of Kasbah Taourirt. S. Macdonald, GCI.



Figure 2. Collapsed tower in the Stara sector. C. Cancino, GCI.

1.2 *Project development*

The selection of Kasbah Tourirt as a project site grew out of a series of partners meetings and a reconnaissance survey of southern Moroccan earthen architecture organized by the GCI in 2010. There are thousands of earthen buildings in southern Morocco which are threatened by abandonment and encroachment. Kasbah Taourirt was chosen as an ideal case study for the project because of its significance, location and active stakeholders including CERKAS and the Municipality of Ouarzazate, who had previously developed a project to rehabilitate the Stara area.

The goal of the project was to establish an appropriate conservation process that respects the original fabric, preserves traditional earthen building techniques, promotes earthen architecture, builds capacity and develops a participatory process for planning conservation that can become a model for similar sites in the region.

2 MODEL PROJECT

2.1 *Project approach*

The CRP was implemented in three phases: Phase 1 included documentation of the site, historical research, and emergency stabilization; Phase 2 was the development of the different components of the plan hereby presented, and the implementation of conservation works on the site; and Phase 3 is the dissemination of information about the kasbah and its conservation to local authorities, scholars, and the community.

2.2 *Documentation and research*

As a Moroccan national landmark, Kasbah Tourirt had been extensively recorded, including several hand drawn architectural surveys. However an accurate survey of the entire complex was never undertaken and precise plans were necessary to implement a large scale rehabilitation project.

In order to develop proper architectural drawings, a new survey of the kasbah began in 2012. Working with Carleton University's Immersive Media Studio (CIMS) as project consultant, the GCI and CERKAS carried out a comprehensive survey of over 300 rooms and public spaces within the kasbah and its various sectors (Ekim et al. 2013) (Fig. 3). In addition to documentation and stabilization, archival and oral history research was carried out. Taourirt has been a favorite subject of artists and photographers for centuries, and there is a great deal of archival materials, including historical photographs and aerial views dating from as early as the 1920 s. These were organized



Figure 3. Documentation of decorated rooms in the Caïd Residence. C. Cancino, GCI.

in a database in order to track changes to the structure over time. Oral history was also an important source of information about the historical use of spaces within the kasbah, and several interviews were conducted with a former servant of the Caïd who had lived in the kasbah during the time of the Caïds in the early 20th century.

2.3 *Assessing significance and values*

An important part of the planning process was to reassess the significance of the site, which was determined in 1954 but never explicitly written. One goal of this effort was to convene stakeholder to discuss the values of the site, and to develop collaboratively a revised statement of significance. The project carried out workshops with CERKAS and architects from the Ouarzazate Municipality on the assessment of significance and values, as well as on drafting a Statement of Significance. In collaboration with CERKAS and the municipality, the project team identified and recorded aesthetic, economic, social, and historical values for Kasbah Taourirt. By mapping these values directly on plans of the site, the team identified spaces that held particular significance, for example, because of decorative features, use in religious ceremonies, or former occupation by the Caïdal family (Fig. 4). This work assisted in identifying the most significant spaces and features of the kasbah as well as architectural patterns in order to preserve and highlight them during the rehabilitation work. The team also worked on issues related to programming for future uses of the various structures (Boussalh et al. 2016).

2.4 *Stakeholders and consensus building*

As a National Monument, Kasbah Taourirt is currently owned and managed by the Municipality of Ouarzazate. CERKAS is involved as a user of selected spaces in the complex and as a

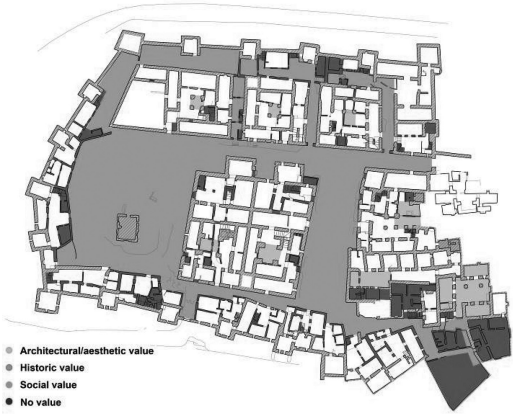


Figure 4. Significance map of the Stara sector. GCI.

governmental institution responsible for preserving and managing the heritage aspects of the historic site. Such an arrangement of ownership and management has resulted in protecting the site and accentuated the need for evaluating the impact of any proposed development projects on heritage values. It is also very important to the local community as a focus of tourism and commerce including local artisans, cafés and restaurants, hotels, and other businesses. Therefore it was critical to convene these interest groups to discuss a common vision for the site.

The GCI and CERKAS held several community meetings as well as meetings with the Municipality of Ouarzazate to develop a reuse plan (Fig. 5). The vision proposed for the site is a multi-use facility including a museum of oasis cultures, housing for researchers, workshops for the production of traditional goods and crafts, and a café. These would complement the existing uses including the library, offices, and event spaces, while the existing museum would be merged into an expanded museum focused on the cultures of earthen construction in the pre-Saharan valleys of southern Morocco.

2.5 *Developing policies and guidelines for re-use*

An important goal of the project was to define a set of policies that would guide both the restoration work and the future management of the site.

2.5.1 *SWOT analysis*

A SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was the first step of this process, carried out to establish a set of recommendations for conservation and rehabilitation of the kasbah based on its points of strengths, and the opportunities it holds to overcome weaknesses and threats. Strengths and opportunities identified included



Figure 5. Community meeting to discuss stakeholder values and vision for the site. S. Macdonald, GCI.

tourism created by the kasbah, its importance to the community and national heritage, as well as the economic engine it provides to the local economy. Weaknesses and threats included the vast scale of the site, the complexity of its management structure, and the poor condition of many of its buildings.

2.5.2 *Rehabilitation principles*

A set of principles was developed that the project should follow in order to abide by the Statement of Significance and achieve the project vision. These 21 principles are considered guiding rules for future conservation and management activities. While these guidelines are commonly incorporated into conservation projects, it was critical to develop them with the project team and clearly state them in the CRP.

Examples of the 21 principles include: to preserve the original form/elements of the listed building (building type, traditional architectural morphology, original openings, internal spatial arrangements, and decorative motifs) and put them in evidence whenever possible; to ensure proper interpretation of the site; to opt for minimal intervention; to preserve the structural integrity of architectural fabric; to opt for the use of traditional materials and techniques in construction; to preserve significant relationships with the natural and urban environment, etc.

2.5.3 *Design and operational guidelines*

Following the development of the set of principles, a workshop was held with stakeholders to develop specific practical guidelines to ensure implementation of the principles. These guidelines fall into two categories:

- Guidelines for the project's design phase
- Guidelines for future operation of the site

The proposed design-phase guidelines are procedures and requirements that should be followed during development and implementation of the rehabilitation plan of the site. The operation-phase guidelines are a set of procedures and actions that

are integrated into management agreements with tenants, and that create an overall framework for future site management and maintenance.

To illustrate one example, for the third rehabilitation principle "Preserve the original form/ elements of listed buildings and put them in evidence wherever possible," design phase guidelines included:

- 3A. Documentation of the existing elements.
- 3B. Preserve and represent elements in a new context.
- 3C. Specify for the consolidation and the stabilization of such elements.
- 3D. Specify a maintenance plan.
- 3E. Specify proper interpretive panels, or other interpretive means for such elements.
- 3F. Take precautions and all protective means not to damage elements during the implementation of rehabilitation works.
- 3G. Respect the original locations of decorative motifs.
- 3H. Prevent addition of contradicting elements, or ones which didn't exist originally.

For the same principle, operations phase (post-construction) guidelines included:

- 3a. Do not change the spatial context of these elements.
- 3b. Respect the maintenance plan devised for the property.
- 3c. Do not disturb viewing of these elements with movable additions.

Design and operations phase guidelines were developed for each principle and referred to in the CRP.

3 IMPLEMENTATION

3.1 *Rehabilitation approach and initial works*

Implementation was planned in conjunction with CERKAS and the Municipality of Ouarzazate. It began, as previously described, with the study of the existing architectural form, including assessing conditions; studying the building materials; distinguishing historic walls from those added after 1956--the year the kasbah was listed as a monument; and identifying modern additions made by squatters (Fig. 6).

Following this phase, a tender went out to select a contractor qualified in the restoration of earthen buildings. The selected contractor specialized in earthen building techniques and had worked on conservation projects at other historic kasbahs.

The work began with cleaning of several tons of accumulated debris and refuse. This was a large task

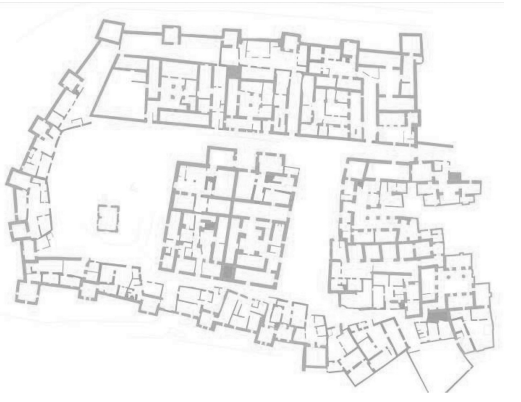


Figure 6. Stara plan showing modern additions (in blue). GCI.

involving the removal of more than a century worth of animal and human waste in addition to general refuse and collapsed roofing materials, which were putting significant pressure on the walls. Following this important step, partition walls and temporary structures built along the defensive walls were removed to reveal the original configuration of the buildings. Once this was accomplished, the work of restoration and repair could begin.

Several *ma'alem*, or specialized craftsmen, were employed to carry out specialized earthen construction techniques. These craftsmen in turn trained and supervised approximately eighty laborers in various aspects of earthen building construction and restoration, including preparing traditional materials such as timber beams, earth for building and plastering, and lime-based plasters and roofing materials.

3.2 *Conservation materials*

Restoration of damaged walls and lost or collapsed parts of the buildings was carried out using primarily rammed earth and mud bricks (Fig. 7). Earth for producing these materials came from a site 15 km from Ouarzazate. The earth from this site is composed of 67% sand and 33% clay, which is considered an adequate ratio for producing rammed earth. It matches the earth used in the original construction, which was mined from the site of Taourirt itself and tested by the project team. Using earth from the site is no longer possible however, as the site is a protected monument (Boussalh 2009).

Mud bricks were produced for the project from a mixture of approximately 35% finer clay, 60% medium-coarse sand, and 2% to 5% straw, and are made in two different sizes. There are usually five people involved in brick making, including a master brick maker and assistants. First, raw earth



Figure 7. View of the worksite showing preparation of mud bricks and roof timbers (foreground), and structural repair of a damaged wall corner (background). B. Marcus, GCI.

is passed through a screen to remove large stones. The earth is then formed into a pile with a depression on top where water is added. The wet earth is left for several days to saturate. It is then mixed with a small percentage of straw and again left several days to ferment, which gives the earth a more plastic consistency and reduces cracking. The material is prepared for forming into mud bricks by trampling the mud by foot into a workable consistency. The mud is then placed into wooden or metal forms, and the fresh bricks are placed in a partially shady area to reduce cracking.

Hydraulic lime is also used in the conservation of roofs and in the repair of walls. It is sourced from outside of Marrakech where it is produced and purchased in bulk quantity (not bagged).

3.3 *Structural works and roofing*

Structural repairs carried out as part of the work in the Stara included stabilization of deteriorated wall bases, stitching of cracks, and selective reconstruction of lost wall sections. Repair of basal erosion was carried out using fired-clay brick/tiles and a hydraulic lime mortar to fill lost areas, as this repair is durable in the long term against future water incursion and is compatible with the rammed earth walls. The bricks used for crack and basal erosion repairs are a low-fire, 0.24 × 0.12 × 0.03 m thin brick used commonly in historical construction in Marrakech and surrounding areas (Boussalh 2005).

The majority of roofing in the Stara had accumulated a significant weight of built-up earthen material and debris and the beams had suffered from deterioration or collapse. Thus they were mostly replaced, though original decorative roofs were kept in certain key spaces. In addition, the principal roof beams mostly remained in sound condition and were preserved in place or reused where possible. New roofing and flooring were installed using traditional materials. The intermediate floors are made of wood framing (poplar beams, joists, and reeds). The main or principal beams of the frame are made of large poplar trunks 20 to 30 cm diameter in section. They were set in the walls on wooden plates or tie beams so that the weight of the roof is evenly distributed and does not create a point load in the wall.

Following the installation of roof beams, ceilings were created using a bed of reeds laid either in simple configuration or arranged in complex geometric shapes known as tataoui (Fig. 8).

3.4 *Conservation of wall paintings*

Another important component of the project was the documentation and conservation of decorated surfaces at the site. Located in the protected center of the Caïd Residence, decorated rooms were used by the wives and children of the Caïd and feature arches, sculpted plasterwork, and colorful wall paintings with geometric designs. Wall painting conservators, working with CIMS and CERKAS staffs, carefully documented the decorated surfaces, assessed their current conditions, researched the paintings history and iconographic significance, and carried out stabilization measures. As part of this work, a glossary of conditions was developed to guide the assessment. After the condition



Figure 8. Workers preparing a reed roof mat. CERKAS.



Figure 9. Wall paintings conservator stabilizing decorative elements in the Caïd Residence. B. Marcus, GCI.



Figure 10. Before and after rehabilitation in the Stara sector. B. Marcus, GCI.

assessment of the wall paintings was finished, the team worked on designing and implementing structural interventions that preserved the decorative surfaces intact, including re-roofing. Following re-roofing stabilization measures were carried out including grout injection of delaminated plaster layers (Fig. 9). Finally, cleaning of the wall paintings has highlighted the vibrant colors and intricate geometric designs.

4 DISSEMINATION

4.1 *Training and capacity building*

Training for CERKAS staff, interns, students and others has been important in all phases of the project. Beginning with the survey of the site, a multi-year program of training was carried out by Carleton University to train CERKAS staff in the use of the total station and other means to document historic sites (Ouimet 2014). This training provided the team with equipment and skills used to document other earthen sites in the region. Training workshops were also held on the subjects of rehabilitation planning, wall paintings conservation, and practical conservation approaches. A laboratory was established on site for training and analyzing earthen materials.

4.2 *Publication, web and video resources*

The final phase of the project has focused on dissemination of the CRP and project methodology both within Morocco and more broadly to the conservation community. A website (www.cerkas.org) has been established as a repository for data, reports and images related to the kasbah and other sites managed by CERKAS. The Conservation and Rehabilitation Plan was presented to Moroccan authorities and academics in various venues including the Ministry of Culture and Moroccan schools of architecture. The CRP was also published and made available on the GCI website as a pdf or print-on-demand book: (http://www.getty.edu/conservation/publications_resources/pdf_publications/cons_plan_taourirt.html.).

5 CONCLUSIONS

The following are some key conclusions of the CRP, which are intended to provide guidance regarding next steps to ensure sustainability of the project activities and to suggest further areas of research for Moroccan cultural heritage authorities and other researchers or professionals working on earthen architecture in southern Morocco.

Firstly, the vast cultural heritage of southern Morocco needs further study and analysis. Earthen heritage should be included in a general inventory of historic sites in the pre-Saharan valleys. While various local surveys have been carried out, further resources are needed in order to properly study and catalogue the approximately 3,000 ksour and 400 kasbahs. The collection of information on this vast earthen heritage should include detailed and complete architectural documentation as part of conservation work.

Additionally, the drawings produced for Kasbah Taourirt served as a recording of the site and as a tool to investigate historic configurations, graphically illustrate oral history, and document the site's pre-rehabilitation condition. Without an accurate survey of a site, it is impossible to make decisions regarding the original functions of the spaces and/or potential adaptive reuse opportunities.

As important as the recording of the physical fabric is the identification of the site's cultural values. Cultural significance is used here to mean the importance of a site as determined by the aggregate of values attributed to it—e.g. economic, social, architectural, historic, etc. These identified values are not an end in themselves but a means to facilitate the decision-making process, and are necessary for planning appropriate re-use.

Also critical to the project was the development of rehabilitation principles—a set of norms to be followed by the groups designing the rehabilitation plan. In the case of Taourirt, the team involved the owners of the site in the creation of these principles so that actions designed as part of the plan, as well as future interventions and/or maintenance of the site, will respect the principles. Furthermore, the design and operational guidelines specify how these principles are to be implemented during the life of a rehabilitation project.

Lastly, the wall paintings that were investigated and stabilized as part of the project are highly significant for Amazigh culture and southern Morocco. However, little research has been done on the conservation of wall paintings in Morocco and there is still a need for scientific testing of painted materials and treatments should be further researched and developed.

In addition to these recommendations, increased support for the activities of CERKAS is needed,

both in terms of human and financial resources, to strengthen the organization and improve the conservation of earthen architecture in southern Morocco.

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Consumption study and energy optimization of a typical Valencian house

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ABSTRACT: This paper reports on the energy consumption study of a typical Valencian house with the aim of achieving a maximum reduction in HVAC energy demand. With this purpose, an extensive simulation project was done by using TRNsys 17 software. Previously, all necessary data were collected and studied. Then, an energy simulation of the original house was performed, hence obtaining experimental evidence to verify the predictive capability of the developed energy model. Subsequently, the energy optimization strategy was proposed and the measures to improve the energy demand were implemented on the model, in order to reach a zero HVAC demand. Finally, the following conclusions were obtained: energy model adjustment is fundamental for reproducing the specific thermal behavior of the studied building and for the optimization of the energy demand and secondly, enhancing the building envelope is the most effective proposal for achieving the reduction in the HVAC requirements for the building.

1 INTRODUCTION

Growing energy dependence, as well as the profound economic crisis, have forced society to question many of the uses and energy procedures employed so far. It is becoming critical for them to be aware of the necessity for a rational and efficient use of energy.

Is essential to understand that energy saving and the efficient use of energy does not mean reducing comfort or well-being. With a change of habits and attitudes it is possible to maintain or even improve comfort conditions and significantly reduce energy consumption as well.

According to Boermans & Petersdorff (2007), up to approximately 40% of worldwide final consumed energy is concentrated in the construction sector. Buildings significantly contribute to the consumption of final energy. Therefore, the actions on the construction sector can be very effective in reducing energy consumption. Consequently, in recent years energy optimization and efficiency have acquired relevance in the building sector, due to its strong potential in saving energy. This is the first approach to an ambitious goal: striving to get energy consumption for buildings to be close to zero before December 2020, according to European regulation 2010/31/CE.

In this context it is of great importance to optimize the thicknesses of insulation to improve the thermal behavior of our buildings as much as possible (Lollini et al. 2006).

This paper presents an energy study for the rehabilitation of a country house made with traditional materials typically used in the Valencian orchard. The objective of this study was to obtain a maximum reduction in the HVAC energy demand with the priority being the application of passive measures, which finally results in zero energy consumption for active air conditioning.

The study has required a laborious and systematic work of simulation with TRNsys 17 software.

In addition, we consider that, on its own, the energy rehabilitation of a traditional house gives high additional value. Nowadays, it seems very convenient to get examples that can serve as models to be followed by other social elements.

2 METHODOLOGY

2.1 *Building description*

The selected building for this study is a two floor house, built in 1930 in the stage prior to the II Spanish Republic (1931–1939). The house is located in a Valencian orchard, 820 meters from the Mediterranean coast, in the municipality of Alboraia (Valencia). The architectural typology is the modern *alquería*, a typical orchard farmhouse from the east and southeast coast of Spain and of Hispano-Muslim origin. Its main façade is orientated towards the east to take advantage of the breeze from the sea for ventilation and cooling of the farmhouse, especially during the summertime.

These types of buildings were houses of tillage in which the ground floor was used as a house, and the "cambra" or volume under the roof was for the storage of the harvest or for the breeding of silk worms. The geometry of the floors was

typically rectangular, or as in our specific case, it could attach two rectangles forming a 90° angle. The ground floor of the house is 60 m^2 in area and 2.8 m. high. The distribution is shown in Figure 2.

Access to the "cambra" is made initially through a staircase outside the house. This floor is 48 m^2 and has an average height of 1.4 m (Fig. 3).



Figure 1. South building façade.

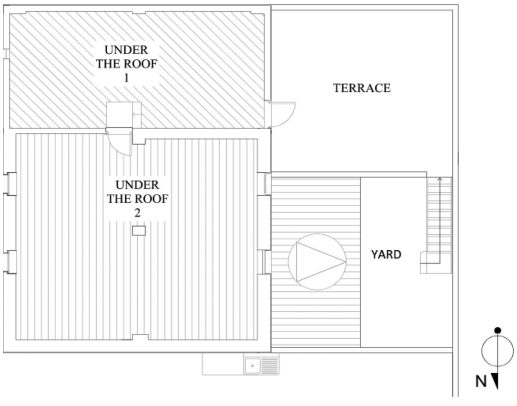


Figure 2. Ground floor building plan.

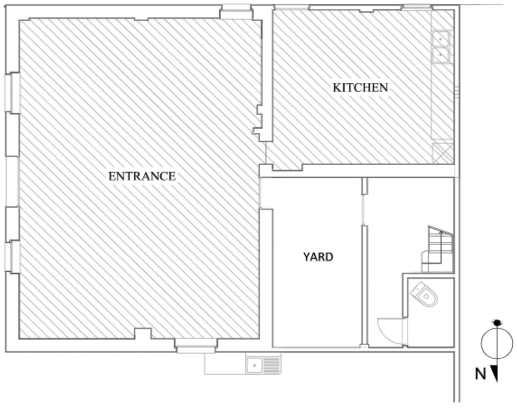


Figure 3. First floor building plan.

To summarize, the constructive characteristics of the building are: old, solid brick masonry walls, without any thermal insulation. The floor and deck structure is made of wooden joists and beams. The pillars are solid brick. The south-facing shed roof is supported on the end gable of the roof east-west.

The roofs are finishing with curved tiles.

In Table 1, the average values of the transmittances of different constructive elements that form the envelope of the house have been collected, as taken from the Catalog of Spanish Construction Elements.

2.2 *Weather data*

The climate of the Alboraia orchard is similar to the city of Valencia: typically Mediterranean, mild and humid and with seasonal rainfall.

The annual average temperature is about 18°C and with no extreme temperature swings.

Normal relative humidity ranges between 60–75%. The summer is warm (temperatures average around 20°C). In July and August temperatures are between 25°C and 30°C, with very few frequent values above 35°C.

On some occasions heat waves have been produced due to the arrival of warm fronts from the North of Africa, or when dry winds blow from the West.

Winters are very mild, with the coldest months being December and January, with minimum temperatures of 5 °C. Very occasionally, there are cold waves due to the displacement of cold air masses coming from the north pole. The annual rainfall is higher than 450 l/m^2, with a very marked minimum in the summer, in the months of June to August. Historically, maximum precipitations have occurred throughout the fall, due to the effect of the weather phenomenon known as "la Gota Fría" which brings severe weather with heavy rain or hail and possible flooding.

Table 1. U-values of constructive elements from Spanish Constructive Elements Catalogue by CTE.

	U-value (W/m^2 K)
External wall	5.2
Floor in contact with ground	20.0
Roof	4.9
External cover	4.0
Single glass thickness = 4 mm	5.8
Aluminum carpentry	5.7
Wood carpentry	2.2

2.3 *Registration and processing of experimental data*

Prior to the energy analysis, an extensive collection and processing of experimental data was performed.

- During 8 months (September 2014-April 2015) monitoring of external climate data with the use of a weather station, *Watchdog 2007,* located in the house, was carried out. With these data, a climate file was produced and was used in the process of adjustment, calibration and validation of the energy model of the house.
- During the same months, a system of monitoring inside the house was installed (Martínez A. et al. 2016) and with which, data of temperature and relative humidity were collected.
- A Blower Door test was carried out according to ISO 9972:1996 and EN 13829. The effective surface of air infiltration was calculated from the data obtained with the test as it is described in Sherman M.H. (1987). This surface is used in the simulation program to calculate air infiltrations in a dynamic way, depending on the interior and exterior conditions at every time step (Martínez A. et al. 2016).

Lastly, in the final process of optimization for the minimization of the energy demand, the simulation uses the data file of historical climate, standardized for the period from 1961 to 1990, made by Meteonorm.

2.4 *Energy model of the house*

The energy model of the house was made using TRNsys 17, a software program for energy simulation.

The building was modeled using the TRNsys multizone standard model known as Type 56. In the energy model, all the features of the house that affect the thermal behavior were defined.

To simulate the airflow circulating in the house, the module TRNflow was used (Transsolar 2009).

The external weather data are incorporated in the model in two different forms:

The first one introduces the built climate dataset. A specific editable text (Type 99) file was used.

The second procedure was to introduce the archive of climatic data from Meteonorm, that takes into consideration a normal period in Valencia. This is done through a TRNsys processor of standard climatic data, known as Weather data.

Previous to the next step, in order to obtain a feasible energy model of the building, a fit, calibration and validation procedure was performed (Martínez A. et al. 2016). The indoor measure datasets were compared with the results from the simulation (Fig. 4) in order to check the predictive capability of the developed thermal model.

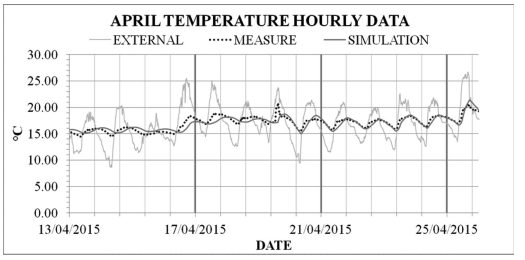


Figure 4. Two weeks of hourly April Temperature data with external measure (EXTERNAL), indoor measure (MEASURE) and hourly indoor temperature data were obtained by means of simulation (SIMULATION) from the entrance zone.

2.5 *Optimization strategy*

To achieve the objective of close to zero HVAC energy demand, a series of measures were sequentially implemented, testing different possibilities and combinations with the objective being to choose the most beneficial ones.

The studied passive measurements were:

- Thermal insulation in roofs and walls.
- Selection of optimized windows surface for south, east and west orientations.
- Glazing characteristics for the windows.
- Shadowing periods for the windows.
- Natural cross ventilation.

The active measurements studied were:

- Use of heat recovery.
- Air ventilation system.

The fundamental improvements have been applied, with the following justification:

- To place thermal insulation in the building envelope is one of the most effective measures to decrease the energy demand for existing buildings. There are a great number of studies in which its efficiency has been evaluated, for example, Al-Homoud D.M.S. (2005), Boermans & Petersdorff (2007).
- Referring again to the study by Boermans T. & Petersdorff C. (2007) (Ecofys VII), the conclusion is that for mild weather, the insulation at ground level is not adequate from a thermal point of view.
- It is usual that windows are the weakest thermal point in the envelope of the buildings, so, it will be fundamental to study this, with the objective to use windows and carpentry that reduce the energy losses whenever possible (Roos et al. 1994).
- The uncontrolled external air inlets and infiltrations are always harmful for periods with heating requirements, so it is necessary to avoid them

as much as possible, taking as a limit the criterion from the Passivhaus standard, of 0.6 renovations per hour for a Blower Door test with a pressure difference of 50 Pa.
When high air tightness for the building is attempted, controlled mechanical ventilation will be necessary to preserve the interior air quality. The ventilation flow is defined according to the limit values described in the Spanish regulation, CTE (Código Técnico de la Edificación) DB-HS3.

– The heat recovery system for this building type with very low energy consumption seems very convenient. Some energy standards such as Passivhaus make its use obligatory.

The first objective was to reduce the heating demand as much as possible, choosing the option that also does not imply an excessive increase in the refrigeration demand.

The second objective was to obtain the highest reduction in the refrigeration demand, without having any important effect on the heating demand.

Finally, some additional adjustments were carried out to achieve the prior objective of effective zero energy demand.

For the first objective, it was decided to simultaneously study the chosen options for the insulation thickness at walls, roofs and south windows glazing surfaces, with the objective being to find a compromise between the heat losses from conduction and the heat gains from direct solar radiation, achieving the most beneficial combination.

After the implementation in the model of the optimal combination of the described measurements, the next step was to study the carpentry and glazing characteristics.

Once the building envelope was optimized according to the heating requirements and minimum heat losses through the envelope were achieved, the definition of the heat recovery began.

The first described objective is achieved when an effective heat recovery performance has been obtained at heating periods. Therefore, the second phase begins, with the next aim being to get the highest reduction in the refrigeration requirements.

Firstly, recovery operation was adjusted to make it work properly in the periods in which the demand is for cooling, and then shadow devices were implemented. Their use schedules were studied, choosing from the possible options the awning, as the authors believe that it is the most suitable system for total protection against direct solar radiation, while it still allows diffuse light so as not to darken the interior of the house completely, contributing in this way to the natural lightning of the building.

For deciding what shadow device was the most appropriate, a study using the Ecotect Analysis (2011) software from Autodesk, was conducted. Once the elements of shadow and their periods of operation are properly defined, the following measure is to reduce the demand for cooling by increasing the ventilation flow.

Finally, the natural cross ventilation is studied, opening and closing doors and windows located in the east, west and south facades. When windows and doors are opened, the forced ventilation and the heat recovery are disconnected, limiting the use of extra forced ventilation solely to periods where outdoor temperatures are very high.

In this way, the second objective is obtained. Then, to finally reach a HVAC demand close to zero, small adjustments are made to insulation thickness, south windows surface, control of extra mechanical ventilation, and cross ventilation from opening of doors and windows.

3 RESULTS

3.1 *Description of the optimized building model*

In the initial state of the building, the annual HVAC energy demand according to the simulation results was 206.5 kWh/ year m^2 for heating and 36.4 kWh/ year m^2 for refrigeration.

The high demand in the original state of the house was due to the bad condition of walls, roof and windows that led to a high level of air infiltration, making the heating requirements very high. Another additional contribution comes from the fact that the house is in darkness for much of the day, and does not obtain heat by direct sunlight through the windows. It is true that cooling requirements are considerably lower than the heating ones, since the conditions of darkness and the high infiltration are favorable to reducing refrigeration requirements.

Prior to the energy rehabilitation, the structural consolidation of the building was required.

A continuous renewal of air by means of a simulated mechanical system of 0.8 renovations per hour is provided when no doors or windows are open in the different rooms, to comply with the provisions in the Spanish legislation on the quality of indoor air, CTE DB-HS3.

In Table 2, the measures implemented in the model to achieve the final optimum level are summarized.

Finally, the demand obtained with the highly optimized model is 0.7 kWh/year m^2 for heating and 2.2 kWh/year m^2 for cooling. So, with the optimized model, a reduction of almost 100% in the energy demand has been achieved.

These values are very low, compared with the specified limits in the Spanish legislation for the climate zone in which the building is placed, 15 kWh/year m^2

Table 2. Summary of energy improvement measures implemented in the energy model.

Nearly zero energy demand house model specifications:
Insulation
Insulation material LW, thermal conductivity 0.04 W/mK.
Walls insulation thickness 16 cm.
Roof insulation 20 cm.
Glazing type
LowE 4/84; U-value 2.48 W/m^{2}k
Window glass area
Ground floor: South: 3.6 m^2, North: 0.75 m^2, East: 2.4 m^2
First floor: East: 0.7 m^2, West: 0.7 m^2
Shadow devices
Awning used, windows are totally in shadow.
Summer: Implemented every day.
Spring and fall: Implemented if exterior temperature is higher than 22°C.
Heating recovery system
Efficiency: 0.75. Connected if doors and windows are closed.
Cooling demand (Indoor temperatures higher than 26°C): Indoor temperature is lower than exterior temperature.
Heating demand (Indoor temperatures lower than 21°C): Indoor temperature is higher than exterior temperature.
Natural cross ventilation
Windows and doors are opened when exterior temperatures are between 21°C and 25°C.
Extra mechanic ventilation
Active in summer, spring and autumn periods, when doors and windows are closed.

for heating demand, with the same value for cooling demand. These coincide with the limits imposed by the Passivhaus standard.

3.1 *Influence analysis of every optimization measure applied*

In this section, an analysis of the impact of every implemented measure is carried out.

In this way, the sequenced stages of the simulation are contemplated, as is outlined in the table in Figure 5, in order to be able to evaluate how every measure affects the improvement in demand with respect to the previous step. And then finally, how the implementation of all of them affects the reference point of the basic model of house demand, observed without any energy saving measures.

As shown in Figure 6 with the improvements of insulation, glass and shadows, the achieved heating demand is virtually the limit in the Passivhaus standard, and the cooling demand is well below this standard. Perceptually (Fig. 7) the implementation

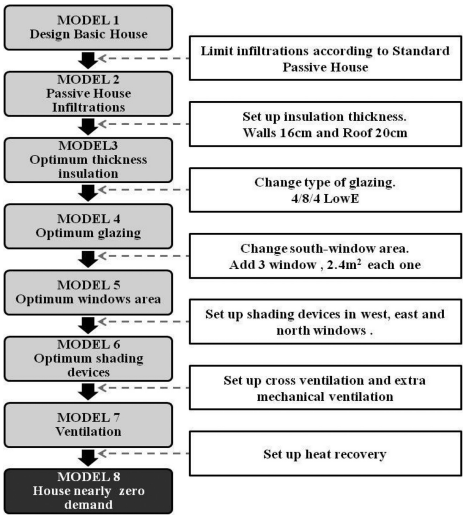


Figure 5. Scheme of the Influence Analysis of every applied optimization improvement.

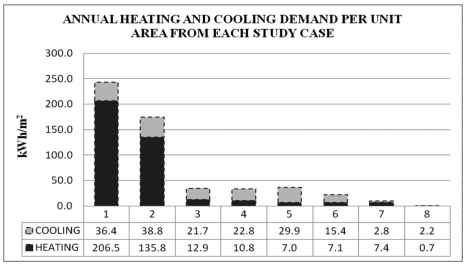


Figure 6. Annual heating and cooling demand per unit area from each energy improvement measure.

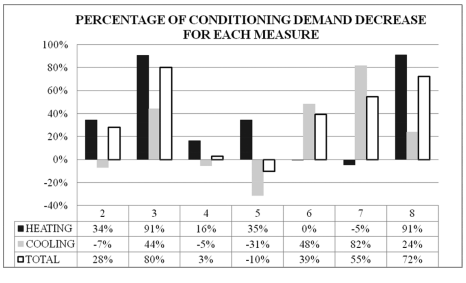


Figure 7. Percentages of heating, cooling and total demand decrease for each improvement compared with the Basic House Design.

of insulation and heat recovery are the measures with the largest effect on the heating demand.

Regarding the cooling, the most effective measures are the proper shading of windows and the natural ventilation of the dwelling.

In Figure 7, there are measures whose effect is an increase in the demand, and those ones therefore

appear with a negative percentage. For example, this is what happens when the infiltrations are decreased to the limit established by the Passivhaus standard, thus causing an increase in the demand on cooling. However, because of the great impact it has on reducing the heating necessities, the final effect on total energy demand is very favorable. Nevertheless, the most critical measurement for the increase in the cooling demand is the introduction of new windows. The increase of the total demand shows clearly that it is not possible to define new glazing without proper shading.

Globally, as seen in Figure 7, the most effective measure for energy saving is the implementation of insulation in the building envelope. Second in order of its effect on the demand would be the implementation of heat recovery, but always with appropriate operating controls and previously optimizing the thermal envelope of the building.

4 CONCLUSIONS

From the study which was carried out, the following conclusions have been obtained:

- The most effective measure is the use of an appropriate and optimized thickness of thermal insulation; the initial total energy demand is reduced by 80%.
- Promoting a high level of air tightness is a priority in the energy rehabilitation of housing, because air infiltrations significantly increase the heating requirements.
- An accurate study of the position of the window in relation to the orientation of the house is fundamental for the following reasons:
  - When dealing with windows with a south orientation, it is necessary to find an optimal ratio between window area and opaque walls in order to get a passive warming from direct solar radiation that is higher than the thermal loss through the envelope.
  - The proper use of cross ventilation has an important effect on the energy consumption
- An effective shading of these windows will be very important so as not to worsen the demand for cooling.
- It is better to avoid windows oriented to the East and West as much as possible and only have what is necessary to ensure proper cross ventilation. In addition they must also be suitably shaded.
- In mild climates such as the Valencian region of the Mediterranean, when referring to the characteristics of the windows, the quality of the glass is more important than the joinery.
- Heat recovery is an effective measure in terms of energy saving if the thermal envelope of the housing has been optimized properly, and its operation controls are appropriate.

5 AWARENESS

After the analysis, new lines of study have been opened up for the future. Some of these ideas are:

- Studying the effectiveness of thermal recovery in mild climates related to acquisition and installation costs.
- Solving problems with the standards for energy efficiency created for cold climates that have to be extrapolated for milder and warmer climates. This is something which is not so easy to do!

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Maps, actors & local policies around earth buildings in Auvergne Rhône-Alpes

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ABSTRACT: The paper presents and analyzes the activities undertaken during the first part of an ongoing research project, which aimed at a better knowledge of the rammed earth architectural heritage in in Auvergne-Rhône-Alpes region and at describing the promotion policies of this heritage. We first describe the results of localizing, identifying and mapping remarkable rammed earth sites and the local initiatives in the region. Then, we explain how this research engaged a co-construction process concerning the tools and mechanism to develop around rammed earth historic and vernacular building promotion and inclusion in local policies frameworks.

1 INTRODUCTION

In Auvergne-Rhône-Alpes Region, France, up to 80% of the old buildings are built in rammed earth in some villages, representing a noteworthy rammed earth heritage. They represent a wide variety of buildings, including country or city houses, mansions, agricultural buildings, public buildings, schools, churches or industrial buildings. Since the end of the seventies, various initiatives were developed to start anew earth building and promote this heritage. They also contributed to understand its architecture, its diversity, its distribution and the specific know-how linked to its retrofitting.

In some of these actions, the old rammed earth constructions of the region were grasped as a development tool for local dynamics. It is therefore part of a global movement that view heritage as a support for territorial project (Magnaghi 2003, Micoud 2007). We considered it relevant to develop a research on these dynamics and examine them through the following questions:

– How are historic and vernacular rammed earth constructions distributed and identified on the territory? How are they used in the development of local dynamics?
– What are the actions implemented locally to use them as a development tool? How could these initiatives be linked together? Could they take part in the development of consistent public policies in terms of conservation and promotion of the built heritage, as well as of town and country planning?

This research project named "Promotion of the rammed earth heritage in Auvergne-Rhône-Alpes Region" is part of the Rhône-Alpes Development Contract Isère, Porte des Alpes, funded by Rhône-Alpes Region. It follows on from 15 years of rammed earth promotion projects lead by CRAterre on this territory. It is coordinated by the research unit Architecture, Environnement et Cultures Constructives from Ecole Nationale Supérieure d'Architecture de Grenoble, and by CRAterre association.

This research aims at a better knowledge of the rammed earth architectural heritage in Auvergne-Rhône-Alpes Region. It also aims at describing the promotion policies of this heritage, understanding the values that are linked to it and the organization of the stakeholders that make it a living heritage. The project is about developing work methods and tools that can be used in the policy framework of the local authority or be decision making support for town and country planning.

The project activities were structured around two main objectives:

– localizing, identifying and mapping remarkable rammed earth sites and the local initiatives in Auvergne-Rhône-Alpes region;
– engaging in exchanges and discussions on the tools and mechanisms used or to develop around its promotion and valorization.

The paper presents and analyzes the activities undertaken during the first part of this ongoing research project that started at the beginning of 2016. We will focus on the results considering the whole Auvergne-Rhône-Alpes region, putting

aside the results targeted at the territory of Isère, Porte des Alpes.

2 LOCALIZING RAMMED EARTH

The aim of this part of the research was to draw up an overview of the historic rammed earth constructions in Auvergne-Rhône-Alpes, with a focus on the sites subjected to heritage protection.

2.1 *Existing data*

The first step was an analysis of the existing data. From the 19th century, studies about heritage and vernacular buildings have been implemented to document it: "Dauphiné" and "Lyonnais" of the Corpus d'Architecture Rurale (Raulin 1977, Royer 1979) and the national Inventaire Général can include information about construction materials such as rammed earth (Guibaud 2005). Local building analysis were also designed to have an effect on these constructions (EDF-PACT 1985). Concurrently with these institutional processes, research focused on earthen architecture has been initiated: mapping, made between 1981 and 1991 (Scarato 1984), more localized census during research projects (Bertin & Clémençon 1983) or heritage promotion projects (Joffroy et al. 1991). Various researches are underway with new aims: participatory inventories for urban rammed earth (Mille 2016) or linked with town and country planning policies (Studer 2016).

2.2 *Method*

So as to draw up this overview, three datasets were set-up: constructions and sites listed or classified as "Monument Historique" and where rammed earth can be found (1), protected areas that can include rammed earth (2), municipalities where rammed earth constructions can be found (3).

The survey was made with two tools: a spreadsheet (list of Historical Monuments and heritage protection areas) and a geographic information system (GIS) for the database of municipalities where rammed earth can be found. An iterative process was set-up. Data collected on the ground, online or from partners (i.e. Service Régional de l'Inventaire, Unités départementales d'architectures et du patrimoine, CRAterre team, Lionel Bichonnet) was summarized into a map. Successive updates led to the current version of the map. Intermediate versions, online or on paper, were used as mediation supports all along the project activities.

The research for listed or classified sites called upon online heritage databases (e.g. Base Mérimée), webpages dedicated to tourism in each territory and documentation from various projects already undertaken (e.g. Terra Incognita Project).

The research for heritage protection areas was made by crossing the GIS files of the protected zones (data from Atlas des Patrimoines) with the areas where rammed earth is present as surveyed by CRAterre-ENSAG laboratory (Leylavergne & Beziane 2012) and with the data of the protected zone's diagnosis reports available on line. The research for rammed earth presence called upon already existing mapping (e.g. (Scarato 1984)) and the knowledge of the members of CRAterre-ENSAG laboratory and other partners. It was checked and completed by a systematic rammed earth visibility check in online photographic data (Google Street View) as well as through visits on site.

2.3 *Results*

All these information are rendered as a static map (Fig. 1) and as datasets (csv). Historical Monuments are also geolocalized on the web (cartoterra.net). This online application allows in the "Terres à Pisé" group to update a georeferenced dataset about the remarkable historic and vernacular rammed earth constructions in the Region.

Those three datasets confirm the significance of historic rammed earth constructions in the region, as much by the geographical area concerned as by the variety of the buildings and sites identified. More than a quarter of all municipalities in Auvergne-Rhône-Alpes region have been identified as including rammed earth. Rammed earth constructions can represent more than 40% of the overall constructions in some municipalities. However, the precision of the collected data doesn't allow yet to establish reliable projections on the number of rammed earth buildings in the region.

Part of these buildings are already covered by heritage protection dispositions: 60 sites are listed or classified as "Monument Historique", and only two of them are in the Auvergne part of the region. It can be noted at this stage a preeminence of rammed earth in the former region Rhône-Alpes, which is caused in part by the lack of data for Auvergne area.

2.4 *Limits*

The whole process generated relatively reliable although not complete datasets. They will require to be updated as the research goes on. Thus, for the identification of the municipalities where rammed earth exists, the limits of the areas where rammed earth is present still needs to be explored. This is especially true for the territories of the former Auvergne region.

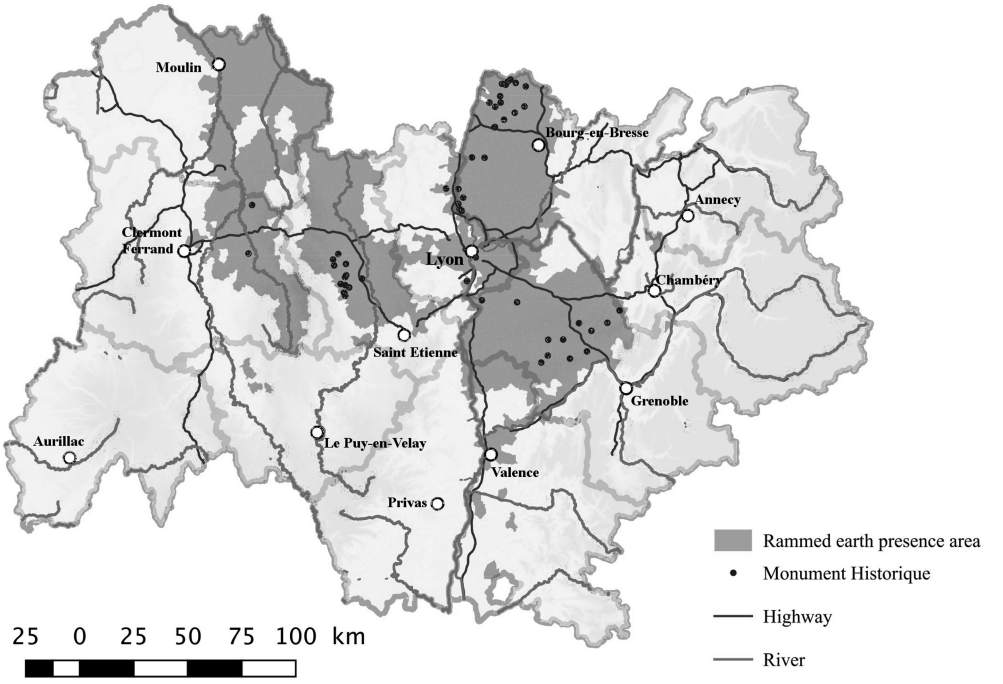


Figure 1. Historic rammed earth in Auvergne-Rhône-Alpes.

The research by keyword in the various heritage databases does not ensure to spot all the monuments and sites concerned as the building technique is not a specific and mandatory field. Furthermore, the building technique doesn't always appear in the description.

All inventory data is not necessarily digitized and available online, and the tools used at different scales by the various heritage institutions are not always interoperable.

The wording used in the heritage databases can require checking: some uses of "rammed earth" did not fit with the use of the technique but rather to the use of earth as building material in a wooden structure (wattle and daub). Some monuments identified from the keyword "rammed earth" in Mérimée database were consequently deleted from our file after additional documentation research. Some were also deleted pending the verification of an effective use of rammed earth for their erection.

3 IDENTIFYING RAMMED EARTH PROMOTION ACTIONS OF THE LAST DECADES

Since the end of the seventies, various actors of the public sector organized actions to improve knowledge, preservation and retrofitting of vernacular rammed earth buildings. These actions can be very different, according to the targeted public, the medium or the time extent of the action.

The second part of our project aimed at identifying these actions to show their number and diversity.

Drawing up this overview aims at improving the consistency between projects and territorial stakeholders according to their field of activity. It also aims at analyzing these initiative's tendencies and thus to point out potential lacks in the type of actions or in the targeted publics.

3.1 *Method*

This projects or initiatives research was undertaken during two weeks. This limited time excludes the possibility to reach a complete result. Choice was made to focus on projects or initiatives engaged by public or nonprofit organizations. This is to mitigate the lack of knowledge of the actions of these organizations towards rammed earth and to avoid favoring private organizations.

Data collection was made through web search and discussions with relevant individuals linked either to the territory or to the research theme. Collected data were gathered in a spreadsheet to ease their sorting.

The following criteria were analyzed: location of the actions, number per Department, timeframe of the actions (5 years range), representativeness of the actions' types, targeted public (level 1: general public of the action, level 2: publics targeted by the specific action).

3.2 *Results*

77 initiatives or projects were identified from 1977 to 2016. The territorial distribution of the initiatives is very unequal in the region: it can be noted that the departments that count the most initiatives on their territory are Isère and Rhône. Departments presenting rammed earth such as Savoie or Drôme count almost no project on the theme. However, it is probable that a bias is caused by the existing network of the research team, making some zones more visible. It is therefore not possible to decide on the correlation between number of actions and significance of the rammed earth buildings in the territory.

Two highlights are noted (Fig. 2): the first is linked to the setup of heritage policies from the eighties, which helped projects about rammed earth constructions to emerge. CRAterre laboratory and other study groups ("groupe Pisé" in Ain département) as well as the local councils for architecture, urbanism and environment (CAUE) were created in these circumstances. The second highlight starts from 2000 and shows an increasing number of actions until today. This interest seems to be part of a growing attention paid to environmental issues, through retrofitting and the use of natural materials for building. The tendency can also be explained by the increased use of web based communication since 2000, when a main data source for the study has been the web.

This study shows publications as the main type of actions (Fig. 3). They can be of different kind (book, leaflet, charter, etc.). A very large majority of all actions are targeted to "general public":

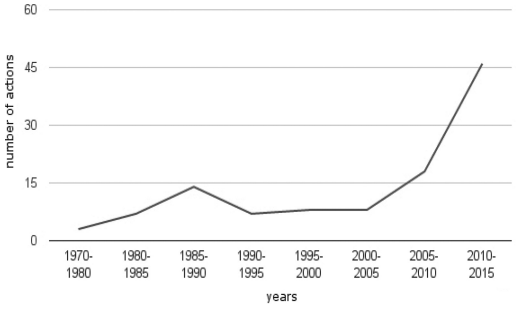


Figure 2. Rammed earth promotion actions in Auvergne-Rhône-Alpes since 1970.

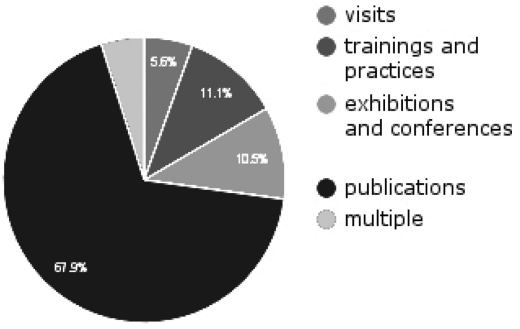


Figure 3. Types of rammed earth promotion actions.

sensitization actions for rammed earth building owners, pedagogical projects for kids. Many projects also target private sector professionals however very few are meant for public sector professionals.

3.3 *Limits*

This research encountered many issues related to the time and material constraints. Indeed, time for data gathering was limited to about two weeks. We also met problems accessing all information on the web: old projects having no online documentation, and some projects were less focused on communication. Access to paper archives was limited due to the time constraints. Thus, the information collected could be more consistent. Further research should be committed to standardize this data.

As vocational training is already been included in an underway research (Ortolan et al. 2013), it was decided not to duplicate the work.

4 BUILDING A COMPREHENSIVE VIEW OF THE NETWORK OF PUBLIC ACTORS INVOLVED IN RAMMED EARTH MANAGEMENT IN FRANCE

Rehabilitation and retrofitting of old rammed earth constructions relate to many public and private actors through various subjects. Diverse levels of involvement are observed among these actors as well as very different approaches. The aim of this part of the research was to get an overview of the network of actors whom activities affect rammed earth buildings.

4.1 *Method*

The data collection focused on the public structures related to rehabilitation and retrofitting of historic and vernacular rammed earth constructions.

It was made concurrently and linked to the survey on rammed earth promotion actions as the last allowed to identify a number of actors.

It was completed with a study of the local and national public administrations structures. As for the rammed earth promotion actions survey, the limited time couldn't allow for a complete inventory but nonetheless provides a useful overview of the situation.

4.2 *Diverse links and subdivided authority*

The data collected shows that many public structures are related to rehabilitation and retrofitting of historic and vernacular rammed earth construction. Although they're not necessarily engaged in specific actions about rehabilitation or preservation, their actions may enable or already include it, and call to diverse fields of expertise and policy. These fields are all in relation with rammed earth, however the issues they develop are not always coinciding. For instance it can be difficult to find common grounds between heritage, retrofitting focused on energy savings and town planning policies.

The fields covered by the identified organizations are heritage promotion, research and development, housing, retrofitting, ecological building, training, assistance for building (especially for self-building), territorial development and heritage projects.

This diversity reflects various *modus operandi* and various kinds of actors: public bodies' officers, private professionals organized in federations or associations to undertake specific projects, professionals and volunteers from nonprofit organizations. Some bodies show a hierarchical organization with territorial agencies.

4.3 *Developing tools with and for public actors*

Regional and local authorities are a very important piece of the network of actors involved in the rehabilitation and retrofitting of old rammed earth constructions due to their spheres of competence. In contact with the daily needs of their territories, they are responsible for setting up territorial development policies while maintaining infrastructures, cultural wealth and local characters. It is therefore especially important that these local authorities have at their disposal resources and methods to undertake their daily activities as well as targeted projects in accordance with the specificities of the historic and vernacular rammed earth constructions.

Yet, the analysis of surveyed projects and initiatives showed a lack of actions towards local and regional authorities and a majority of actions targeted at cultural promotion of rammed earth. As practices and needs dealt with by local authorities seems to be closer to everyday issues and uses, the last part of this research focuses on this scope rather than heritage-based approaches. Based on the analysis presented above, we aimed to co-construct a rammed earth constructions management tool targeted to local and regional authorities.



Figure 4. Co-constructing a tool: Workshop with local authorities and professionals from public sector.

4.4 *Towards a better management of rammed earth buildings*

The process engaged to setup this tool brings to the forefront dialogue with the public actors involved in spheres of competences related to rammed earth. Methodological foundations were established from the analysis of the identified projects and initiatives around historic and vernacular rammed earth constructions and from methodological guidelines for projects targeted to public actors (Fauvel et al., 2015). They were discussed and amended during workshops with local actors and during in-depth discussions with some professionals from public bodies of Isère territory (Fig. 4).

These first exchanges brought out the main approaches of rammed earth constructions in the public bodies practices and policies through the concerns raised by the participants. These questions make visible how transversal old rammed earth constructions preservation and retrofitting is. It concerns many actors in the territory and implies decisions at big scales as well as everyday activities. They also highlight a range of issues: temporality and governance, heritage knowledge and training, or consistency of the policies across the decision-making levels.

5 CONCLUSIONS

This project allowed to improve at the same time the knowledge of rammed earth constructions

and the public stakeholder's dynamics around it in Auvergne-Rhône-Alpes region. The co-construction process engaged with local authorities is leading up to a methodological tool for the rammed earth constructions management in this territory.

The project updated the regional mapping of rammed earth constructions and provided interoperable data at municipal level. The current dataset includes buildings protected at a national level as "Monument Historique" and areas of protection. This work is a foundation from which the knowledge of rammed earth distribution in the region territory can be refined. It can also be helpful to incorporate rammed earth in the local and regional authorities GIS.

On management grounds, the aim in the long run is to co-construct a methodological tool allowing to catch the width of rammed earth range in public policies. Within this project, the process to create this tool was initiated and the tool is in the first steps of being tested while this paper is written. It already proves its ability to open a dialogue on the integration of rammed earth old constructions in local policies.

The collaboration with various public bodies is still underway. The trajectory initiated by the project is to reinforce links between stakeholders and explore tracks to make this dynamics sustainable. The activities considered to extend the project are for instance:

- the setting up of meetings gathering public bodies concerned with rammed earth issues, including collectives and organizations from outside the region who have an experience of working together around earth buildings management;
- the assembly of an application for the inscription of Auvergne-Rhône-Alpes rammed earth on the World Heritage List.

The progress of the research can be followed online: terrespise.hypotheses.org

NOTE

In this paper, we consider historic and vernacular buildings built before 1948 according to INSEE.

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Rammed earth buildings to meet Italian thermal regulation: Monitoring and sample tests

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ABSTRACT: Rammed earth has large thermal inertia due to its high density as to its hygroscopic properties and to the state changes of the water vapor component contained into the building material. That means a strong capability to store heat inside the wall and then drop it within rooms' environments with a considerable delay, as, at the same time, with certain attenuation of heat wave temperature peaks. Nevertheless rammed earth building heritage hardly can meet the thermal performances requests of Italian legislation. Paper presents results of a thermal monitoring of a recently refurbished rammed earth building, in Piedmont, Italy; monitoring study results show an interesting rammed earth walls thermal behavior, when considered on a whole year cycle. In order to verify low insulated rammed earth wall ability to reach regional regulation, also laboratory thermal tests on rammed earth, coupled with lightweight earth samples, in dynamic and steady state conditions, were conducted.

1 INTRODUCTION

1.1 *Hygrothermal behavior of rammed earth*

Rammed earth (RE) is a high density polyphasic porous material (Laurent 2010), composed of a granular structure of gravel, sand, silt, clay, and a porous part consisting of free voids between grains filled with water and air. Its thermo-hygrometric behavior depends on its mass and vapor transfer, as on heat transfer and storage abilities (Hall & Allinson 2009a).

Heat transfer through the wall has been demonstrated to depend largely on grain particles and pores size distribution, density degree and on the water amount inside pores. Evaporation and condensation phenomena inside the wall also have great influence (Hall & Allinson 2008). The greater the saturation degree, the great is the heat flow transmitted through the material.

A rammed earth envelope has an high thermal mass and it is able to store large quantities of heat inside the wall and release it inside, with certain attenuation and a considerable thermal lag; it is also able to absorb and release significant amounts of water vapor, regulating indoor relative humidity, due to its high hygric mass (Hall & Allinson 2009a, Minke 2006). So RE heat and vapor exchanges with ambient air, are strictly correlated and can help to control indoor temperature and relative humidity, as keep healthy indoor environmental conditions.

Nevertheless RE walls show a reduced thermal resistance and considerable thermal conductivity values, usually 0.7–1.4 W/mK (Rhölen & Ziegert 2011), strongly related to its bulk density.

This latest aspect means that rammed earth walls could suffer not neglectable heat drain from the building, in winter, and show not so good thermal performance if the only steady-state behavior is considered. This framework suggests RE has an effective thermo-hygrometric behavior in dynamic conditions, but when facing thermal building regulations for retrofit, in Italy, relevant problems arise.

1.2 *Rammed earth old buildings to meet Italian building requirements*

Earth building to face national thermal building regulations is a theme of great actuality, not only in Italy. Studies have been implemented in Australia, England and France (Dong et al. 2014, Goodhew & Griffiths 2005, Buzo et al. 2015), showing how rammed earth is often penalized by national thermal regulations requirements if founded on steady-state performance standards.

Italian regulation for thermal retrofit of buildings only takes into account the external envelope as average thermal transmittance U, and only during winter period (D.lgs. 192/2005, D.lgs. 311/2006). In Piedmont region, claimed as climatic zone E and F, DGR 46–11968 imposes minimum thermal

transmittance $U = 0.43$ W/m^2 K for opaque vertical structures in case of retrofit; this requirement is actually unreachable for un-insulated rammed earth walls, generally attesting on 1.0–1.3 W/m^2 K U values (Bollini 2013).

Despite poor affinity with building regulation standards, earth buildings inhabitants often reported positive feelings about their thermal comfort; moreover considering its high inertia, the thermal performance of RE envelope may be not so penalizing, if assessed considering its time-dependant behavior and optimizing passive solar strategies (Goodhew & Griffiths 2005, Dong et al. 2014, Bollini 2013). Moreover recent studies in Australia reported rammed earth buildings to show very low energy consumption, if compared with other buildings of the same climatic zone (Soebarto 2009).

Although the uncertainty due to the material complexity described before, methods to measure the simultaneous heat and mass transfer phenomena contribution to rammed earth thermo-hygrometric behavior have been proposed recently (Chabriac, et al. 2014).

1.3 *Rammed earth walls insulation*

Rammed earth walls insulation demonstrated could be a quite effective method to increase thermal resistance and improve the whole thermal behavior of the envelope. Although not easily comparable with climate conditions in Piedmont, Australian studies showed the effectiveness of insulating RE walls especially in winter and avoiding summer overheating (Soebarto 2009). Hall and Allinson studies on rammed earth insulated walls using cyclic-response admittance method showed how insulation significantly affects non steady-state thermal properties of a wall. Besides the need to find the way to evaluate simultaneously heat and mass transfer effects they concluded that it can help contain the heat exchange with the external environment through the wall (Hall & Allinson 2008).

Anyway there are several aspects to be evaluated when considering rammed earth insulation on both sides of the wall. Internal insulation could present several aspects difficult to handle: indoor ambient is decoupled by wall thermal mass, likely disabling its advantages, as cold bridges could be created; moreover inner room surfaces are reduced (Bollini 2013). It may present overheating risks too, though in cold climate internal insulation is suggested by some authors, to lower heat loss heat flux variations through the wall, avoiding indoor overheating (Hall & Allinson 2008).

External insulation is generally preferable (Bollini 2013) as it has shown to reduce energy load of the buildings (Soebarto 2009), but aesthetic and appearance issues related to cultural heritage aspects should be took into account. Cavity insulated RE walls result quite effective in temperate climates (Hall & Allinson 2008), but it is a highly complex technology and hardly eligible in case of retrofit. Anyway insulating material performances should be careful verified to be consistent with rammed earth hygrometric behavior (Bollini 2013).

In order to evaluate further aspects in continental-humid climates, a thermal monitoring on a recently restored rammed earth building in Piedmont was carried out. Besides in-situ measurements, laboratory tests were carried out in steady-state and dynamic conditions on RE samples, subsequently coupled with lightweight earth panel prototypes in order to meet the thermal requirements imposed by the Italian regulation in case of retrofit.

2 RAMMED EARTH BUILDING THERMAL MONITORING

2.1 *The restored "Cascinotto" Giacobbe*

The monitored building is a two floor square plan rammed earth load-bearing structure, with inner spaces distributed around a central stairwell and with an under roof not habitable space. The building, probably built in XIX century, is located in the countryside close to the town of Novi Ligure and could be classified as a "cascinotto", which is not a so usual typology in that area (Bollini 2013).

Load-bearing uninsulated rammed earth walls are 50 cm thick and stands on cobblestone and bricks foundation foots, while the roof is a two pitches wooden structure covered with local brick tiles. All house inner horizontal structures present cloister vaults. On the South-East front, a porch was built afterwards and, later, partially closed with rammed earth non load-bearing walls. Recently the building was completely restored by arch. G. Bollini, as described in Bollini (2013).

The building is equipped with a mixed heating system, with a wood stove and radiators, and is naturally ventilated.

2.2 *Thermal monitoring methodology*

Despites recently being recognized as key parameters, methods to measure, in-situ, the moisture content variation, as the impact of the phase change phenomena inside the wall, on a rammed earth inner temperature variation and on the whole building thermal behavior, are still under development (Chabriac et al. 2014).

The main aims of thermal monitoring of the building were:

– to measure indoor air temperature against outdoor temperature as index of the attenuation of heat flow fluctuation through RE walls, during summer period;
– to measure in-situ thermal transmittance in order to assess RE walls heat transfer ability, during winter period.

Three rooms have been chosen, according to different use and exposure to solar radiation, as shown in Figure 1. Particularly, thermal transmittance measurements were carried out in the bedroom at 1st floor facing north-west, avoiding direct solar radiation on tested RE wall.

2.3 *Air temperature monitoring*

Each of the three rooms was equipped with a data logger to record air temperature data every 900 s over a summer period of three months (July–September). A further data logger was put in the courtyard to record the external temperature trend. During the monitoring campaign natural ventilation was reduced and controlled since the house was largely unoccupied and windows were seldom opened up.

2.4 *Thermal transmittance measurement*

In situ measurements were carried out during winter (November 28th–December 9th) according to the heat flowmeter method (HFM), described in the standard ISO 9869.

The north wall of the bedroom was chosen in order to avoid the influence of direct solar radiation, whilst internal conditions were kept constant by the heating system.

Surface temperature sensors and two HFM probes were placed in two points of the internal surface considering the wall homogeneity. Besides thermal flux measurements, indoor and outdoor air temperature data loggers were installed at both sides of the tested wall. Data from the HFMs and the temperature sensors were acquired over a period of 10 days, without interrupting the data acquisition process. To reduce the measurement uncertainty, indoor air temperature was kept as constant as possible and the temperature difference against outdoor air temperature was kept higher than 10°C over the whole measuring campaign.

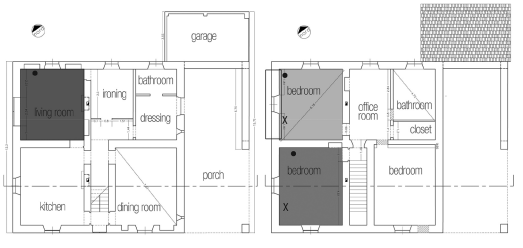


Figure 1. "Cascinotto Giacobbe" floor plan and 1st floor plan. Re-elaboration from Bollini (2013).
• data logger summer position; **X** data logger winter position; circled wall was used for U measurement.

3 THERMAL MONITORING RESULTS AND DISCUSSION

3.1 *Air temperature monitoring results*

During the monitoring period indoor air temperature of the three rooms presented a similar trend, almost unaffected by daily fluctuation of outdoor temperature (Fig. 2), if not due to opened windows recognizable in the graphs of Figure. 3 (in bedroom n.1 and in the living room during a warmer and a cooler period respectively).

Mean values of recorded rooms temperatures ranged from 23°C to 24°C and mean outdoor temperature was 22.5°C, resulting in an optimum comfort temperature limit of 25.7°C accordingly to Humphrey and Nicol equation for non conditioned buildings (Humphrey & Nicol 1998).

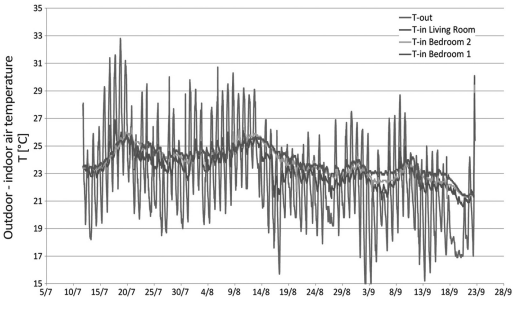


Figure 2. Three months measured air temperature trend.

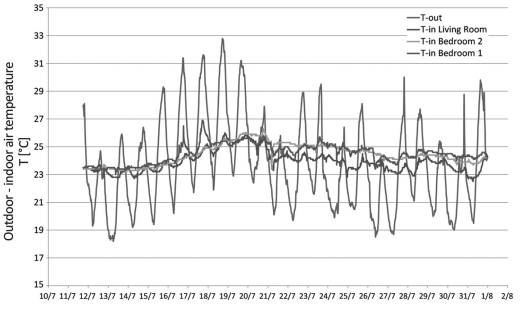


Figure 3. Measured air temperature in July.

Data confirmed RE walls ability to soften outdoor temperature fluctuation during the summer period.

3.2 *Thermal transmittance results*

Measured data through HFM probes and temperature sensors were processed using the progressive average method over the acquisition period of 10 days, as described in ISO 9869. The result of measured transmittance was $U = 1.23$ W/m^2 K for the RE wall of the bedroom, congruent with typical U values for un-insulated RE walls.

Therefore an improvement of thermal performance for this kind of RE walls is necessary, in order to comply with the Italian regulation in case of thermal efficiency retrofit.

4 THERMAL LABORATORY TESTS ON SPECIMENS

Two rammed earth walls specimens RE *A* and RE *B*, 50 × 50 cm, 12 cm thick, with two different compaction water content 12% and 15% respectively, were built in laboratory; a natural earth mixture coming from a cave very close to Novi Ligure and the monitored building was used. Earth mixture grain size distribution could affect samples thermal behavior (Hall & Allinson 2009b) but as local soil, it's assumed to be reasonably similar to that used for the monitored building construction.

At the same time, lightweight earth panels prototype were also produced in laboratory, using straw as the fiber component. All production process of both rammed earth and lightweight earth panels are described elsewhere (Pennacchio 2015 unpubl.). Two different earth and fiber mixture proportions panels, described in Table 1, have been used for thermal tests. Thermal tests on both RE specimens and lightweight panels alone, as on coupled specimens, were conducted at Department of Energy (DENERG) of Politecnico di Torino. Tests were carried out according to heat flow meter method, using the experimental apparatus with guard ring, *Lasercomp FOX600*, in accordance with UNI EN ISO 13786, UNI EN 12664 and ASTM C518.



Figure 4. RE and Lightweight samples realized in laboratory.

Main aim of the test was to verify if rammed earth walls could accomplish with Piedmont regional regulation for thermal retrofit of buildings, adding lightweight earth panels, with limited insulating capacity, as not to completely lose walls' thermal inertia characteristics.

Lightweight panels were tested only in steady state conditions, while rammed earth samples in both steady-state and dynamic conditions. Tests in dynamic conditions were repeated coupling RE samples with lightweight panels and thermal performance variations have been observed.

RE specimens were naturally dried in laboratory for 60 days and then further dried in oven at 60°C for 48h before thermal tests.

4.1 *Steady state thermal laboratory test*

Since it was not possible to control relative humidity inside the test apparatus chamber, RE specimens were wrapped and sealed in a plastic sheet, in order to avoid water content variation. This way test was limited to the sample physical controlled variables, excluding water content.

Sample *A*, 12% compaction water content and sample *B*, 15% compaction water content were tested; test was performed with three different average temperature settings: 20°C, 30°C and 40°C, imposing for each one a 10°C temperature differential between plates. Test were conducted over 24h and allowed to determine samples thermal conductivity λ, as shown in Table 2.

Test conditions applied to lightweight prototype panels were the same used before, but panels were left naked. Specimens thickness and thermal conductivity was defined as shown in Tables 1, 2.

Table 1. Rammed earth and lightweight panels characteristics.

Rammed earth samples			
Samples	Water content %	Size cm	Bulk Density kg/m^3
RE *A*	12%	50 × 50 × 12	1573
RE *B*	12%	50 × 50 × 12	1645
Lightweight earth prototype panels			
Samples	Mixture earth-straw	Size cm	Bulk Density kg/m^3
LE *A*	1:3	50 × 50 × 3.2	403
LE *B*	1:1	50 × 50 × 3.2	740

Table 2. Samples steady-state thermal conductivity.

Samples	Mean T °C	Upper λ W/m K	Low. λ W/m K	Avg λ W/m K	λtot.eq W/m K
RE *A*	20.02	0.438	0.410	0.424	0.473
	30.02	0.440	0.419	0.429	
	40.02	0.434	0.438	0.436	
RE *B*	20.02	0.552	0.534	0.543	0.601
	30.02	0.547	0.542	0.545	
	40.02	0.544	0.559	0.552	
LE *A*	20.02	0.104	0.102	0.103	0.072
	30.02	0.108	0.106	0.107	
	40.02	0.112	0.111	0.111	
LE *B*	20.02	0.104	0.102	0.103	0.111
	30.02	0.108	0.106	0.107	
	40.02	0.112	0.111	0.111	

4.2 *RE samples thermal laboratory test under dynamic conditions*

RE samples have been tested for 48–72h under dynamic conditions; temperature fluctuations on the upper surface of the tested samples, have been induced, keeping the apparatus upper plate in a dynamic state by varying temperatures cycles with a 10°C amplitude, between 25°C and 35°C. Consequently a heat flux through the sample and its lower side has been registered. Detected heat flux and temperature fluctuations (Fig. 5) were used for data elaboration.

Once obtained *Periodic transmittance* Y_{ie}, *Thermal lag* φ, and *Attenuation* f_a values, they were used for RE samples *Specific heat c* calculation, using UNI EN ISO 13786. Starting with entering thickness, density and λ data experimentally obtained, in the related spreadsheet, *c* values have been then modified in the spreadsheet, until samples dynamic conditions thermal properties values, previously experimentally achieved, were reached. Resulting *c* value, for both 12% and 15% starting water content samples, was 950 J/kgK, which is in accordance with literature data (Houben & Guillaud 1994, Bollini 2013). Calculated *c* value is used to determine RE walls thermal performance in dynamic conditions, through UNI EN ISO 13786, imposing a wall thickness of 50 cm; a comparable value to RE wall actual size and to the monitored building ones; results are shown in Table 3.

4.3 *Composite wall samples thermal tests under dynamic conditions*

For composite wall sample tests, RE specimen *B*, with 15% compaction water content, was chosen, due to the better maximum reachable bulk density results, showed during the *Standard Proctor* test (UNI EN 13286–2:2005).

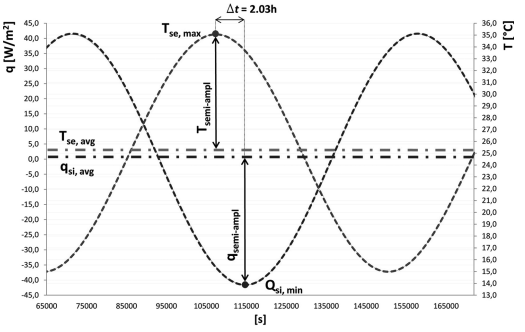


Figure 5. Temperature T trends acting on sample RE *B* upper side, and heat oscillatory flow q outgoing from the opposite side.

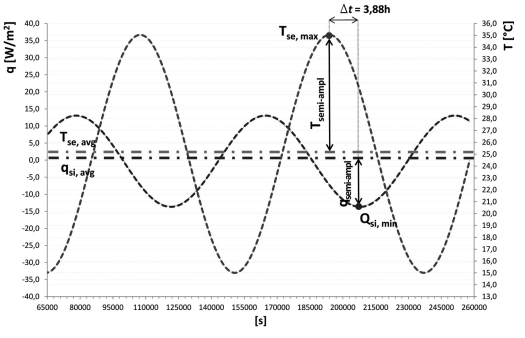


Figure 6. Temperature fluctuation on RE B + LE A upper side and heat oscillatory flow outgoing from lower sample side.

Table 3. Rammed earth walls samples thermal tests results under dynamic condition.

Samples	s cm	f_a –	φ h	Y_{ie} W/m² K	U W/m² K	C W/m² K
RE *A*	12	0.76	2.35	2.95	–	3.88
RE *B*	12	0.81	2.02	4.14	–	5.13
RE *A**	50	0.038	19.6	0.030	0.81	0.94
RE *B**	50	0.053	17.8	0.053	0.998	1.20

*Thermal values are determined through UNI EN ISO 13786 starting from experimentally detected data.

Previously used protocol for tests in dynamic conditions, was repeated coupling lightweight prototype panels *A* and *B* to the RE *B* sample, one each time; results are shown in Table 4.

Lightweight panels specific heat *c* was calculated as before for RE samples, using UNI EN ISO 13786, resulting in both cases 1000 J/kgK, very closed value to lightweight earth available literature data (Volhard 1995).

Table 4. Composite wall samples thermal performance.

Samples composition	s cm	f_a -	j h	Y_{ie} W/m² K	U W/m² K
RE *B* – LE *A*	15.5	0.83	3.87	1.33	3.88
RE *B* – LE *B*	15.0	0.53	4.07	1.62	5.13
RE *B** – LE A*	61.0	0.01	23.27	0.004	0.395
RE *B** – LE *B**	67.0	0.005	27.48	0.002	0.395
RE *B** – LE *A***	61.0	0.014	22.71	0.005	0.395
RE *B** – LE *B***	67.0	0.007	27.09	0.003	0.395

*With LE *A** and LE *B** 11 cm and 17 cm thickness respectively while RE *A** e RE *B** 50 cm thickness.
**Lightweight prototype panels are considered on the inner side of the sample walls.

Coupled samples thermal performances were calculated analytically, again according to UNI EN ISO 13786, using obtained *c* values, and imposing RE sample thickness 50 cm.

The aim, this time, was determining the necessary lightweight panels thickness, in order to reach the thermal transmittance value in steady-state conditions requested by Piedmont regional regulation in case of retrofit (DGR 46-11968). Table 4 shows how to remain comfortably within the imposed *U* values limits, 11 cm and 17 cm lightweight earth panel *A* and *B* respectively, were needed.

4.4 *Thermal laboratory test results and discussion*

RE samples *Thermal conductivity* λ, (excepting for sample *B*), *Thermal transmittance U*, *Periodical thermal transmittance* Y_{ie}, *Attenuation factor* f_a and *Thermal admittance* Y_{ii} values (4.01–4.31 W/m² K) found experimentally, appear slightly below those available in literature (Röhlen & Ziegert 2011, Bollini 2013). Reasons could be found in the sample bulk density, reaching minimum values in sample *B*, and too low in sample *A*.

Comparing RE samples and composite samples thermal performance in dynamic conditions, adding lightweight earth panels to RE sample *B*, *Attenuation factor* f_a and *Periodic thermal transmittance* Y_{ie} sharply drop; internal temperature fluctuations suffer a further decrease, while also *Thermal lag* φ, already excellent in the sole RE, is improved.

Composite sample RE *B* – LE *A* show excellent thermal performances, under dynamic conditions, even using 8 cm lightweight earth panels thickness, but it doesn't reach *U* values requested by Piedmont building retrofit regulations.

Although their not particularly low λ, if coupled with RE samples, LE panel *A* show good results, even on winter thermal performance, with limited thickness.

RE good performance in summer period is not compromised if LE panels are used on external side of the wall. Composite wall sample dynamic thermal performances were then verified moving panels on the inner side. *Attenuation factor* f_a, *Thermal lag* φ, and *Periodic thermal transmittance* Y_{ie} values, didn't show consistent variations (Table 4).

5 CONCLUSIONS

Thermal monitoring of a rammed earth building confirmed RE walls ability to soften outdoor temperature fluctuation during the summer and showed a thermal transmittance value congruent to literature data. Steady state thermal tests on rammed earth samples confirmed thermal transmittance values registered during the building monitoring, and showed the impossibility for rammed earth walls to accomplish with Piedmont retrofit regional regulations.

Tests under dynamic conditions allowed a more suitable samples thermal performance assessment to define rammed earth wall thermal behavior. Composite wall samples, realized coupling lightweight earth prototype panels with limited insulating capacity, although yet under development, with rammed earth wall samples showed interesting potential to accomplish with thermal regional regulations in case of building retrofit.

As a further development, vapor transfers wall-indoor environment contribution to the thermal performance of a rammed earth envelope would be interesting to assess.

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A pilot project, a tool for conserving the historic city of Cuenca, Ecuador

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ABSTRACT: The historic city centre of Cuenca in Ecuador is mainly built with earthen material. Although prestigious rehabilitations are undertaken on major historic buildings, common dwellings, which compose the majority of the city centre, are in poor condition and gradually abandoned. In this context, earthen conservation works are particularly difficult because of poor interest on earthen material, lack of arguments and incentives for conservation of earthen architecture, difficult materials supply and lack of technical skills on earthen architecture. A pilot project undertaken in 2015, by CRAterre has been instrumental to strengthen capacities of the municipality; bring awareness and disseminate good practices in the maintenance of private houses; to demonstrate how it is feasible and financially accessible to prevent major decay in the houses; and to train at once craftsmen's, architects, technicians and staff from the municipality.

1 INTRODUCTION

Cities are the most quickly evolving environments on the planet. In this framework, promoting sustainable urban development is a key issue, because it concerns more than half of the world's population, who lives in cities today.

According to UNESCO, "The starting point for the development of sustainable urban development strategies is the conservation and safeguarding of tangible and intangible heritage. Without an effective safeguarding action, the legacy of the past can rapidly be lost, as it is happening in many urban contexts characterised by intensive and rapid development processes, with the loss of connection between communities and the built environment in which they live" (UNESCO 2016).

In this framework of rapid urban changes, a handful of cities can be sources of inspiration. These are the 193 cities listed on the prestigious World Heritage list, because of their outstanding universal values and their management and conservation practices that allowed their permanence during centuries.

Despite this recognition, these cities have faced pressure of several kinds (war, natural disaster or real estate development projects). According to UNESCO-WHC, "Reports on the state of preservation of this heritage are reflecting more and more frequently the difficulty of balancing the interests of modern urban development and respect for patrimonial values" (UNESCO 2016). For 1/3 of these cities, the situation is more complex because they are built with earthen material, which deserves particular attention in terms of conservation and maintenance. Local know-how conservation is crucial.

Concerned by the multitude of challenges facing these world heritage sites, and prone to develop best practices, the World Heritage Committee has set two programmes: in 2005 the World Heritage Cities Programme (WHCP) and in 2007 World Heritage Programme on Earthen Architecture (WHEAP). They both aim at developing guidelines, methods and techniques in conservation and management and in capacity building, in their fields of action.

World Heritage Cities built with earthen material are particularly interesting cases studies because they face major stakes. First, it can be mentioned among other aspects, the urgency to act before the loss of knowledge on earthen architecture, key resource for maintenance and development of new ecological houses, indeed: craftsmen who own this kind of know-how are getting retired. Secondly, the importance of regenerating downtowns through fostering maintenance and adaptive reuse of houses, in order to improve liveability and living condition for

inhabitants. Finally, the complexity of intervention in an urban environment (density, supply of materials, availability of craftsman, regulatory framework, etc.).

The case study of Cuenca historical centre is particularly interesting for the large impact it had on earthen private housing through the strong collaboration between concerned stakeholders: municipality, universities (architecture, media, etc.), architects, craftsmen and representatives of the civil society on conservation and management of historic city build with earthen material. This case study is based on research and documentation, field experiences and interviews with main players of the conservation and development of earthen architecture.

2 THE PROJECT

2.1 *Context*

Cuenca is a city located in the southern part of the Republic of Ecuador. Its historical centre is a World Heritage Site since 1999. It is considered an outstanding example of a planned Spanish town built in the Andes. Its remarkable urban planning is populated by a very rich architecture: "Its exceptional value is due to the capacity to absorb the different architectural styles of the past while retaining its basic character of a colonial town. The successful fusion of different societies and cultures in Latin America is vividly symbolized by the townscape and traditions of Cuenca" (UNESCO 2014).

The majority of the historic centre of Cuenca is built using earthen materials, including different techniques: adobe, wattle and daub, earth in roofs or plasters (UNESCO 2012). It is considered that about three-quarters of the historic city of Cuenca is built with earth This rich architecture is elaborated with a great variety of technical details which have been developed through centuries of evolution of traditional techniques.

Despite its wealth, there are many threats upon this heritage. Earthen techniques are often poorly valued by its inhabitants and by professionals. In many cases, the architectural heritage of the city is prone to abandonment or is threatened by bad practices. The dynamics of change are also strong, in particular with the phenomena of gentrification. Each building loss represents one step closer to the demise of the rich cultural heritage of the city.

The will to put an end to bad practices that affect earthen architectural heritage of the city of Cuenca is at the origin of the project "City of Cuenca, Ecuador: mobilization of women and youth in the transmission of traditional techniques for the preservation of earthen architecture", which was undertaken in 2015, with the aim of preserving this UNESCO World Heritage Site.

2.2 *Key actors for the revitalization of the architectural heritage in Cuenca*

The project was developed in cooperation between UNESCO - World Heritage Centre - Latin America and Caribbean, CRAterre (France) and the National Institute of Cultural Heritage of Ecuador (INPC - R6), and thanks to the support of the Panasonic Foundation.

The commitment of the State is fundamental for heritage conservation. In this sense, INPC R-6 has been a driving force for the project.

These partners collaborated with the main local stakeholders. In first place, the Municipality of Cuenca (GAD), and in particular the Historical Areas Directorate, that has embraced the problematic of earthen architecture revitalization in the urban context, with special emphasis in the necessary tools to accompany buildings' owners and inhabitants for proper maintenance. Next to them, the experience of the Faculty of Architecture and Urbanism of the University of Cuenca, member of UNESCO Chair in "preventive conservation, monitoring and maintenance of monuments and sites", and the CRAterre Association, member of the UNESCO Chair in "Earthen architecture, constructive cultures and sustainable development", accompanied the project. The technical assistance of the World Heritage Center, through the regional office for Latin America and the Caribbean, has ensured the quality of the project.

2.3 *Objectives and main activities*

Four objectives were researched: first, to formulate and implement harmonized, equity focused and gender sensitive oriented trainings, in accordance with the Local Government's commitments to the "Buen Vivir" policies, that promote harmonious living between people and nature; second, to raise awareness amongst owners about monitoring the state of conservation and preservation of their properties, associated with a heritage conservation programme for their maintenance and use; third, to develop training courses in earthen architecture artisanal production techniques to support the conservation of buildings; fourth, to implement training workshops on site management.

To meet the above objectives, two main activities were accomplished, between April and November 2015. One activity consisted in a series of interinstitutional Workshops on heritage management in order to define a strategy to support citizenship in the conservation of their earthen houses. The other activity was a pilot conservation project to demonstrate to the authorities, professionals and house owners the interest of preventive conservation and the effectiveness of this kind of projects as a training platform. In this framework, raising awareness campaigns were

undertaken, capacities were built and the necessary pedagogical material was produced.

2.4 *Main results*

2.4.1 *Seven interinstitutional meetings*

The project gave priority to "strengthen technical and managerial skills in conservation of earthen architecture" through the organization of workshops involving the different stakeholders. These interinstitutional meetings brought together representatives of the National Institute of Cultural Heritage, the City of Cuenca Municipality (GAD) and the Faculty of Architecture and Urbanism of the University of Cuenca. During the process, this core group was extended to the Municipal Housing Company, the Escuela Taller of Cuenca, the District Committee of El Vado neighbourhood, craftsmen, and technical professionals.

Seven meetings have resulted in a roadmap for the different stakeholders but especially for the Municipality, in order to help and support citizens in the conservation of their dwellings.

In a first phase, priority objectives were defined, according to their importance and to the relation between needed resources and potential impact. In a second phase, pragmatic strategies to achieve priority challenges were defined, and a list of proposals for actions was drawn up, organized by objectives. The proposals were focused on preventive conservation approach, as one of the most participative and accessible (easy and low cost) conservation methods. They promoted awareness, dissemination of good practices and involvement of the inhabitants and owners in maintaining their homes.

At each meeting, the proposals were detailed and at the same time a particular theme of the heritage conservation in Cuenca was analysed. The discussed topics were: monitoring, diagnosis and preventive conservation; management and management framework; masons and craftsmen; maintenance, preventive conservation and interventions; monitoring and sensitization; emergency and counselling; and funding. In the end, 23 proposals had been determined. Some of the measures were the creation of a materials bank, a support office for inhabitants and owners and the creation of a masons and craftsmen group prepared to act in urgent situations (SOS Heritage).

At the end of the project, the stakeholders were committed to continue to carry out these meetings and to work together on specific projects and priority lines of action.

2.4.2 *Open conservation work site*

Preventive maintenance is the best way to conserve buildings with reduced means, in particular for citizen with little resources.



Figure 1. Works during a practical training session. (E. Sevillano Gutiérrez 2015).

As a demonstration of preventive maintenance, urgent maintenance works to prevent major decay with reduced means (2500$ for labour, materials and training activities) were carried out in a house of the historic centre, Casa Otorongo. It was decided to open the work site to the public in order to demonstrate that it is feasible and accessible to prevent major decay in the houses through regular maintenance.

During two weeks the site constituted a place of exchange about the conservation of earthen heritage.

2.4.3 *Trainings for about 60 people*

The maintenance works on the Casa Otorongo were the opportunity to implement a series of trainings for more than 60 professionals: practical trainings for craftsmen, and theoretical-practical trainings for architects, technicians and representatives of the institutions including the municipality, as well as professors and experts.

During the works, 7 masons were trained by working during 10 days besides architects specialised in earthen heritage conservation. The masons undertook a wide range of works and learnt new conservation techniques. They also led the earth construction workshops addressed to the citizens during the Day of Earthen Architecture.

In order to train architects and technicians who work in the conservation of earthen heritage in the historical centre of Cuenca, 5 training and sensitizing sessions of 3 hours were developed for 10 people each time. These sessions were supervised both by the professionals in earthen architecture and by the craftsmen. In order to raise awareness, these 5 trainings sessions were partially open to public and received visits from institutional representatives. Therefore, in addition to training, masons were able to transmit their knowledge, and give 50 professionals some initial orientations to develop a quality work.

2.4.4 *Educational and awareness materials for all publics: long-term impact*

Detailed researches have been carried on by professionals, Phd students and researchers about

traditional building techniques of Cuenca historical centre's dwellings, and particularly about common problems and damages (Abad Rodas & Tommerbak 2009, Pedra 2008 and others). Nevertheless, these monographs and Phd thesis are hardly accessible for most owners of the houses. Sensitization and pedagogy are two priority lines of action to promote the conservation of the city of Cuenca. The project therefore aimed to create different pedagogical materials that have been designed to reach different target groups: from craftsmen, to architects, professors and technicians of the institutions in charge of heritage, to inhabitants and owners.

A range of educational and awareness tools were thus created:

- a technical guide in 100 exemplars, and available on-line for free download,
- eight series of posters and 300 brochures for citizens,
- 500 booklets presenting the project, also available on-line for free download,
- a video to raise awareness about the importance of heritage.

The preparation of these materials was also the opportunity to involve and sensitize students from other two local universities: the Faculty of Architecture of the Azuay University, for the technical guide, and the Information and Communication Science School, for the video.

This material is available to local authorities and partners: they can use it, update it and disseminate it in order to reach the greatest possible impact.

2.4.5 *A public event: Day of earthen architecture*

A Day of Earthen Architecture was programmed and developed at the Casa Otorongo working site as a public event to bring awareness to citizens, students, masons, architects, technicians and professionals and to allow a rich exchange between all of them around earthen construction.

More than 100 people participated in the different demonstrations activities that took place during the day: guided visits of the construction site, workshops and practical demonstrations as well as a debate and presentations on conservation and contemporary earthen architecture projects in Ecuador by their architects.

This day was an opportunity for citizen participation, and was animated by a gastronomic fair developed with the support of the El Vado neighbourhood Committee.

The Day of Earthen Architecture was also a preliminary event for the 15th SIACOT Seminary (Seminario Iberoamericano de Arquitectura y Construcción con Tierra), organised in Cuenca by the Iberoamerican PROTERRA network as well as the University of Cuenca that could present the event to the participants.

2.4.6 *Participation in the 15th SIACOT in Cuenca*

Apart the organisation of the Day of Earthen Architecture as a pre-SIACOT event, the project also participated in the Seminary with the development of a workshop by Wilfredo Carazas (Test Carazas) open to 150 people, and with a conference on the project by architect Lourdes Abad, with more than 100 participants from different countries: Peru, Colombia, Ecuador, Mexico, Nicaragua, Brazil, Portugal, etc. The booklet presenting the project was distributed to 180 people.

2.4.7 *Media large-scale dissemination*

The preventive maintenance works on Casa Otorongo, as well as the organisation of the Day of Earthen Architecture were a great opportunity for large-scale dissemination in different media. The objectives were to communicate regarding the project's achievements and to promote the importance of earthen architecture conservation as irreplaceable Cuenca cultural heritage.

A press conference, attended by numerous media, was held in the house itself. The press also participated in the Day of Earthen Architecture.

Different articles were published in greater diffusion newspapers of the city, in which the project was explained, the city's heritage was valorised, and masons were interviewed and valued.

The project was also presented in two prime time programs in local radios and on a television chain.

2.4.8 *A group of friends of earthen architecture in Cuenca*

The enthusiasm for the project led to create a group of "Friends of earthen architecture of Cuenca". This network aims to be a meeting point for all people interested in the conservation of the earthen heritage in Cuenca and in contemporary earthen architecture. The network unites more than 300 professionals and



Figure 2. A series of educational and awareness materials. (E. Sevillano Gutiérrez 2015).

inhabitants of earthen dwellings connected to each other. Its purpose is for users to share information, raise doubts and generate a collective discussion about the participants' interests and concerns.

3 PROJECT'S APPROACH

3.1 *Pilot conservation works project: A key to convince all stakeholders*

A number of institutions and individuals are concerned with earthen architecture in Cuenca. However, when the project began they were facing a kind of fatigue, in front of the enormous challenges of the city centre heritage conservation. To instill a new dynamic, it was necessary to be pragmatic and demonstrative, and to convince that changes can be achieved step by step.

The main stakeholder to convince was the Municipality, who since several years was seeking for major funds for a large conservation program.

In order to convince, the project was built on available human resources and was implemented at a very limited scale, both physically and timely, but numerous tools explaining and demonstrating the interest of its approach were developed: documentation, teaching materials, demonstration project, etc. Besides its limitations, the intervention, management and training model of the project drew the attention of the authorities. Now, it would be necessary to evaluate its impact in detail and to include it in a longer-term and larger-scale strategy, according to the roadmap.

3.2 *Satisfactory results in a limited time*

The project allowed to set collaborative conceptual, methodological and pedagogical bases for long-term earthen architecture conservation strategies in Cuenca. The stakeholders were satisfied with the results achieved. The project had many positive results in spite of being executed in a very short time (6 months). This permitted to be more efficient and intense in terms of commitments and actions development. The different players worked from the beginning with a short time lapse perspective in mind, trying to put all available means to facilitate the project development.

3.3 *Preventive maintenance as a key for large scale conservation plan*

Constructions in the historic city centre of Cuenca are often inhabited by impoverished tenants or by families that are unable to maintain big houses, following the fact that families' size has decreased and thus the needs of space have changed. The issue of maintenance becomes soon financially problematic for these groups.

Working with limited economical resources, this project succeed in the crucial aim of demonstrating that preventive maintenance is the best way to conserve the built heritage with reduced means. Letting the problems worsen leads to an increase of the need of economic and technical means for intervention at a later time. This often leads to the destruction of the building and to its sale to wealthy families, strengthening the gentrification process.

3.4 *Interinstitutional and collaborative work*

One of the main strengths of the project was that the different actors involved in heritage management and conservation on both national and local level were brought into contact and worked together to a roadmap. Collaboration of such an extent had not always been easy in the local context, and a rich exchange took place between the different actors involved in the project.

Moreover, involving stakeholders from civil society, such as universities, professionals and neighbourhood committees, enhanced the endurance of the roadmap development in the long term, beyond short-term political decision-making.

3.5 *The neighbourhood scale*

Most projects and programmes aimed at promoting earthen heritage conservation focus on specific, valuable buildings. Concerning ordinary historical buildings, their protection is often put in the hands of urban planning, which have very large extent and long-term timelines. Often urban programs approval needs a considerable financing, so that the process takes time, while heritage is in danger.

This project shows the effectiveness of actions carried out on the neighbourhood scale. This enables to raise awareness on a specific network of inhabitants and owners. Furthermore, maintenance works shown in a pilot project are suitable for a specific kind of building, and the limited spatial extent enables to work on short-term projects.

In this pilot project, it was necessary to establish strong bonds to reach the citizenship. In this way, the El Vado neighbourhood Committee had a fundamental role spreading information towards inhabitants. The presence in the neighbourhood of the vocational school for masons, Escuela Taller, was also a strategic factor.

The project hold in 2014 in San Roque neighbourhood of Cuenca by the FAUC in collaboration with the Municipality also shows the advantages of neighbourhood scale approach. Experiences like these ones should be propelled in other neighbourhoods of the city.

3.6 *The importance of specific training*

Likewise, the municipality's vocational school for masons, the Escuela-Taller of Cuenca, was fundamental in disseminating to young trainees information about the project and the pedagogical material on earthen heritage conservation developed during the project. This school must be an essential stakeholder of heritage management programmes, as training young masons to work appropriately on earthen architectural heritage is a key factor for its conservation.

3.7 *Contemporary architecture role for a change of image of earthen materials*

In Ecuador, earth is still stigmatised as a poor building material. Nevertheless, a new generation of prize-winning architectural offices (Al Borde, Chaquiñan, Al Cubo) is re-introducing earth in valuable contemporary architecture projects. This could contribute importantly to change the image of earth, both to spread its use in new building projects as and to sensitize citizenship towards earthen heritage conservation.

During the Day of Earthen Architecture, contemporary architecture projects both on a local and national scale were presented by their designers.

3.8 *A pragmatic and multidisciplinary approach*

The project adopted a pragmatic approach, providing managers and technicians with tools and methods to accompany the inhabitants in the conservation of their built heritage. This project worked with people.

Moreover, these actions were based on a multidisciplinary approach, associating university students and professionals of diverse horizons: heritage experts, historians, architects, communication sciences experts, engineers, etc.



Figure 3. Workshop during the Day of Earthen Architecture. (E. Sevillano Gutiérrez 2015).

4 CONCLUSIONS

4.1 *Way forward*

Some learnings about the Cuenca project are worth underlining for programs promoting the preservation of vernacular non-monumental earthen heritage.

The strategy based on a pilot conservation works project gave positive results in different directions. Built on available human resources, on a small scale, with a limited budget and over 14 days, the pilot project on a single house allowed nonetheless to train both artisans and architects and technicians in earthen constructive cultures applied to the conservation of vernacular non-monumental heritage. Taking into account and developing local knowledge and know-how in conservation and management is crucial for such projects, as it will ensure social, economic and spatial continuity.

Furthermore, the pilot project led to the sensitisation of a large number of inhabitants and owners, together with the numerous tools developed to explain and demonstrate the interest of the project.

Finally, its multidisciplinary approach based on preventive maintenance and interinstitutional cooperation can be a source of inspiration in other contexts.

Regarding this, working with institutions within the project also highlighted the question of governance: it is crucial to continue identifying strategies that cover not only technical issues but also governance issues. The challenge is to take stock and enhance practices for the permanence of world heritage cities, in order to set effective policies embraced by all concerned stakeholders, public and private.

In this framework, the World Heritage Cities Programme (WHCP) and in 2007 World Heritage Programme on Earthen Architecture (WHEAP) are instrumental. Thus, it would be interesting to have a special set of projects on World heritage cities built with earthen material: urban contexts are specific, and most importantly they are a good frame for the development of effective, concrete strategies for a culturally, socially, economically and ecologically sustainable development.

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Vernacular change in Brazil southeast region

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ABSTRACT: Studies in the field of vernacular architecture have argued that changes and transformations should not be seen as obstacles, but rather as a necessary part of its survival. Under this new perspective, this article analyses these changes in two villages in the southeast of Brazil. Specifically, it seeks to understand the meaning and dynamics of the transformations occurring in the vernacular architecture of these communities. The methodology included the registration of buildings, interviews with local residents and builders, and use of the anthropological method of Participant Observation. The results showed a process of dynamic transformation in which tourism played a decisive role in the continuity of the vernacular building tradition. Additionally, a new perception of the use of adobe was noted, as evidenced by the unplastered adobe facades. It was also observed that self-build has fallen into disuse and is being replaced by the hiring of construction workers.

1 INTRODUCTION

Recognized scholars (Upton 1993, 2001, Oliver 1990, Vellinga 2006) have argued that the changes and transformations are characteristic of vernacular architecture, and not a break or danger to their authenticity or tradition. Both Upton (1993, 2001) and Vellinga (2006) go so far as to argue that this is the great challenge found in the last few years for this field of research.

In southeastern Brazil, one of those challenging changes is taking place. In this region, the most industrialized and densely populated in the country, and where it was thought that the vernacular architecture had suffered a definitive process of discontinuity, there are villages where this vernacular building culture has survived in a transformed way.

What is the meaning and dynamics of the transformations that are taking place in the vernacular architecture and building culture? Seeking to answer this question, two researches in two of the most significant of these locations were developed. This work will compare the results provided by these two researches and analyze the most relevant aspects.

2 METHODOLOGY

The first question for this study was how to compare the two researches. The two researches used the same methodological basis, which facilitates this comparison. The option was first to study each one of the researches, and than decide which are the main points to be analyzed and compared. The theoretical frame allowed finding these main points.

The strategies used by the two researches were, taking into account an ever dialectic and dynamic interaction between each of the study phases and survey data: a survey and a photographic record of all the buildings in each village; interviews and re-interviews with the local adobe producers; interviews with the builders that use adobe masonry; interviews with the residents of the communities; and finally, the anthropological methodology of Participant Observation (François 2007, Angrosino 2009).

In the Participant Observation method, the researcher, without ignoring the ethnocentrism of his/her culture, seeks to effectively participate in the life of the community under study, aiming to capture not only its discourse, but also (and especially) its habits, routines, behaviors and attitudes. This approach was aimed to penetrate and unveil the tradition (Bronner 2006) of the two studied communities.

3 TRANSFORMATION IN VERNACULAR ARCHITECTURE

Oliver (1990) already advocated the importance of understanding vernacular architecture as subject

to the dynamics of change in the 90 s. Continuing, the author comments on how a certain false academic purism was unable to understand the need, and before that, the reality that while the vernacular building culture is "alive", it will mean changes in vernacular architecture. Thus, the researcher considers it inappropriate to take it as an object that cannot be transformed.

Similarly, Upton (1993, 2001) draws attention so that the researchers of the area set aside a search in a certain positivist sense for tradition and authenticity and seek to understand the importance of change and transformations on the vernacular horizon.

Bronner (2006) states that the great transformation process, and the possibility of innovating contemporary society, does not necessarily mean the end of tradition, but its survival in new forms and contents.

Vellinga (2006) also identifies the need for a new understanding of the role of tradition in vernacular architecture, understood not as static, but as a constantly changing heritage seeking adaptation to the current reality.

Vernacular architecture is then taken as a cultural component that has its own transformation dynamics (Oliver 1990) and the transformations that occur therein not as a "deviation", but as an important analysis factor to understand it in all its dimensions (Upton 1993, Bronner 2006, Vellinga 2006) follow with the discussion of case studies.

4 THE CASE STUDIES: A BRIEF DESCRIPTION

4.1 *Bichinho*

Bichinho is located in the south of Minas Gerais State and is part of the municipality of Prados. (Fig. 1). It has approximately 1,000 inhabitants. Although its official name is the Victoriano Veloso district, it is better known as "Bichinho". It has handicrafts and tourism as its main sources of income (Prefeitura Prados 2010).

The settlement emerged in the early eighteenth century as a result of activities related to gold mining and its urban and architectural evolution followed the same dynamics of the other mining towns at that time. At first, it was established with rustic houses built in adobe and roof covered with plant leaves. In 1795, the village had 661 inhabitants and 184 houses, almost all of them built in adobe (Prefeitura Prados 2010).

In the nineteenth century, with the decline of gold mining, there was a considerable decrease in the local population. This is reflected by the abandonment, deterioration and reduction of the number of houses. In 1824 there were 61 houses with 298 inhabitants (Prefeitura Prados 2010).



Figure 1. Brazilian map with states division the country capitol, the state of Minas Gerais capitol, the biggest country cities and Bichinho and Lapinha da Serra (J. Vale).

In the early twentieth century, the population practiced subsistence agriculture and had small cattle ranches. Local handicraft production begins at that time, by producing bamboo mats for ceiling lining and jewelry assembly for the manufacturers in the nearby town of Tiradentes, as well. The census of 1900 recorded 600 habitants and 140 houses (Prefeitura de Prados 2010).

As it was already happening all over the country since the nineteenth century, throughout the twentieth century it is witnessed the creation of some small baked solid brick ceramic producers in the village.

With the production it has began a replacement of adobes by this bricks, but it was not carried out completely due to the costs and the inability of the small factories to meet the existing demand. The brick mortar often continued to be made from dirt, with lime added sometimes.

The improvement of the roads from the 70 s facilitates the access of the inhabitants of the village to cement and, later on, to extruded ceramic bricks and new materials, such as metal windows and ceramic floors, which generated changes in the production and formal composition of housing. This process started with the purchase of solid brick, but it was accelerated with the new materials and possibilities started in the 70's. It is interesting to highlight that the growing replacement of subsistence agriculture by salaried work also contributes for this process to take place, since the self building are substituted by the hiring of

professionals and the purchase of materials to build the dwellings.

Concerning the formal composition of the constructions, the use of metal windows, of parapets and even a new distribution of rooms leads to a new composition of facades that is very different from what it had been done until then (Figs. 2, 3). The vernacular typology that maintained itself without many changes over the years starts, then, to suffer an important modification.

The lack of resources of the villagers did not allow the full and immediate change in all dwellings, but as could be noted in interviews with older local people, the majority of the population at that time preferred this new kind of housing. However, in the late 80 s and 90's, four main events contribute for change this perception concerning housing and promoted a very particular development of Bichinho's vernacular constructive culture.

First, a local craftsman, in order to reduce costs, decides to construct the first hostel in the village using adobe. That first construction at that time encouraged the use of that technique in other constructions during the late 80's.

Another important point was an increase in the tourism during the 90's. The tourists enjoyed the adobe houses and began a promotion of the adobe use.

Some time later, in 1994 there was the begin of a craft workshop in the city. Owned by an artist of another city this workshop was very important for the development of the local art craft and for development of the district itself. This artist had a clear option for the adobe as a construction material. He and his craft workshop had a great influence over the local culture

Finally, in 1996, after taking part in a training course for the production of adobes during the restoration of an adobe construction in Tiradentes, an inhabitant of Bichinho began the production of adobes for sale. An interview realized by a national architectural magazine helped him to become the first adobe supplier in the village. Currently, Bichinho has three adobe producers.

Thus, there was a revival of the adobe the use in the village. However, with three main differences from the way it was done before.

The first difference is regard to the production. The first houses were self-build. Currently, the adobes are bought and masons are hired to construct the house.

A second aspect it that the majority of the elderly constructions used the adobe walls as its structure. Currently, the adobe is used as an infill wall with the structure in wood or even concrete framework.

At last, the use of unplastared adobe walls which has a great impact over the visual aspect of the new buildings (Fig. 4).

Thus, from the formal point of view, it is currently possible to identify three types of buildings in the community: the oldest made with adobe



Figure 2. An old adobe building in Bichinho (Authors).



Figure 3. A house from the 80's in Bichinho (Authors).



Figure 4. A new adobe new adobe building in Bichinho (Authors).



Figure 5. A house with extruded brick in Bichinho (Authors).



Figure 6. New house with unplastered adobe wall in Lapinha da Serra (M.M.K. Moreira).

and then plastered (Fig. 2), the newest made with adobe but without plaster (Fig. 4), and also among the new, those made with extruded brick masonry and/or reinforced concrete (Fig. 5), often with plastered walls. There are even older houses made of adobe, from which the owners are removing the plaster. Finally, there are a few old burnt brick houses, which from the point of view of the façades and formal composition are very similar to the old adobe houses.

4.2 *Lapinha da serra*

Lapinha da Serra belongs to the municipality of Santana do Riacho, located in the central region of Minas Gerais State (Fig. 1). It has a population of about 300 inhabitants and has subsistence agriculture and tourism as its main activities.

The settlement of Lapinha da Serra began only in the late eighteenth century. Its first buildings were built with adobe, a technology found in many parts of the country at that time. One peculiarity of its development is that adobe building were kept during nineteenth and twentieth centuries, unlike what happens in the rest of the country. It is explained by its lack of roads and communication with other cities, what kept its isolation and its culture of construction.

In the 80 s, the movement of tourists began. In the 90 s, this movement increases, especially from 1996 onwards, when a road linking the village to the city of Santana do Riacho was opened.

The opening of the new road allowed the arrival of new construction materials for the inhabitants as well as a greater flow of tourists.

Tourists enjoyed adobe constructions, and those who decided to build houses in the village opted for this material. It began a movement of revalorization of the constructions in adobe.

So, the tourists' appreciation of the adobe played a decisive role on its use. This is the second major feature of this community building history. When the process of abandoning of constructions tecniques in adobe by the local population starts, it coincides with a process of re-valuation and re-discovery by the same people coming from the tourists opting for the buildings in adobe. The value attributed to the adobe constructions by tourists produces a redefinition on its value for the community itself. The material, seen as inferior and "poor" by the local community at that time, began to be seen as an special material.

This adobe revival comes with a use of unplastered walls (Fig. 6). Until the 90 s, the adobe constructions were made in the conventional way, with plastered walls (Fig. 2). The absence of the plaster is a change that produces a great impact on the façade of the buildings.

Concerning the building production there is a difference too. In the past, the owners, their friends and relatives used to make the constructions. Today, masons are contracted to do it.

The analysis of the meaning of this whole process, as well as its comparison with that experienced in Lapinha da Serra, is the subject of the next section.

5 MEANING AND DYNAMICS OF TRANSFORMATION: COMPARING RESULTS

Similarities and differences can be found in the transformations occurring in the vernacular architecture and constructive culture of Bichinho and Lapinha da Serra villages.

Tourism plays a significant role in the two communities. Without the intervention of the tourists

bringing the different values presented by each of the communities in relation to the adobe buildings, it is hard to imagine that this building culture would be present in these communities to this day.

In Bichinho the key factor pointed by interviews with local inhabitants for the revaluation of the adobe constructions is the aforementioned opening of the Agosto workshop. To the extent that this work incorporated new inhabitants and became the main source of income for the locals, the values and enjoyment in relation to the inhabitation of these new residents were merged into the local population. And the preferences for the adobe as building material by these new residents were very strong.

On the other hand, it is undeniable that the local tourism was an important factor in enabling the Agosto Workshop, and moreover, in the development of local crafts. These artisans and traders are the first to recognize the importance of adobe constructions in attracting customers.

Tourism helps explain how two communities separated by long distance and with different histories, has such a similar adobe revival.

Another common aspect of the two communities analyzed is in the domain of the vernacular building culture by locals. If this is a common feature, the way that it was processed is distinct in the two communities.

In Lapinha da Serra, there was not a period in which the adobe buildings were no longer built. As already seen, at that time, when the use of adobe began to decline, the tourist activity reversed this process. Perhaps this can explain the option most commonly found in the village to use the adobe walls as a structural element, just as was done in the old buildings.

In Bichinho, the building culture of adobe was almost lost. People over 40 years old reports having participated, in some way, in adobe buildings, but don't have their practice anymore. So, the fact of the building culture of adobe was almost lost, maybe is the reason for the most common option in Bichinho for using adobe only as an infill wall in wood or even concrete framework.

Comparing the building culture present in two communities, one can say that in Lapinha da Serra, the inhabitants retain a larger domain of adobe constructions demonstrated by an intensive use of structural adobe walls.

In Bichinho, the "expertise" of workers in adobe production allowed an optimization of this production, and a facility for the inhabitants to obtain the adobes. On the other hand, it created a separation between the producers of adobe bricks and building masons, which may have caused difficulties in maintaining building memory in the construction of adobe walls.

Another point is the use of the unplastered adobe walls. Observing the new buildings and after analyze the interviews there is no doubt the adobe is been used as an expressive element in the new buildings. All the interviewed argue does not make sense constructed a plastered adobe wall. In fact, in both communities, the resumption of adobe use does not occur within the same values as the building tradition of the native inhabitants. It is no longer simply building, it is necessary to clarify that this construction is made with a material different from the conventional: adobe. In this sense, the material is much more than just a construction component; it is a symbol and a search for social acceptance. A symbol of the will to seek a new perspective, a "new life", different from the major centers.

The curious thing is that this "new aesthetic" is not absorbing or resuming that which was used in the adobe homes in the villages, but creating a new strange enjoyment also, at least initially, to local residents. Perhaps this is because these same locals in early contacts with tourists were in a process of devaluation of their own building culture.

Anyway, the fact is that the revival of adobe constructions would generate a very different cultural landscape from that one that prevailed until then in both villages.

Another common aspect of the two cultures is the problems arising from not using the plaster with a material that needs this protection from moisture. The solutions—found has been the use of a protective adhesive dilution with white glue and water, and some types of varnishes. There is not a standard solution in either of the communities.

Do all these transformations mean the end of the vernacular architecture and building culture, and the birth of a contemporary, non-traditional architecture and building culture?

Upton (1993, 2001) and Vellinga (2006) argue that the changes are a component of the vernacular architecture. Furthermore, it is the native residents in these locations who carry out the adobe constructions. In other words, the adobe technique is still alive.

It could be argued that this new aesthetic dimension is not part of the authentic culture of the locals. Wouldn't these values be imposed on locals by outsiders and thus are actually destroying the local culture? This vision implies that in a community there is an architecture and a tradition that are authentic and should never be changed, are untouchable. However, it's necessary to ask if that makes sense when the study of vernacular architecture has to do with history, with culture, with human habits that change and evolve all the time. For Upton (1993: 14), "We should turn our attention away from the search for the authentic, the characteristic, the enduring and the pure,

and immerse ourselves in the active, the evanescent and the impure...". This criticism is made in the sense that it is the reality experienced by the changes in the various building cultures and vernacular architecture that require a new approach to concepts, at the risk of not analyzing the most significant aspects of vernacular culture in contemporary society. According to Upton (1993: 14) "They study efforts to preserve traditional culture or to reproduce old ways in new settings. We know this material well enough for the moment. Now we need to be interested in what didn't happen, in what collapsed, in what went awry…".

Accepting this view does not mean denying the transformation experienced by communities with the arrival of tourists and new residents that influenced, of course, the perception that the locals had of the adobe constructions. It's possible to recognize them as elements initially "external" to this local culture. However it was this dynamic transformation process that played a decisive role in preserving at least some aspects of the local architecture and building culture, which otherwise would be quickly replaced by the usual forms of contemporary construction.

If the first interests in the adobe revival came from the tourists, the know-how have always been from the local habitants. It is thus a process in which the local culture also has a decisive weight. A complex cultural phenomenon, which results in a building culture and an architecture that represents perhaps not the break with tradition, but its survival in the only way possible, since there is no denying that a different phenomenon from the usual is happening in these communities. And unlike the abandonment of the vernacular architecture and building culture experienced elsewhere, in these two villages, it is undeniable that it survives.

6 CONCLUSIONS

The dynamics of the changes in the vernacular architecture and building culture of Bichinho and Lapinha da Serra showed a decisive role from tourism in its preservation. Even in Bichinho, where the establishment of a craft workshop was decisive in this process, the existence of this workshop is directly linked to tourism.

The unplastered adobe walls and the interviews with habitants showed the architecture produced by these changes used the adobe as an expressive element in the architecture which a new aesthetic enjoyment, with a need for owners to expose adobes. This need involves, in some sense, even a different ethics in relation to old adobe architecture, because it reflects a need to seek a certain "social acceptance" arising from the use of adobe.

The changes experienced in both communities also showed differences like the separation and specialization among adobe layers and masons in Bichinho and absent in Lapinha da Serra, as well as the use of structural walls in Lapinha da Serra, absent in Bichinho.

The process of change in the vernacular architecture and building culture of the two communities is very complex and still requires other studies. However, if the arrival of new values with tourists is undeniable, it is also undeniable that without local communities, this process would not exist. As a consequence, this new architecture should highlight the need of a change in the perception of what is a vernacular architecture tradition.

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Investigating the preservation of vernacular earthen buildings of Louroujina (Akincilar) in North Cyprus

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ABSTRACT: Earthen materials provided the most affordable solution both in the urban and rural area in the lowlands of Cyprus, and adobe buildings dominated the construction field until the mid-twentieth century. This study aims to investigate the preservation situation of North Cyprus's vernacular adobe architecture, looking into the case of Louroujina (Akincilar) village. The study addresses the role of the newly emerging heritage consciousness and the resultant socio-cultural activities in stimulating the preservation of the extant adobe buildings. By looking into the restoration and rehabilitation projects recently implemented in the village, insights are provided regarding the inhabitants' perception for heritage. Whilst the study highlights an emerging interest in the rehabilitation of existing vernacular-earthen houses, it also reveals how implementations undertaken without restoration know-how have caused irreversible damage rather than protection. Finally, the paper stresses the importance of collaboration between the community and the professionals for formulating sustainable restoration guidelines.

1 INTRODUCTION

Earthen architecture dominated the vernacular built environments in the lowlands of Cyprus since the establishment of the first Neolithic settlements. As it has been witnessed in all the other geographies lacking local stone resources, Cyprus has become home to a millennia-long tradition in adobe architecture. The tradition in designing and constructing buildings in adobe started to change towards the mid-twentieth century when the industrialized fired-bricks as well as reinforced concrete became affordable for the rural communities of the island. Transition was not limited to the construction materials; there were also changes in the traditional plan typologies. From the 1950s onwards, the rural settlements in the island entered into a new stage, where houses were designed in modern typologies, utilizing reinforced concrete and brick. Although the change in the rural settlements were not as fast as the urban areas, it eventually brought an end to the vernacular design and construction systems, with houses built starting in late 1960s onwards were all being in the modern style. These flat-roofed, squarish prismatic houses started to be inserted within the existing empty plots, creating a visual division between the new and old; in a way bringing an end to the tradition in earth. The reinforced concrete and brick was considered 'new' and fashionable, whereas the adobe was considered 'old' and obsolete. As expected, modern architecture took precedence over the vernacular quickly.

Deterioration of the vernacular fabric of the rural settlements in Cyprus did not take much attention from scholars until towards the end of the last century. One of the pioneering studies was undertaken in the 1970s by Sinos, where he focused on analysing the plan typologies (Sinos 1976, Sinos 1986), which was followed by Ionas (1988). Towards the ends of the century, local academics started to engage in research projects in North Cyprus, which not only aimed for the documentation of the rural-vernacular heritage, but also revealing their sustainable design values (Dincyurek & Numan 2001, Dincyurek et al. 2003, Dincyurek & Turker 2007). At the same time, the emergence of sentimentality started to occur within the local society as a yearning for the long lost-past. This initiated societal attempts for preventing further loss as well as reviving the past as much as possible. Non-governmental organizations (NGO) started to be established in the villages for promoting the restoration and rehabilitation of the vernacular buildings. Amongst the best cases to exemplify this new phenomenon is Louroujina (Akincilar), a village in the Northern Cyprus. The village was abandoned by the majority of its population in the aftermath of the 1974 war, which saw the de facto separation of Cyprus. The earthen built environment of the village has dramatically deteriorated and partially destructed as a result of this abandonment. An awakening towards the protection of the survived vernacular built environment as well as the intangible traditions has surfaced since the beginning of this millennium.

2 METHODOLOGY

This research aims to investigate the role of socio-cultural developments in the restoration and rehabilitation of the earthen-vernacular built environment of the Louroujina (Akincilar) village in Cyprus.

A qualitative research approach has been adopted, based on a field work which included physical observations in the village and semi-structured interviews with the inhabitants as well as the villagers who relocated elsewhere.

Vernacular-architectural characteristics of the existing buildings were observed in-situ, followed by photographic documentation. Twelve people were interviewed for the purpose of the research. The names of the interviewees, except for the Mayor's, remain anonymous throughout the paper. Interviewees were selected with snowball method. Semi-structured interviews were developed using open-ended questions, aiming to find explanations for the following:

- role of socio-cultural developments in stimulating restoration and rehabilitation projects;
- perception of inhabitants regarding the heritage values of the earthen-vernacular built environment;
- restoration methods and techniques.

3 ANALYSIS AND RESULTS

3.1 *A Glimpse into the earthen-vernacular built environment in Louroujina*

Louroujina (Akincilar) is located in the junction of the southern edge of the Mesaoria plain and the hilly Malloura valley, with origins going back to the Venetian period (1489–1571) (Kiessel et al. 2016). Similar to other settlements in the lowland, earth brick has been the main construction material throughout centuries until the mid-twentieth century. Foundations and lower parts of the walls have often been constructed in a local variety of rubble-limestone, and the upper structure has been laid in earth bricks. Use of wood is limited to lintels used at the ceilings and to door and window frames. The mud-brick walls were covered with mud-plaster in the outer facades and gypsum plaster in the interiors (Fig. 1). Louroujina was in general an earthen settlement, where houses were located in plots, either linearly designed either in I or L shapes (Kurt et al. 2013a). The earliest surviving mud-brick structures in the village go back the end of the nineteenth-century.

Change in plan typology that is seen in Cyprus' urban settlements towards the end of the nineteenth-century (Demi, 1997), gained visibility in the village from the 1940s onward. This change was in part stimulated by the transition in social culture of the Turkish community, who had by then gained a secularist vision inspired by the revolutionist developments during the 1920s–1930s republican Turkey.

Hence, the privacy concerns that dominated the evolution of the formal aspects of vernacular houses of the Turkish community lost its former importance. It has been well documented that the traditional houses inhabited by the island's Muslim-Turkish community had the privacy aspect as the main concern in planning and design (Atesin et al. 2005). Accordingly, houses of the Muslim-Turkish community did not have direct



Figure 1. Exterior views (left) from the uninhabited mud-brick houses. Interior view (right) from an uninhabited house.

visual relationship neither with each other's outdoor living areas nor with the streets, especially on the ground floor levels. The elimination of the privacy concerns presumably played a key role in the sudden appearance of street oriented serial type houses in predominantly Muslim-Turkish Louroujina starting with the 1940s. The consequence of this new planning approach has been in traditional orientation pattern. It is known that prior to this new planning approach houses in the island were located on the south-north axis, aiming at controlling sun exposure and maximizing indoor comfort conditions (Philokyprou & Michael 2015).

On the other hand, earth brick remained as the main construction material in the village well into until 1960s, during when it was replaced with factory produced fired-bricks. Reinforced-concrete structures, enclosed by fired-brick walls became the norm from the late 1960s onwards. These were often inserted in the yards of the familial plots, next to the existing mud-brick houses, which started dramatically altering the solid-void relationships of the vernacular fabric.

As it has been argued by Philokyprou (2015), vernacular architecture has been a timeless architectural endeavour where buildings are continuously developed to satisfy the temporal requirements of the users. This is clearly visible in the vernacular fabric of Louroujina, where houses were expanded in time to accommodate the growing families, and new typologies (such as the street facing houses) were developed and gained popularity in line with the changing socio-economical structure of the village community. It is also clearly visible that vernacular-earthen tradition in the village continued until it was totally replaced with industrialized construction methods, techniques and materials in the late 1960s.

3.2 *The present situation of the earthen-vernacular built environment in Louroujina*

Having remained at the edge of the Green Line that has divided Cyprus into two political entities after the war of 1974, the village has suffered partial evacuation. According to a census which was held in 1973, the number of local inhabitants of the village, which were dominantly Turkish Cypriotes, was approximately two thousand (Kiessel et al. 2016). Besides, the village had attracted Turkish refugees from the neighbourhood, which informally tripled the population between 1963 and 1974, when the island suffered from ethnic conflicts. Refugee houses, designed in one and two-storey townhouse style were constructed in the western zone of the village in 1965. These are considered as the last adobe buildings.

According to the information provided by the interviewees, when the construction of refugee houses started in the village, the island's Turkish community was confined in the enclaves with limited access to industrialized materials. Hence, mud-brick production was resumed for a period in the 1960s to construct the first phase of the refugee houses. Fired-bricks became available when the second phase of the refugee houses was under construction. The village had to be evacuated a few years later in 1976, during a period of an ongoing transition from vernacular plan typologies and materials to modern house plans and industrialized materials.

Following the de facto division of Cyprus in 1974, the accessibility to the village remained confined to a road that crossed through the military zone, which forced the villagers to relocate elsewhere in the island. 75% of the villagers relocated elsewhere in the Northern Cyprus and abroad between 1976 and 1980, leaving behind hundreds of uninhabited houses. This situation prevented the erection of new buildings within the vernacular-earthen fabric of the village, because there was already a substantial house stock. However, the demand was much less than the existing stock, so the uninhabited buildings were gradually deteriorated and demolished, often to be cleared away by the Municipality. Most of the yard walls and ancillary buildings were disappeared in the 1980s and 1990s. Solid-void relationships dramatically changed, where empty plots gained predominance over the formerly dense fabric. Interviews has revealed how during this period arches, wooden doors and lintels, and floor and roof tiles in the uninhabited houses were dismantled and sold to be used in restorations elsewhere (Fig. 2).

At the outset of the twenty-first century, Louroujina acquired the image of a frozen settlement in its 1974stage, often named by the outsiders as the 'dead village'. It was at that moment when the villagers in the diaspora came forward with the idea of establishing an NGO, named as 'Louroujina is Living Association'. This initiative started

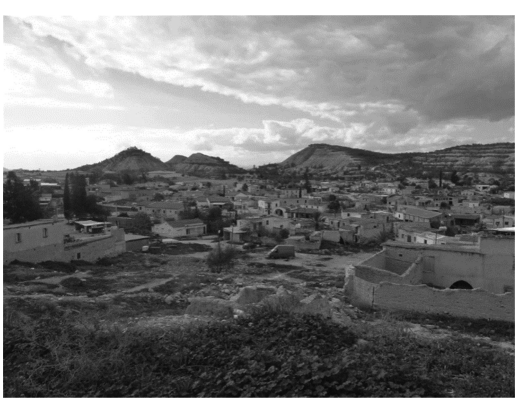


Figure 2. View from Louroujina (Akincilar).

raising awareness both for the importance of the preservation of the village's vernacular fabric and its intangible cultural values. The village's long forgotten traditional food production started to be revived, leading to the initiation of the first cultural food festival in 2011. The Association has also been instrumental in attracting UNDP-PFF Cyprus (United Nations Development Programme Partnership for the Future in Cyprus)'s attention, resulting in the partial restoration and revitalization of the village square which was surrounded by traditional Turkish coffee shops. The project aimed at public space improvement and facade upgrading. It was implemented between 2010 and 2012 (UNDP 2017). Another project, again financed by the UNDP-PFF was the restoration of the primary school building, built in the early 1940s and evacuated during the 1980s. The restoration project was implemented between 2012 and 2014, and the building was adapted for reuse as a village activity centre for the elderly and females, essentially for training and production of traditional handicrafts (YENIDUZEN 2017). The first 'Once Upon a Time Louroujina' cultural festival was organized in May 2011, to be followed annually until 2015, when its success encouraged the organisers to turn it into a bi-annual event (Fig. 3).

The one-day long festival attracted thousands of visitors, initially only those originated from the village but later others as well. The interviewees argued that this event brought the village to life again, resulting in a collective consciousness which stimulated the inhabitants to improve its image.

3.3 *Restoration and rehabilitation the earthen-vernacular houses of Louroujina between 2011 and 2017*

Collective awakening that Collective awakening that started for the preservation of the traditional-cultural tangible and intangible assets in the village



Figure 3. Views from the 'Once Upon a Time Louroujina' cultural festival.

stimulated a university based academic research project, sponsored by Turkey's TUBITAK (Scientific and Technological Research Council of Turkey) between 2012 and 2015. Kurt et al. (2013a) maintains that this project aimed for the documentation and analysis of the vernacular structures in the village to be utilized in future heritage management and restoration planning. According to Kurt et al. (2015: 46), '911 buildings were identified during the documentation project, of which 250 units were already dilapidated beyond repair and 210 of the houses were contemporary buildings.' Hence, revealing the existence of existing 450 houses with vernacular characteristics. Hasan Barbaros, the Mayor of the village since 2006, has confirmed during the interview that 18 mud-brick houses have been extensively restored and 4 were reconstructed since 2011. This, according to the mayor, means 3 restorations per year, which is more than the annual restorations before 2011. Nearly half of these recent restorations have been undertaken by villagers, who do not currently live in the village. There also is, a relatively increasing number of Londoners, who are taking up residence in the village for their retirement years. It must be noted that London has been the major destination of migration from the village from 1955 to 1980.

Interviews have revealed that they are either restoring their own properties, or buying from others. The interviewees have also commonly argued that the activities of the 'Louroujina is Living Association' and the 'Once Upon A Time Louroujina' festivals have increased the visibility of the cultural importance of the village in the news and social media, and turned it into a heritage site. The mayor, now more cautious, accepts the Municipality's role in the demolition of entire sections of the vernacular fabric for the sake of cleaning the village from the badly decayed uninhabited adobe buildings. Yet, he maintains that these are private properties and unless the legal owners decide to take action, they will continue to deteriorate. Evidently, starting from the beginning of this decade, people have taken an interest in the restoration of the earthen buildings in the village, which is clearly associated with the increasing sentimentality for the long lost-past. The critical issue here is how this awakening has influenced the actual restoration and rehabilitation practice.

Physical observations on the restored mud-bricked houses have revealed extensive alterations on the original designs and materials (Fig. 4). New kitchen and bathrooms were added in almost all of the restored houses, additional bedrooms were added in some of them, and in the majority of them the main hall has been extended towards the yard to create a larger living room. Amongst the commonly practiced alterations on the layout is



Figure 4. Views from vernacular-mudbrick houses with recently implemented alterations and repairs.

the enclosing of the semi-open terraces and balconies by aluminium framed light walls covered with large windows. In several cases, air conditioning units were installed for heating and cooling purposes. Besides, there have been cases, in which the inhabitants decided to decrease the height of ceiling as it was too costly to heat the space during the winter months. Often, the original wooden door and window frames were replaced with aluminium frames, which according to the interviewees, for its affordability, durability and low maintenance. In some cases, the roofs were rebuilt with corrugated layers of metal. Another commonly used material is the plaster of Portland cement variety, which has been banned from the restoration practice since the declaration of the Venice Charter in 1964.

The interviews have revealed that cement plastering has been practiced on the mud-brick walls since the early 1960s. One of the interviewees, for instance, has explained how the mason had cladded the external facades of his then newly finished mud-brick house with cement plaster, which was the common practice in the village during the 1960s. The interviews have revealed that, this method of inserting a layer of wire mesh on the mud-brick wall surfaces and cladding them with a thick layer of cement plaster has continued until present. New additions were all built in non-vernacular industrialised materials. It has also been noted that seeking professional expertise has not an option due to financial limitations. Hence, decisions regarding the materials and techniques have been taken by the owners or by the contractors, commissioned for the job. The situation with the four reconstruction projects that have been implemented recently is even more critical: upon deciding in consultation with the contractors, the owners have decided to demolish the survived earthen structures on their plot to be replaced with new buildings.

Evidently, there is a lack of restoration know-how, which is clearly visible the implemented projects. The first attempt in providing the locals with knowledge in this direction has been taken by the TUBITAK research team, who advised on restoration methods for the partially demolished Old Khan (Kurt et al. 2013b). However, the set of recommendations that was released was not more than a general template reiterating textbook information for material repairs and structural strengthening.

4 DISCUSSION AND CONCLUSION

The emergence of sentimentality for the vernacular life in the abandoned Louroujina, has stimulated a

collective awakening towards the preservation of the tangible assets and intangible values of the area. Initiation of the cultural food festivals in 2011 has turned into a milestone in this endeavour, increasing the village's popularity, and motivating some for taking up residence either permanently or as second home. This is visible in the increasing numbers of restoration and rehabilitation projects. Although this new situation indicates the initiation of a preservationist attitude, it is not aimed towards architectural values. Physical evidence has revealed how the practice on tangible assets has developed in accordance with the user society's understandings. Evidently, the community in Louroujina has utilized restoration as a practice for adapting the old buildings for their use without much consideration for the alterations on the original design and materials. Hence, restoration acquired a negative meaning, defining the activity of repairing the earthen-vernacular buildings with new materials and altering the layouts to fit into their lifestyle, which often results in a complete renewal. This ultimately brings into question how this moment of increasing popularity for reviving the vernacular-rural environments shall be utilized to introduce the community with a more academically acceptable sense of preservation understanding.

Apart from material repair and structural consolidation related problems, there is also the issue of providing these houses with climatic comfort conditions. South-north axis orientation of the buildings, which offers the best indoor comfort conditions and as such it is considered as one of the main environmental design principles of the vernacular houses in Cyprus has not always practiced in this settlement. In certain situations, the sloppy topography pressurised the orientation of the houses towards east-west. Moreover, as mentioned earlier, due to the socio-economical changes that took place in the twentieth century, constructing houses with street orientation, which was not necessarily on the best direction, had gained popularity during the last decades of earthen-vernacular architecture. In fact, overlooking the importance of the orientation of the houses has remained as a main problem until the present. Evidently, Louroujina and similar other earthen-vernacular settlements in the lowlands in Cyprus, will benefit from a well formulated set of affordable restoration materials and techniques as well as design solutions that will aid in transforming the buildings into environmentally responsive architecture. It must also be noted that whilst international documents such as the Venice Charter (1964) or the ICOMOS Charter on Built Vernacular Heritage (1999) provides the general framework, in reality, it is the local circumstances that predominate the practice, which brings forward the importance of appreciation, negotiation, and collaboration.

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Campiña Segoviana's earthen heritage and conservation clues from Isère

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ABSTRACT: Nowadays, in many territories of Western Europe it is difficult to conserve earthen constructions with adapted techniques and materials, as the know-how is rarely present and the economic logics of construction have evolved from local to industrial solutions. In a global and connected world where local action is more than ever necessary, we shall find inspiration in successful cases. We will put in contact two territories in Western Europe: the Campiña Segoviana in Spain, where earthen vernacular heritage is generally suffering from bad conservation practices, and Isère, in France, were we can find many actors gradually improving the conservation of earthen constructions. We will focus in some examples of how professionals and practitioners are in the core of this positive evolution.

1 INTRODUCTION

In Western Europe, earth has been used in construction for millenaries, but it has been almost completely abandoned since the mid-20th century. Local constructive cultures have switched from local materials and techniques to a global system of industrialised materials. The loss of earthen construction know-how has been progressive as traditional masons and builders have passed away. This change affects new constructions, but also the way of maintaining and conserving vernacular ones.

This paper presents an approach to the earthen vernacular heritage in a Spanish territory, the Campiña Segoviana. This territory is located in the South of Castile-and-Leon region and it is extremely rich in terms of earthen architecture. This heritage has not been sufficiently identified and valorised. Unfortunately, today very few professionals renovating this heritage are aware of the specificities of earthen and other vernacular constructions. The majority of these constructions has suffered of bad conservation practices, and they usually have a lack of maintenance and a progressive loss of authenticity.

Searching for solutions to these conservation problems, we have crossed the French border to the territory of Isère, in the Auvergne-Rhône-Alpes region. Here, we can find a very rich rammed-earth heritage that has long time been in danger. Nowadays, the situation is far from being perfect, but we can find competent professionals who keep these constructions in a good conservation condition, authentic and alive. We go over the cases of a masonry enterprise, of an ecological materials producer and distributor and of an association promoting self-construction and training through practice.

In this paper, we set the hypothesis that practitioners are at the heart of earthen heritage preservation or destruction. We consider that is a matter of training, sensitization and vulgarization of good practices to get to preserve our earthen constructions.

2 VERNACULAR HERITAGE IN THE CAMPIÑA SEGOVIANA TERRITORY

2.1 *Description of the territory*

The Campiña Segoviana is located on the Northern Plateau (Meseta Norte) of Spain in the region of Castile and Leon, province of Segovia.

The altitude of the territory ranges from 770 m in the north to 1064 m in the south. Its climate is continental, with an irregular rains regime and extreme temperatures. Winters are cold with temperatures below -10°C and summers are hot with over 36°C. Precipitation is rare, from 400 to 550 mm per year, between autumn and spring.

This zone bears the name of Campiña because of the cereal fields (*campos*) that compose most of its landscapes. There are pine and scattered green oaks forests, some vineyards and meadows. Streams and small rivers, usually dry in summer, are surrounded by rows of poplars and small vegetable gardens.

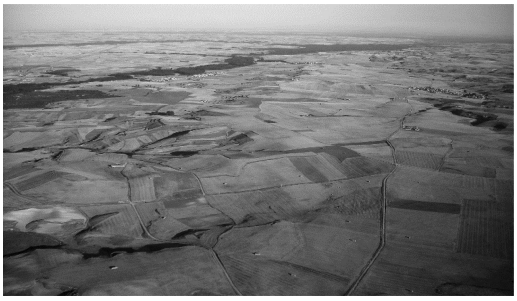


Figure 1. The Campiña Segoviana's cereal landscape (B. Sevillano Gutiérrez, 2011).

The territory has an extension of about 1600 km², 21,700 inhabitants in 73 villages, (INE 2013). It is very sparsely populated (13.5 inhabitants per km²) in spite of being well connected with Segovia or even Madrid. Since the mechanization of agriculture in the 60 s, the area has lost half of its population. Today, remaining inhabitants are mostly seniors.

2.2 *Vernacular materials and techniques*

Vernacular heritage in the zone has a wide variety of techniques and locally available materials such as stone, wood, ceramic tiles, fired bricks, lime, earth and fibres. One of the main characteristics of these buildings is the mixing of different materials and techniques within the same construction.

Stone masonry is present in every village to a certain extent, at least in the foundations and plinths of most buildings. Stone types vary according to the soils: pebbles, limestones and slate, among others.

Fired bricks are used in the region from ancient times and are often present in earthen constructions, especially for reinforcements of weak points with a structural function. Bricks are used in arches and lintels, and in locations such as foundations, corners, window frames, cornices, ornaments, etc.

Vernacular buildings are covered with terracotta roof tiles that were manufactured locally in the craft industries called *tejeras*. These roofs are called *tejados a la segoviana*, and have the specificity of only having the under tiles, placed over an earthen mortar which allows the expansion and waterproofs the joints. These tiles have the same width at both ends to permit a better fitting of the pieces.

Floors in lower levels were very usually made of ceramic tiles, sometimes decorated with coloured geometrical or vegetal designs. Other techniques used in floors included dammed earth.

Wood is present in the cover frames of almost all buildings, in stairs structures, as well as in the structure and in the surface of upper floors. This local wood comes usually from river trees or pines.

Lime mortars were used mainly in fired bricks and some stone masonry walls, in tiles floors as well as in exterior plasters. Lime sgraffitos are commonly present in the decoration of main façades. Gypsum was also used, mainly in interior plasters.

2.3 *Earthen techniques*

Earth is present in the whole territory. There are constructions built in adobe and rammed earth, but also half-timber (*entramado de madera)*. Earth was also used in mortars for stone masonry walls and for tiles roofs as well as in ground-level floors. Earthen constructions are built on a stone or brick plinth and foundation. We also find excavated troglodyte wine-cellars in some hills and in some houses' basements.

Adobe masonry walls were widely built in the area. Adobes have been used for large buildings as well as for modest accessory constructions. Adobe bricks were made with earth and straw from threshing when possible. Most buildings constructed with adobe were lime-plastered, at least on exposed facades. Uncoated adobes are sometimes visible in auxiliary constructions, on the unexposed walls of the houses and on the adjoining walls.

Rammed earth or *tapia* was also a widely used technique. Observation and conversations with elders suggest that this technique was abandoned before the adobe one. Rammed earth in this region is made with a similar earth to that used for adobes, without straw and more gravel and pebbles. Rammed earth was usually built in coalition with adobe or fired bricks, which serve as columns and form horizontal rows between the different levels of rammed earth: *tapia con machones y verdugadas*. Another common technique is *tapia calicostrada*, which has a lime and sand mortar placed against the formwork before filling it with earth. It was commonly used in high status buildings.

Half-timber or *muro entramado* comprises a wooden frame with a filling. The interval between vertical and diagonal timber elements is filled with adobes often placed in fishbone, but also diagonally and even horizontally. These adobes have a bracing function. Filling can also have other materials or waste elements: broken bricks or irregular pieces of stone. It is the least common technique of the three and it is rather restricted to the most forested areas, towards Tierra de Pinares, an immense pine forest in the northeast of the Campiña.

2.4 *Modest and monumental buildings*

In the Campiña, we can find residential buildings as well as all kind of dependencies associated with the agricultural, breeding, productive and handcrafting works. Most of these buildings are



Figure 2. View of a selection of earthen buildings in the Campiña Segoviana. (E. Sevillano Gutiérrez, 2012–2016).

concentrated in the centre of the villages, forming streets and quite densely populated areas. Agricultural buildings are contiguous to dwellings, or placed at the periphery of the villages. In contrast, there are few buildings in the countryside: chapels, dovecotes, shelters for shepherds and *caseríos* (farms with dwellings which once belonged to landowners such as the church or nobles and were almost real villages).

Earth buildings are not only modest constructions. There are also churches and palaces built with earth. This is the case of the Cardenal Diego de Espinosa Palace, which is located in Martín Muñoz de las Posadas. Its construction dates from the 16th century and its architects were Gaspar de Vega (1523–1575) and Juan Bautista de Toledo (1515–1567). Fired bricks and rammed earth form its walls. We can also find 20th century constructions, as the flour factory of Nava de la Asunción, currently abandoned. This industrial building is built in adobe with fired brick reinforcements and is listed as historical monument.

2.5 *Main conservation obstacles*

This rich heritage, and mainly the non-monumental one, is now in danger due to progressive abandonment of villages; changes in economic dynamics; insufficient sensitisation of inhabitants, professionals and decision makers; insufficient valorisation; absence of preventive maintenance; poor conservation practices as a consequence of a lack of know-how and knowledge of professionals; absence of availability of appropriate materials, etc.

2.5.1 *Obsolescence of buildings and abandonment*

The mechanisation of agriculture changed modes of production, economic and social dynamics. People had to migrate. The loss of population and economic activity led to the abandonment of buildings and to difficulties to maintain collective facilities. Some agricultural or industrial buildings became obsolete. Constructions with no use are difficult to maintain, thus some of them tend to disappear.

2.5.2 *Deficit of valorisation and community awareness*

Vernacular earthen heritage is often emotionally linked by people to poverty. Modest houses in this area were sometimes difficult to live in, but earth also served to build good quality constructions. There is a need of appreciation of the positive values of vernacular heritage. If the population is not at the core of a demand of good practices, it is more difficult that they happen.

2.5.3 *Absence of maintenance, wrong conservation practices, loss of know-how and lack of professionals*

Poor maintenance and bad practices are rather acute obstacles. The biggest problems come from excessive humidity in the base or in the head of walls. Lack of maintenance in roofs is also very harmful, as once they are damaged, water reaches the walls and quickly endangers stability. Humidity problems are worsened by cement coatings.

There are other poor technical implementations that create disorders in earthen constructions, such as: too large openings that create instabilities, sewers that pour close to the walls, waterproofing of floors, etc.

Sometimes, walls lose their stone or fired bricks plinths under new sidewalks or asphalt roads, causing big damages in earthen walls.

Poor maintenance and bad practices are mainly due to the absence of sufficient competent professionals, from architects to masons, who know how to work in vernacular buildings and use traditional materials and techniques. Even though there are good masons in the area, they do not master vernacular constructive cultures, and therefore they propose inappropriate solutions. Sometimes they propose the demolition of the vernacular building to leave the place to a new conventional construction.

2.5.4 *Lack of available materials*

With a construction sector using exclusively ready-to-use materials, it is necessary to facilitate the access to natural materials as earth, fibres, lime,

etc. There is a need of easily finding the pertinent materials, as otherwise they are substituted by conventional ones.

2.5.5 *Economic accessibility*

Due to the mentioned obstacles, renovating with traditional materials can become more expensive than conventional options. Materials are expensive and difficult to find, specialised masons are rare and there is usually more labour associated to such works.

2.6 *Looking for inspiration*

In an interconnected world, it is important to take inspiration from good experiences. That is why we have crossed the border to look at some examples in a French territory: Isère.

3 CONTRIBUTIONS TO EARTHEN HERITAGE CONSERVATION FROM ISÈRE, FRANCE

3.1 *Introduction to the situation in Isère*

Isère is a Department situated in the centre-east of the Auvergne-Rhône-Alpes region, in France. Here, we can find a very rich rammed-earth heritage, from isolated farms to town centres. This heritage faces different threats similar to those presented in the Campiña. Nevertheless, we can find some players who facilitate intelligent conservation practices in rammed-earth constructions. Without being exhaustive, it is possible to cite some actors involved in conservation programs and practices in this territory. The CRAterre laboratory and the National Superior School of Architecture of Grenoble (ENSAG), have contributed to train architects and other professionals in earthen architecture and heritage. The Grands Ateliers de l'Isle d'Abeau, amàco and CRAterre association have helped to develop real scale pilot projects, pedagogical research, dissemination materials and open events like Grains d'Isère Festivals. This has permitted inhabitants, students, architects, engineers, decision makers and practitioners to reflect and work together in earthen architecture and vernacular heritage. To some extent, as a consequence of these efforts, some architects, engineers and design offices work in this heritage with good technical approaches: Abiterre, Caracol Architectures, BE-Terre or Osmia.

We also find engaged local authorities as Pays d'Art et d'Histoire du Pays Voironnais which is involved in the development of heritage studies and valorisation documents and activities for citizens. The authorities of Isère Porte des Alpes have also supported heritage studies as well as the organisation of Grains d'Isère Festivals during the last 15 years.

Thanks to sensitisation, we find that a significant part of the population is sensitised about the value of earthen heritage and about ecology and has a demand for technically adapted works in houses.

In order to keep this heritage well conserved, practitioners are needed. In the vocational training field, we find institutions like Aplomb, which offers 9 months theoretical-practical trainings in vernacular heritage rehabilitation and eco-construction, including earthen techniques. The GRETA Nord-Isère used to offer trainings in the same fields.

The citizens, the precedent institutions and players and many others have a growing influence on the conservation of rammed-earth heritage in Isère. That said, in the paper we will now browse mainly through the cases of three actors that facilitate and develop adequate construction works. We have chosen a masonry enterprise, an ecological materials producer and distributor and an association which promotes training through self-construction and participative workshops in real buildings. The authors have met and worked, when possible, with the three of them.

3.2 *A masonry enterprise: Heliopsis*

There are several enterprises and masons specialised in earthen vernacular heritage and eco-construction based or working in Isère: Naturabati, Xavier Auplat, Heliopsis SARL… Working in the latter, we have made a reflection about the importance of competent practitioners attached to a territory.

Heliopsis is a family enterprise based in Le-Grand-Lemps, which works in contemporary eco-construction and in vernacular heritage. Since 2002 they have built a real local anchorage. They have a large client's network mainly localised within a distance of about 40 km. They offer a real expertise in rammed-earth constructions and merge architectural and practical competences. They perform diagnostics, propose and perform technical integral solutions. Heliopsis offers a very wide range of services, what is essential to keep their activity economically sustainable. In new earthen constructions, they use evolutions in order to go faster to adapt to present economic logics. In rehabilitation, they try to respect traditional techniques, but mechanic means are used when necessary. Their know-how is large: earth, lime and gypsum plasters; rammed earth and adobe; ancient masonry; arcs and vaults; vaulted staircases; drains and sanitation; timber structures; tadelakt.



Figure 3. Heliopsis team working in a rammed earth building (E. Sevillano Gutiérrez, 2015).

They organise sensitisation activities for children in schools, they frame workshops during the Grains d'Isère Festival and in different villages. This is a way to sensitize a broad public which includes rammed-earth houses inhabitants, architects, students, etc., about adequate rehabilitations.

Economic accessibility can be an obstacle for some people, but they adapt the implementations to be done to the budget of each client. This company enables many inhabitants to undertake adapted works in order to improve the quality of the spaces, reduce energy consumption, improve the walls perspiration and insulation where necessary. To sum up, they facilitate a general improvement of living conditions and foment the conservation of habitats, guaranteeing that the investment is worth making.

3.3 *A natural materials producer and distributor: Alliance 4*

It is not easy to develop earthen construction if materials are not ready-to-use, notably in rehabilitation works. Alliance 4 was created with the objective of facilitating this task. The activity of this family enterprise is a unique opportunity for the development of eco-construction and earthen rehabilitation in Isère. This company is based in Commelle and it provides natural materials in a local scale making part of a short supply chain. They give advice for eco-responsible renovation solutions that they experiment before. In their website, they provide customers with technical sheets of all the products they sell and how to implement the different techniques.

They extract earth from the site where the company is installed and the family lives, sift it on site and put it in big-bags. As for 2014, they were selling around 110 big-bags (1 m^3 each) of earth per year. This earth allows many individuals and masons in the region to undertake construction works. They also condition earth for plasters in different colours and produce adobes and adobe ovens. Beyond the earthen materials they produce, they have a natural materials warehouse with natural lime, gypsum, natural pigments for lime coatings, sand of different particle sizes, marble powder, natural insulant materials, hemp, traditional bricks and tiles, etc.

Alliance 4 supplies natural materials to masons and builders, to training centres and to self-constructors, and they largely advice the latter when it comes to program rehabilitation works. They also frame and accompany self-constructors and develop short trainings in different techniques.

3.4 *An association for self-construction framing and training: Terre, Pierre et Chaux*

The association Terre, Pierre et Chaux promotes supervised trainings in private eco-construction worksites. A trainer, a family owning a site and around 10 trainees each time participate in these real implementations which are usually developed during weekends and holidays.

The professional trainer helps a family to rehabilitate their vernacular house, is responsible for the technical solutions to be used, informs the owner about the necessary materials, provides the necessary tools, trains and monitors the participants' progress giving them confidence and motivation. The framer warns the family about the fact that they cannot expect professional results. The family participate in the construction and proportionate the necessary materials and technical means. They are responsible for taking out an insurance for all participants, for providing food and for facilitating a place to sleep to trainees. The owner learns, saves money, goes forward in its construction site and has a human worksite.

The trainees learn with the supervision of the coach and thanks to the implementation itself. They undertake to do the scheduled work as well as possible, so they can later apply what they have learnt in their own homes or elsewhere. A good atmosphere in these working sites is quite common, because all participants register voluntarily.



Figure 4. Alliance 4 conditions and sells earth and natural materials in a short supply chain (E. Sevillano Gutiérrez, 2014).

Everything is done so that the work is fulfilled as good as possible.

4 LEVERS FOR EARTHEN VERNACULAR HERITAGE CONSERVATION

As we have seen with the precedent case-studies about Isère, solutions exist to respectfully renovate vernacular earthen buildings. Taking into account these experiences and the main obstacles described for the Campiña Segoviana, we will now analyse some levers for earthen vernacular conservation in territories like this one, following the VerSus project's sustainability pillars (Guillaud & et al. 2014).

4.1 *Environmental levers*

Maintaining vernacular buildings in use and alive implies a gesture of environmental sustainability to be supported, rather than rising new constructions with imported or high embodied energy materials.

Ecological and energetic renovation may help reduce pollution and waste. Local resources with very low or zero associated embodied energy shall be used, in order to reduce the ecological footprint.

The hygrothermal regulation and thermal inertia that earth brings to constructions also contribute to the reduction of energy consumption.

These aspects, linked to the fact that earth is a healthy, natural material, imply an improvement in the living conditions of these houses' inhabitants.

4.2 *Sociocultural levers*

The conservation of earthen heritage contributes to cultural diversity, now threatened by productivity and speculation.

Training of competent professionals in earthen construction at the local level, both in schools of architecture and of vocational training, is an essential step to conserve this heritage. Conventional local builders and masons must be integrated in this dynamic, upgrading their know-how and reinforcing their pride through involvement in projects with materials that allow more creativity.

It is also necessary to recognise the values of local vernacular constructive cultures in order to reinterpret them in a contemporary way adapted to the present social reality, thus fostering the continuity of local culture and reinterpreted local based aesthetics.

Special attention may be payed to users, through raising awareness campaigns, pilot projects, valorisation of heritage, etc., in order to facilitate their support and pride for the maintenance of this heritage.

In this sense, it is necessary to promote further implication of users in their earthen rehabilitation projects. These projects shall be undertaken with participatory systems aiming the inclusion and training of participants and a better acceptance of earth.



Figure 5. Participative workshop of the association Terre, Pierre et Chaux (E. Sevillano Gutiérrez, 2014).

4.3 *Socioeconomic levers*

The promotion and creation of local materials supply chains and the capacity building for masons and family construction enterprises can contribute to strengthen the dynamics of an impoverished local economy as they can become new sources of income. Ecological and technically appropriate earthen constructions renovation must be promoted among builders and inhabitants to make earth and other eco-materials available like the conventional ones. Nevertheless, it is necessary to promote a local scale production of these materials, and to avoid the homogenisation of large scale producers. In order to facilitate economic accessibility to earthen construction and rehabilitation in these contexts, it is necessary to study ways of mechanising techniques and improving working time. Accessibility can also be promoted through self-construction and framed participatory projects. Earthen cultures can enable the population to recover a part of autonomy face to habitat needs.

5 CONCLUSIONS

The three case-studies from Isère show us that rehabilitation is possible within this territory in a conscious, respectful, technically appropriate and flexible manner. The main lessons about these experiences can illustrate territories like the Campiña Segoviana where very little players are ready to achieve correct conservation works in earthen heritage.

First of all, valorisation of both earthen vernacular and monumental heritage is a main point. It is necessary to appreciate something in order to take care of it. At the same time, the rehabilitation

and adaptation of these buildings is essential in order to update them to present needs in a sustainable way.

Inhabitants do not always have the economic means to undertake respectful works. Sensitisation of citizens about the importance of preventive maintenance, more economic, is a key aspect. Adaptation to different budgets can be reached widening the variety of offer for conservation works, from the classic enterprise to framed self-construction. Further inclusion of inhabitants in conservation projects is primary.

In order to widen the use of adequate materials, it is necessary to promote short supply chains of ready-to-use ecological and natural materials. Today, not many people are ready to excavate to get earth to build with, so it is central to facilitate this task and make earth as accessible as industrial materials are.

Finally, training of conventional practitioners must be promoted to make them competent to execute good conservation works and to give advice and technical support to inhabitants. It is necessary to train all professionals working in this heritage and not only an elite of practitioners specialised in earth.

These actions shall be adapted to each local context. More contexts could be studied in order to widen the reflexion and learn from other positive experiences of conservation of earthen constructions.

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Transformation in the Kasena's large earthen compound houses in Burkina Faso

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ABSTRACT: The large earthen compounds of the Kasena in Burkina Faso, called *songo*, are famous for their complex structure and decoration. However, earthen houses are no longer inherited and have thus almost disappeared. In this paper, we attempt to verify the chronological transformation of the housing and family systems of the Kasena. Consequently, we indicate that all the 8-sided rooms (*diniya-didiyou*) have been abandoned, a *songo* is not a connected compound, but consists of clusters of rooms, the eastern half of the clusters is densely constructed, but the western half is not, each cluster roughly corresponds to a *dâ* and generally comprises the founder of the *songo*, his wives, their children and their wives, and some, but not all, *dâ* have changed in accordance with the founder's life cycle. For these reasons, the *songo* have expanded unequally and the transformation of "traditional" architecture is not uniform.

1 CONTEMPORARY "TRADITIONAL" EARTHEN COMPOUNDS (SONGO) OF THE KASENA

1.1 *Background and context of research*

The Kasena belong to the Gur language group located in the south of Burkina Faso and north Ghana. The Kasena in Burkina Faso constitute the (big) Gurounsi with the Lyélè, Nuni, and Ninkare, and mainly inhabit Nahori province in south-central Burkina Faso. The Kasena comprise the majority people in Nahori province, making up 60% (80,000) of the overall population (137,000).

In 1983, at the time of the establishment of the "Little World Museum of Man" (later "Little World") in Inuyama (Japan), a Kasena *songo* (or large earthen compound) was restored based on research by Prof. Junzo Kawada and curators from the 1960s. The *songo* in Little World, in fact, was not restored precisely, as cement was used rather than the mud originally used by the Kasena in Burkina Faso. Prof. Kawada's group had submitted detailed ethnographic resources such as a blueprint of the *songo*, family trees of the informant they researched, and the *diga* (room) in which each family member lived.

The traditional Kasena *songo* has been advertised as a symbolic touristic site in Burkina Faso as it is organized in a complex fashion, with an "8-sided room" called a *diniya-didiou*; the houses are decorated with geometric patterns (Fig. 1). Despite the distinctive houses and advertisements by the Embassy of Burkina Faso in Japan, Little World, and a number of organizations attached to



Figure 1. Decoration of *Diniya-didiyou* (Tiébéré, 2013–01–17).

Burkina Faso, we could only find one completed *songo* in Kasena country apart from the big chief's village, Tiébére. Most *songos* in the Kasena villages that the authors visited had constructed tin-roofed houses using blocks, rather than earthen houses.

Thus, the harmony between the family and housing structure has not been well maintained and it is also becoming difficult for the Kasena to preserve their indigenous building technology.

1.2 *Kasena families and residences*

To understand the family and housing system of the Kasena, we must first consider some local names and related notions. Among the Kasena, the family is organized patrilineally and each clan basically settles within the same *songo*. The clan that lives in a *songo* is also called a *songo*. There can be multiple clans in one compound, with the oldest member becoming chief of the *songo*, called the *songo-tu*. The *songo-tu* cannot make decisions alone but must discuss them with other elder males and then approve the matter they have discussed. In the case of constructing a new *diga*, the place and size are decided by him.

When a male marries, he constructs his own couple's *diga* in some *songo* or another, to disperse different *diga* within an adjacent parcel of land owned by the clan. This is the clan settlement. Residence is virilocal: that is to say, in marriage, a daughter leaves the house to join husband who is in his father's house (Cassiman 2006: 7–8). In addition, the *songo-tu* and elder members indicate that the new *diga* is sometimes called a *dâ* (see 2–2).

Cassiman and Kawada indicated that *songo* and *diga* are the key definitions of units of large earthen compounds of the Kasena (Kawada 1979, Cassiman 2006). Cassiman has introduced these definitions in her book as follows: "the smallest unit within the social organization of the kin group is a room (*diga*)" while the *songo* is "the physical earthen structure consisting of an amalgam of walks, open spaces and terraces, as well as the residential rooms" (Cassiman 2006: 8). *Diga* is also categorized into four types (Table 1).

The earthen houses of the Kasena are constructed by *songo* members and neighbors according to a gendered division of labor whereby matters of construction are entrusted to males while the decorations are the responsibility of females. To complete one *diniya-didiyou*, for example, takes two to three weeks. During the process of construction, the owner of the new house must provide meals, coffee, cigarettes, etc., to all the contributing members. In the case of decoration, collective work is implemented both for new houses and for house maintenance. The owner gathers female *songo* members and neighboring females to help, and provides meals and supplements to contributors.

Table 1. Four types of *diga* in Kasena.

Type of *diga*	Characteristic
Manguelo	Square house for male
Diniya-didiyou	8-shaped' house for first wife of songo
Dikili	Round house like Mossi style (Pibot 2009: 22)
Tol Tigue	Zinc-roofed house

1.3 *Objective of this paper*

Through our research from 2013–2016, we noted certain points of transformation in Kasena houses and housing. First, both males and females have been allowed to live in any type of housing in recent years. Second, there is no one living in the *diniya-didiyou*, which means there are many empty houses. Third, the use of a *tol-digé* (zinc-roofed house) is expected to further increase owing to its ease of construction compared to earthen-roofed house. Fourth, the women in Langouerou gave economic reasons for why they have not continued with decoration. In this way, the traditional Kasena's earthen houses have almost disappeared and modern ones, such as the *tol-tigue* are constructed with *banco* (sun-dried brick) instead.

Given the current situation, these traditional earthen houses may completely disappear in the near future. Our study ultimately aims to contribute to the preservation of their tradition. However, before this study, we attempt to contextualize the actual family and housing systems and to analyze the chronic transformation through comparison with Kawada's study.

1.4 *Methodology*

This study is based on field research conducted by two architects and three anthropologists from 2013. The field research was conducted in Langouerou village in Nahori province where Kawada also conducted his research. To connect our research effectively to Kawada's study from the 1960s to 1970s, our research was conducted in the same village, Langouerou, which is located approximately 20 km from Pô, the provincial capital of Nahori. This village was founded by Apadré, the grandfather of the ex-*songo-tu* (chief of *songo*) who was installed from Pô. Thus far, we have conducted collective fieldwork with architects and anthropologists together with a gatekeeper and some interpreters.

As the aim of our study was to analyze the current family system, we conducted anthropological

research. However, because of the limitations of time, finance, and security on the field site, the fieldwork did not include participatory observation. Therefore, we visited Alampoa *songo* and Aipokogé *songo* for a few days to draw up some plans of their respective *songos* and to interview the family members of each.

2 DEVELOPMENT THEORIES OF HOUSING

2.1 *Previous study: "developmental cycle"*

To examine the transformation of housing in Kasena, we must review the studies of a number of anthropologists. The most important was that of Fortes, who studied the relationship between the family system and houses in West Africa. Fortes described the developmental stages of domestic groups in line with the phases of the male's life cycle (Fortes 1969: 10–12). He described the "developmental cycle," which shows how the four steps in the male's life cycle are reflected in the housing cycle. These steps are:

Childhood: the male grows up in his father's concession.

Adulthood: the male leaves his father's concession and builds his own.

Marriage: the male builds his wife's and son's houses in his concession.

Death or marriage of the eldest child: the division of the male's concession.

It is certain that the "developmental cycle" model provided an important guideline for understanding the relationship between the life cycle and housing for the Gur ethnic group. However, Yanagisako criticized the universal definition of domestic groups that Fortes and others discussed.

Following these critiques (e.g., Yanagisako 1979), cultural anthropologists hardly studied the developmental stages of the domestic group with the exception of a few ethno-archaeologists (e.g., Agorsah 1985, 1993; Gabrilopoulos et al. 2002).

Considering also the current situation of the Kasena's compounds, it is difficult for this model to explain their transformation. It is certain that the *songo* have expanded the corresponding life cycle of the male, while most *diga* have been abandoned and most earthen houses have not been inherited. The *diniya-didiyou* of Langouerou are a remarkable example of this. We confirmed, for example, that there used to be four *diniya-didiyou* in this *songo*, but currently, all have fallen out of use, and are now used as chicken coops or for storage. According to the village people, the last one was abandoned approximately 20 years after the death of the wife of the chief at that time. Compared to Kawada's study, the landscape of Langouerou has changed over the course of 40 or 50 years and the aspects of transformation of the *songo* have become more complex than Fortes's model allows.

2.2 *Dâ: Another developmental theory of the songo*

In the context of development of the *songo*, a *diga* cannot simply be constructed in any location. The *songo-tu* and elder males in the same *songo* described other theories to us. At first, the *songo* is developed in the center of a *naabo* (courtyard). The *naabo* has an important function in the *songo* as a courtyard for livestock, which are an important economic resource for the Kasena (Kawada 1979: 32, Cassiman 2006: 20–21) and as a ritual space in which to establish a *toule* (a ritual grain store) deep inside the *naabo*. This is why they refrain from constructing new *diga* in the *naabo*. The function of the *naabo* might be one reason why the *songo* expand toward the exterior rather than the interior (Figure 1).

Second, the definition of *dâ* is important but has not been considered a key word in the theory of transformation of the *songo*. This word is used for the house(s) that are separate from the mother's house and can be defined in two ways: one is to describe new couples who have just started living separately but are not completely independent; the other is to describe a *diga* for this couple (Fig. 2).

3 EXPANDING THE SONGO AND THEIR TRANSFORMATION

3.1 *Economic factors in ceasing construction of traditional houses*

In this paper, we focus on the causes of transformation of the Kasena's earthen houses in terms of the transformation of "tradition." The people of Langouerou stressed that economic factors were

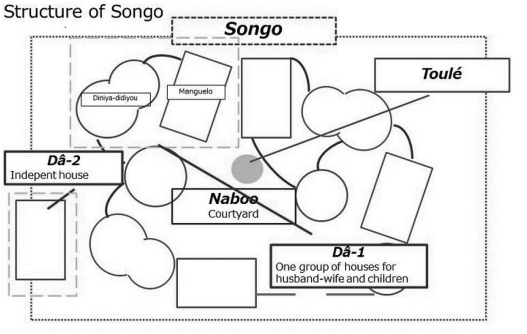


Figure 2. Structure of the *songo*.

important reasons for the difficulty with continuing the traditional method of construction and decoration. As we showed in 1–2, it is necessary to acquire some materials and the help of neighbors through bartering or crops. However, through the penetration of a money economy in this area over the decades, it became the norm to buy materials or pay honoraria to helpers. Consequently, it is certain that the money economy caused the suppression of the earthen houses' traditional construction.

3.2 *Chronological transformation of the songo: 1970s to 2016*

Although Cassiman pointed out that the *songo* signifies both the compound itself and the families that inhabit the compound (Cassiman 2000: 116), the family and compound do not correspond in the case of Alampoa *songo*. Some houses in this *songo* are grouped as *dâ* and some *dâ* aggregate as a *songo*. We confirmed that nine clusters (six *dâ*) were associated in Alampoa *songo* in 2016 (Fig. 3).

In this *songo*, each six *dâ* named a male in the second and third generation as the founders of the *dâ* and its corresponding clusters (Fig. 4). It is remarkable that units of the "founder of the *dâ*-his wife-their son with his wife-grandchildren" are associated with each cluster.

On the other hand, the other two *dâ* were not associated with such a simple structure, in which the members of one expanded and the others reduced. In the case of the reduced *dâ*, the male, who must be the core of a *dâ*, was absent, and the divorced person rejoined the expanded *dâ*. The latter case meant that it was not separated into one *dâ*. The following four figures indicate the chronological transformation of the Alampoa *songo*.

Most of the structures in the framework, which were constructed before the 1970s, have remained in this *songo*. In this *songo*, the structures have been concentrated in the west and east parts, and the clusters are simply organized around the structures constructed after the 1970s (Fig. 6). Most of the oldest males in each *dâ* were in their 30 s when each *dâ* was organized and had married and had

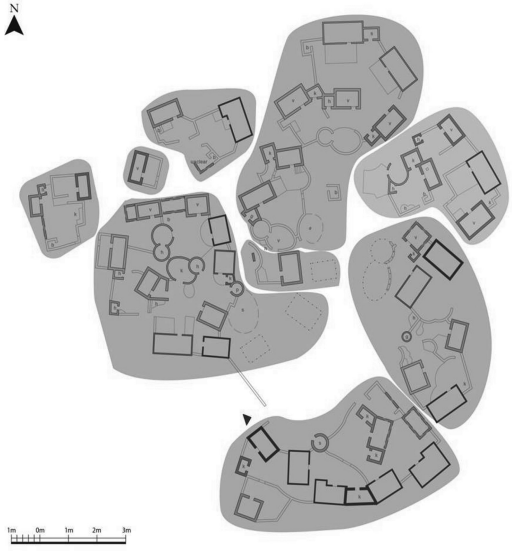


Figure 3. Ground plan of Akampoa *songo* (Drawing and arrangement by Kobayashi and Nakao 2016).

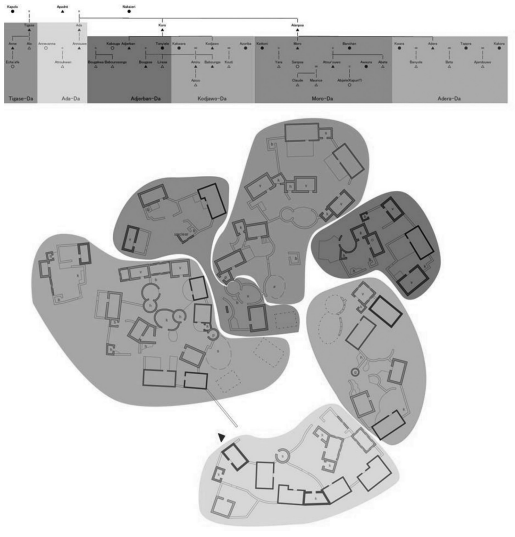


Figure 4. Cluster of the *songo* and family tree of the Alampoa *songo* (Nakao and Kobayashi 2016).

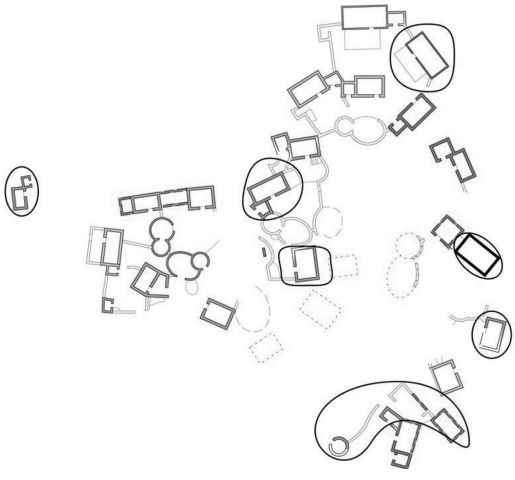


Figure 5. Alampoa songo in the 1970s.

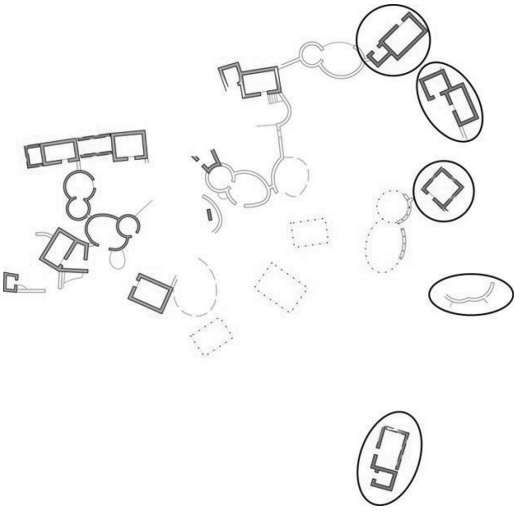


Figure 6. Alampoa *songo* in the 1990s (Kobayashi and Nakao 2015).

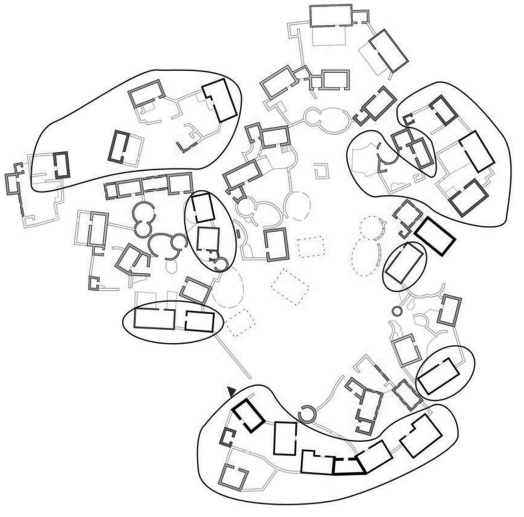


Figure 7. Alampoa *songo* in the 1990s (Kobayashi and Nakao 2015).

children. Consequently, although this was not the case for all, some *dâ* tended to develop in accordance with the male's life cycle.

In the 1980s, members of Tigase *dâ* (the eldest child) were connected with the parent's *diga* (Fig. 7).

The *songo* were expanded by constructing new *diga* of Adera *dâ* and combining the existing *songo* in the 1990s. Between the 1990s and 2016, Moro *dâ*, Adjedern *dâ*, and Adera *dâ* constructed a

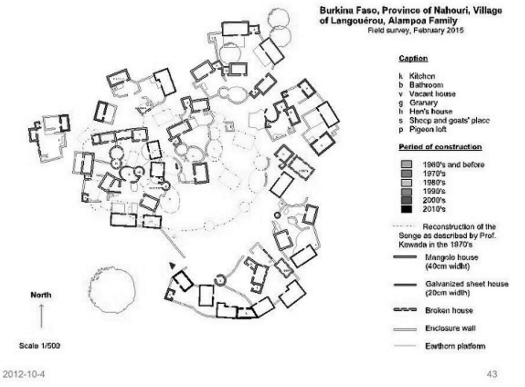


Figure 8. House conditions of the Alampoa *songo*.

remarkable number of *diga*. In contrast, Tigase *dâ* has not constructed *diga* for more than 25 years.

We have examined the process of expansion of Alampoa *songo*, and found that the transformation not only comprises expansion as Fortes mentioned. Figure 8 shows the condition of the *diga* on January 2015. As it indicates, while some *diga* have already collapsed, others have vanished without a trace.

3.3 *Analysis of songo in Langouerou*

Based on the overview above, the structure of transformation of the *songo* can be summarized into four points as follows: i) a *dâ* is a component of a *songo*, ii) each *dâ* has been transformed, iii) the *dâ* is associated with the "founder of the *dâ*, his wife, their son and his wife, and grandchildren," and iv) the *dâ* develops in accordance with the male's life cycle.

Only iv) could be said to adopt Fortes's theory regarding which housing style corresponds to the male's life cycle (Fortes, 1969), but Fortes's theory could not encompass the entire transformation in the case of Langouerou. This is because structures built before or during the 1970s have not been separated because of the increasing irregularity of members. This phenomenon shows that generations of members and structures have been renewed in the same way and at the same time as mentioned in Fortes's model. The difference stems from both human and structural factors. The human factor is led by the issue of succession, whereby the members of a *dâ* must not change according to orthodox generation alternation. On the other hand, in respect to the structural factor, more than half of the cases of abandonment of a *diga* were not due to the inhabitant's death. This means that generation alternation and human death are not the orthodox reasons that Fortes supposed. In addition,

approximately 30% of *digas* were inherited by descendants and the *songo-tu* then indicated that anyone could inherit any *diga*, if the *songo* members accepted it. The *diga* in Langouerou have thus been inherited by indeterminate successors who are not always descendants of the deceased.

In this way, although the succession theory of *diga* basically follows Fortes's model, the segmentation and expansion of the *dâ* has caused different issues in Langouerou. The transformation of usage of the *diga* occurred in relation to how the inhabitants abandoned them and how they continue to leave.

4 CONCLUSION

The transformation of the Kasena's earthen houses seems to involve the expansion of the *songo* itself following Fortes's "developmental cycle." However, the abandonment of the traditional decoration method has been caused by two factors: a) economic and social change, and b) the structural system. In respect to b), Fortes demonstrated a "developmental cycle" in previous studies of transformation. We focused on analyzing the latter point with reference to some data from our field research and pointed out the following five factors of transformation: (1) all the 8-sided rooms (*diniya-didiyou*) had been abandoned, (2) the *songo* is not a connected compound, but consists of clusters of rooms, (3) the eastern half of the clusters is densely constructed, but the western half is not, (4) each cluster roughly corresponds to a *dâ*, which means the "extended family" that generally contains the founder, his wives, their children, their children's wives, and grandchildren, (5) the *dâ* changes in line with the founder's life cycle, but this is not the case for all *dâ*. For these reasons, the *songo* has expanded unequally and the transformation of "traditional" architecture is not uniform.

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Hassan Fathy's humane considerations in design and the significance of New Gourna

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ABSTRACT: Hassan Fathy's heritage in Egypt, particularly New Gourna Village, is an example of vernacular and recent heritage patterns that are under-represented on the World Heritage List, which enjoys exceptional heritage qualities. One of the major aspects that contribute to New Gourna's heritage qualities is the humane considerations in its design. Nevertheless, none of the projects that Hassan Fathy designed has been inscribed as a World Heritage Site. The aim of this study was to discuss the contribution of Hassan Fathy's humane considerations in design to the outstanding significance of New Gourna, and to discuss the potential criteria that can be adopted to justify New Gourna's Outstanding Universal Value on the basis of the humane considerations in its design. The findings revealed the significant contribution of Hassan Fathy's humane considerations in the design of New Gourna to its outstanding universal significance. As a result, the study recommends adopting criterion (i) to justify New Gourna's Outstanding Universal Value on the basis of the humane considerations in its design.

1 INTRODUCTION

Since the World Heritage Convention has been adopted in 1972 (UNESCO 2005), States Parties to the convention have embarked upon inscribing properties on the World Heritage List, WHL. However, a recent study revealed that particular UNESCO's regions and particular heritage patterns are under-represented on the WHL. The Arab States region, to which Egypt belongs, was found among the under-represented regions, while vernacular and recent heritage were found amongst the under-represented patterns (UNESCO 1994). To overcome the previous problem, the World Heritage Committee adopted a strategy called the Global Strategy in 1994 (UNESCO 1997) and undertook a number of measures to implement it, one of which is encouraging the nomination of the properties that belong to the under-represented patterns for the listing as World Heritage Sites, WHSs. Consequently, many Sates Parties listed on their Tentative Lists properties representing vernacular and recent heritage for the future listing on the WHL. For instance, Mali listed on its Tentative List in 2009 a property representing recent and vernacular heritage, which is "La grande mosquée de vendredi de Niono" (UNESCO World Heritage Centre 2016a).

"Alexandria, ancient remains and the new library" is the only property that is listed on the Egyptian Tentative List that incorporates within its boundaries an element representing recent heritage, which is the library of Alexandria (UNESCO World Heritage Centre 2016b). On the other hand, one of the Egyptian WHSs incorporates within its boundaries two properties designed by Hassan Fathy, which is "Ancient Thebes with its Necropolis" in Luxor. These two properties are New Gourna Village and Stopplaere House. However, these two properties are not considered among the elements that contribute to the WHS's Outstanding Universal Value, OUV (UNESCO 2011) that is because this WHS has been inscribed because of its archaeological value. Moreover, the earthen heritage elements that are recognized inside this WHS do not involve any of the properties designed by Hassan Fathy (Joffroy 2012). All the justifications of this WHS's OUV have focused on the archaeological sites in the property except for the justifications of criterion (vi) that address the contribution of the property's villages of artisans and artists to its value (UNESCO 2008). These justifications have not been clear about whether those villages involve New Gourna or not. However, the properties designed by Hassan Fathy still enjoy outstanding heritage qualities that allow them the chance to qualify for the WHS status (Abdel Tawab 2012).

Paimio Hospital in Finland, which represents recent heritage and the architectural heritage of the modern movement, has been nominated for the inscription on the WHL in 2004 (UNESCO World Heritage Centre 2016c). The justifications of the property's OUV concerning the world heritage criterion (i) attribute the property's OUV to the humane considerations in Alvar Aalto's design (National Board of Antiquities 2005). Humane considerations in design can also be adopted to justify the OUV of New Gourna Village in Egypt.

2 THEORETICAL BACKGROUNDS

There are three dimensions that are important for establishing the significance of heritage properties; which are scale, importance, and uniqueness and representativeness. The scale of heritage significance is concerned with the level at which the heritage property is considered important. A heritage property might be important to a local community, a region, a state, the entire nation, or globally. The importance of the heritage property is concerned with how important is this property at the appropriate scale, while the uniqueness or representativeness of the heritage property attributes heritage properties' significance to their being unique examples of particular patterns or their being representative examples of these patterns (Aplin 2002). The level of significance of heritage properties might vary from the personal and/or familial level to the local level, the regional level, the provincial level, the national level, or the international level where the heritage property is considered of significance to the people of more than one nation (Abdel Tawab 2013). The maximum level of significance is the OUV level, which is usually associated with WHSs. Stakeholders of a particular heritage property, who might involve the community, cultural groups, the market, the state, conservators and other experts, property owners, and ordinary citizens (Mason 2002), can indicate the level or scale of significance of the concerned heritage property. The universal significance of a particular cultural heritage property can be indicated by its being an authentic or a true expression of a specific culture (Jokilehto 2006).

The World Heritage Convention, which introduced the outstanding universal significance of heritage values as a level of heritage significance, indicates that the WHSs that enjoy an OUV are either cultural or natural properties that are important for all the peoples of the world, and represent a significant part of the world heritage of mankind as a whole (UNESCO 2005). The expression "Outstanding Universal Value", which has been interpreted in a number of cases to imply the "best of its kind", incorporates both notions of uniqueness and representativeness (UNESCO 1997). Properties nominated for listing as WHSs are usually considered to enjoy an OUV if they were found to satisfy one or more of a list of 10 criteria (Table 1). In addition to these 10 criteria, nominated properties should also meet the conditions of integrity and/or authenticity and must have adequate protection and management systems, so that they can be inscribed on the WHL (UNESCO 2015).

Table 1. The World Heritage Centre's criteria that are used to justify the Outstanding Universal Value of the properties nominated for the inscription on the World Heritage List [UNESCO 2015, pp 16–17].

Criteria*	
(i)	to represent a masterpiece of human creative genius
(ii)	to exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design
(iii)	to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared
(iv)	to be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history
(v)	to be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change
(vi)	to be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance. (The Committee considers that this criterion should preferably be used in conjunction with other criteria)
(vii)	to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance
(viii)	to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features
(ix)	to be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals
(x)	to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation

*Criteria (i) to (vi) belong to cultural heritage properties, while criteria (vii) to (x) belong to natural heritage properties.

3 THE AIM AND THE METHOD

The main aim of this study was to discuss the contribution of Hassan Fathy's humane considerations in the design of New Gourna to the justifications of its outstanding universal significance. The study also aimed at discussing the most relevant world heritage criteria that can be adopted to justify New Gourna's OUV on the basis of the humane considerations in its design. The study achieved

these aims by means of a thorough preview and exploration of the humane considerations in Hassan Fathy's design of New Gourna. A brief comparative analysis of the humane considerations in design that were adopted to justify the OUV of another property representing 20th century heritage, which is Paimio Hospital in Finland designed by Alvar Aalto, was also carried out.

4 NEW GOURNA VILLAGE IN EGYPT

4.1 *Introduction to the architect, Hassan Fathy, and New Gourna Village*

Hassan Fathy was born in Alexandria in 1900. He studied architecture at Cairo University and graduated in 1926 (Steele 1997). Following his graduation, Hassan Fathy worked as an engineer in the Central Administration of Schools. In 1930, he was appointed as an instructor in the Faculty of Fine Arts. Between 1949 and 1952, Hassan Fathy was appointed as director of the Educational Building Department in the Ministry of Education. From 1953 till the late 1950s, he was appointed as head of the architecture department in the Faculty of Fine Arts in Cairo University (Serageldin 2007). Hassan Fathy designed a large number of projects many of which were constructed. Among them we find Hamed Said House, Fouad Riad House, and the schools at Fares and Idfu (Steele 1997). New Gourna Village is considered to be the best known project designed by Hassan Fathy (Serageldin 2007), who passed away in 1989.

New Gourna Village lies inside the agricultural land on the western bank of the Nile in Luxor. The village was planned to be inhabited by a relocated indigenous community residing inside a nearby village called Old Gourna that lies on the edge of one of the mountains outside Luxor. The construction of New Gourna began around 1946 and was suspended later in 1947. Only a small section of the village was constructed. Some of the buildings that Hassan Fathy built in the village were demolished, such as the boys' primary school, while others survived; such as the mosque, the theatre, the khan, a small section of the marketplace, Hassan Fathy's house, and some of the peasants' houses (Abdel Tawab 2014). A previous study reveals that New Gourna enjoys a large number of heritage values that enjoy an international level of significance and might allow the property the chance for listing as a WHS. However, the study reveals that most of the values that New Gourna enjoys are not expected to satisfy the conditions of authenticity and integrity (Abdel Tawab 2012).

4.2 *The humane considerations in the design of New Gourna*

The diverse projects that Hassan Fathy designed express his humane considerations in architecture. Whether they are community projects or elites' private houses, all the projects Hassan Fathy designed were responsive to the users' physical, psychological and cultural needs (Serageldin 2007). Hassan Fathy's concerns about the energy and thermal efficiency of his projects as well as the concerns about the problems of the poor (Serageldin 2007), emphasize his humane considerations in architecture. In the community projects that he designed, Hassan Fathy avoided using expensive modern building materials and preferred using a cheap material, which is earth (Steele 1997), and using vaults and domes for roofing (Fathy 2000) hoping that this would help in building cheap and affordable residential units.

Hassan Fathy believed in the individuality of architecture and in the right of the poor to participate in the design of their homes. In his vision every family house should be unique because every family is different. As a result of those believes he disagreed with the prototype approach that the government adopted to build affordable residential units. Hassan Fathy described the prototype mass production approach as a massacre of individuality, and the residential units produced through this approach as hideous and inhumane (Fathy 2000). The disagreement with the prototype approach emphasizes Hassan Fathy's humane approach to architecture. Hassan Fathy's previous stance was based on two humane considerations; which are the failure of the prototype and mass production approach in allowing the users the chance to clarify their needs and to participate in the design process, and the peasants' poverty and inability to buy the architectural products manufactured through this approach (Fathy 2000).

Hassan Fathy's humane considerations in architecture are emphasized by his aim of designing New Gourna to provide safe, sanitary and inexpensive houses for the peasants. These humane considerations are also represented by his insistence on maintaining the social structure of Old Gouran's community. Hassan Fathy divided New Gourna's layout into four quarters so that each one houses one of Old Gourna's four tribes (Steele 1997). Hassan Fathy's interest in retaining Old Gourna's traditional way of marriage emphasizes the humane considerations in his design of New Gourna. Hassan Fathy did not provide the peasants' houses in New Gourna with running water because he did not want to dismiss the only opportunity that young girls might have of being seen by prospective husbands gathering to watch young girls during their daily parade to the well. Instead, he installed a central well (Fig. 1) in each of the four quarters to maintain the social tradition of the daily water parade (Steele 1997). Hassan Fathy's trial to maintain a close relationship with Old Gourna's reluctant peasants and the subsequent gradual change of this relationship from hostility, from the peasants' side, to sincere friendship (Steele 1997) reflects another

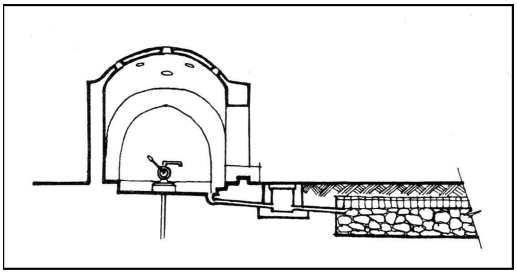


Figure 1. A section of one of the water points provided by Hassan Fathy inside New Gourna Village [Fathy 2000, p. 100 illustration 120].

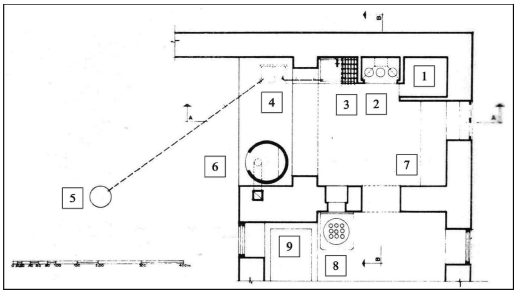


Figure 2. A plan of the cooking place inside one of the peasants' houses in New Gourna Village [Fathy 2000, p. 98 illustration 119]. 1. Fuel bed, 2. Stove, 3. Sink, 4. Grease trap, 5. Bore hole, 6. Summer oven, 7. Seat, 8. *Kachelofen*-baking oven, 9. Bed.

humane aspect in the design of New Gourna. In order to maintain this close relationship, Hassan Fathy stayed in Luxor during the design and construction stage of the village (Steele 1997).

One of the humane aspects in the design of New Gourna is Hassan Fathy's devotion to raise the peasants' awareness of the significance and richness of their architectural heritage and traditional arts and crafts. In order to achieve this aim, Hassan Fathy wrote a play entitled "The Tale of the Mashrabiya" that was performed on the theatre he designed in the village (Steele 1997). This play reflects Hassan Fathy's humane ideas concerning the role of architects. The gouaches that Hassan Fathy painted for New Gourna, which express his empathy with the peasants' poor living conditions, and his interest in anticipating the peasants' needs in his design of the village (Steele 1997) emphasize his humane approach to architecture.

Hassan Fathy's care to design the smallest details and the furniture elements in the peasants' houses and his devotion to understand the peasants' needs and way of life emphasize the humane considerations in his design of New Gourna. He observed that the peasants' houses should have enough space for fuel storage and for cattle, and that their kitchens should be larger than those in city houses. That is why he provided every peasant's house with a cattle-shed and enough storage space (Fathy 2000). Taking into consideration the poverty of the peasants, Hassan Fathy provided the bedrooms in their houses with built-in beds that have storage area under them. He provided every bedroom with specially designed scorpion troughs to repel dangerous insects (Fathy 2000). To provide the peasants' houses with a cheap and efficient heating system, Hassan Fathy designed a special heating device based on the Austrian heating and cooking device known as *kachelofen*. Hassan Fathy visited Austria to learn how *kachelöfen* work then returned to Egypt and commissioned a local craftsman to produce cheap revised versions of these devices for the peasants in New Gourna (Fathy 2000).

Hassan Fathy's meticulous design of the cooking place in the kitchen (Fig. 2) and his devotion to understand the way the peasants cooked emphasize the humane considerations in his design of New Gourna. Based on his observations and analysis of women's movement during cooking in rural Egypt, Hassan Fathy concluded that it was important to retain the squatting position for cooking because it is considered more comfortable than the standing position. That is why he designed the cooking place as a lower version of the European range that has a permanent grate for the fire, a firebrick grid for the pans, and a large hood placed above it to get rid of the fumes. Following the same meticulous approach, Hassan Fathy designed the other spaces in the peasants' houses, such as the laundry place and the bathroom. He made careful observations and measurements of the way women in rural Egypt do their laundry, usually in the lake, and even tried the laundry seated position. Following his observations, Hassan Fathy designed the laundry place so that it allows women to do the laundry the way they were accustomed to (Fathy 2000: 101). In relation to the bathrooms, Hassan Fathy believed that if the peasants' houses were provided with clean bathrooms, a flushing system, and a sanitary drainage system, it would be possible to combat dangerous rampant diseases; particularly typhoid, bilharzia, dysentery and ancylostoma. Consequently, he provided each house with an individual drainage system that consists of a large inspection chamber and a septic tank in the same time that drains into a borehole working as a percolating pit in the courtyard (Fathy 2000).

Hassan Fathy's efforts to combat bilharzia disease represent one of the key humane aspects in his design of New Gourna. Bilharzia parasite infects the peasants when they use water from the Nile River to irrigate their crops. Since the peasants continuously use water from the Nile, they are susceptible to a recurrent infection of bilharzia. Since it is impractical to

decontaminate the entire river to get rid of bilharzia, Hassan Fathy provided New Gourna with a subsidiary canal and an artificial lake that were decontaminated against bilharzia. He consulted the director of the Parasitology Department in the Ministry of Public Health and revised his design of the canal and the artificial lake following the director's recommendations. Hassan Fathy also designed very cheap protective clothes for the peasants to wear when they get inside the canal water to irrigate the crops. These protective clothes were made of ordinary peasants' trousers that were coated with linseed oil and attached to rubber soles made of old cars' tires. To raise the peasants' awareness of the dangers of bilharzia and to convince them to use the protective clothes, Hassan Fathy wrote a special play for them (Fathy 2000).

5 COMPARISON WITH OTHER RELEVANT PROPERTIES

Amongst the most significant recent heritage properties that have been nominated for the listing on the WHL is Paimio Hospital in Finland. The hospital was designed by the Finnish architect Alvar Aalto. The humane considerations in Alvar Aalto's design of the hospital have been adopted among the justifications of the hospital's OUV, which have been adopted through criterion (i). The justifications of criterion (i) focus on Alvar Aalto's experimentation with new technological solutions, characteristic of modernism architecture and functionalism, in order to serve the needs of the patients (National Board of Antiquities 2005).

Amongst the most significant humane considerations in Alvar Aalto's design of the hospital are using technics to serve human beings' needs, employing architecture to serve society and to improve social disadvantages (National Board of Antiquities 2005), and Alvar Aalto's meticulous design of the various architectural elements and spaces in the hospital to promote the patients' physiological and psychological wellbeing. These architectural spaces involve mainly the sun balconies, the sun decks (National Board of Antiquities 2005), and the rest halls (Fleig 2014). The humane considerations in Alvar Aalto's design of the hospital involve his meticulous design of the smallest details in the patients' rooms, and his careful design of many furniture elements in the hospital to create a comfortable and peaceful internal environment for the patients. These furniture elements involve mainly Paimio chair and the non-splash wash basin in the patients' rooms (National Board of Antiquities 2005). The landscape elements that Alvar Aalto designed in the adjacent green areas also emphasize his care for the patients' needs and the humane considerations in his design of the hospital (National Board of Antiquities 2005).

6 THE RELEVANT WORLD HERITAGE CENTRE'S CRITERIA

Three of the World Heritage Centre's criteria have been adopted to justify the OUV of Paimio Hospital; which are criteria (i), (ii) and (iv) (National Board of Antiquities 2005). Criterion (i), which is concerned with the cultural properties representing a masterpiece of human creative genius (Table 1) (UNESCO 2015), has been adopted to justify the OUV of the hospital based on the humane considerations in Alvar Aalto's design (National Board of Antiquities 2005). It is also possible to consider that the humane considerations in Hassan Fathy's design of New Gourna profoundly contribute to the justifications of its OUV. Criterion (i) is also very relevant to the humane considerations in New Gourna's design. Hassan Fathy adopted many creative answers to the environmental challenges facing New Gourna's traditional community and diverse creative ideas to design buildings that are sensitive to their socio-cultural and environmental contexts. He used the most advanced scientific knowledge to design buildings that enjoy extraordinary passive energy qualities. Hassan Fathy's creative design of New Gourna focused on maximizing air movement and minimizing solar gain in its buildings (Steele 1997). These creative answers were not only based on advanced scientific knowledge but also benefited from traditional architectural paradigms like courtyards and wind catchers.

7 CONCLUSIONS

New Gourna Village in Egypt represents two patterns of cultural heritage that are under-represented on the WHL, which are vernacular and recent heritage. Although the village lies inside a WHS, New Gourna has never been recognized among the elements that contribute to the property's OUV. None of the projects that Hassan Fathy designed has been listed on the WHL or on the Egyptian Tentative List. New Gourna is Hassan Fathy's key community project whose exceptional heritage qualities allow it the chance to qualify for the WHS's status. One of the major themes that contribute to New Gourna's exceptional heritage qualities is the humane considerations in Hassan Fathy's design. Humane considerations in architecture have been adopted to justify the OUV of Paimio Hospital in Finland, a recent heritage property designed by Alvar Aalto, which has been nominated for listing as a WHS. Criterion (i) has been adopted to justify the previous property's OUV based on the humane considerations in Alvar Aalto's design, in addition to other considerations and criteria.

The findings revealed the diverse humane considerations in Hassan Fathy's design of New Gourna.

Hassan Fathy's concerns for the peasants' needs and their poverty, his design that responds to New Gourna's socio-cultural and environmental contexts and the efforts he made to combat bilharzia through his design of the village are some of these humane considerations. The findings emphasized the contribution of the humane considerations in Hassan Fathy's design of New Gourna to the justifications of its potential OUV. The study recommends adopting criterion (i) to justify the OUV of New Gourna on the basis of the humane considerations in its design. The study also recommends revising the Statement of Outstanding Universal Value of the WHS in Luxor in order to recognize New Gourna among the elements that contribute to its OUV based on the humane considerations in the village's design.

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A temporary pavilion as a way to experiment with mud. The case of Roly Poly

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ABSTRACT: Roly Poly pavilion was designed as a temporary intervention, built in Almeria in 2016, to be part of the International Festival of Art and Construction. This project aimed to reuse an early-developed economic construction system commonly used in the Japanese and the Latin-American architecture as a technique for the design of the tea houses and 'quincha', respectively. The current proposal aims at the implementation of wood structures packed with reed and mud, materials all available near to the construction location. Six people without previous experience undertook this project. The outcome of this project was the construction of a pavilion built on the basis of ancient techniques, which exhibited contemporary qualities. In a period of economic crisis, we propose to build affordable and self-made architecture. Thus, architecture should not be only a matter of money, but a resource to be useful to anyone, making it fast, affordable and available to everyone.

1 INTRODUCTION

The Roly Poly pavilion is a temporary intervention developed in the highest part of a valley in Baños de Sierra Alhamilla, Almeria (Spain), between the desert and an oasis. This project was built in that location as a selected proposal for the International Festival of Art and Construction (IFAC 16), which took place from the 16th to the 25th of September in 2016. The project was framed in the proposed topic of the festival named 'the Fragile Limit'.

The aim of the project was to reuse an early-developed affordable construction system mainly based on mud and canes, which was commonly used in Japanese tea pavilion architecture or in the construction system called "quincha" in Latin America.

Participants have experienced with the system, using it for the design of a pavilion with a contemporary shape, where people could stay and enjoy the scenery provided by the desert landscape (Fig. 1).



Figure 1. General view of Roly Poly (Lucía Balboa).

2 OBJECTIVES

There is a general lack of knowledge and expertise using materials in the schools of architecture. Furthermore, fieldwork often takes place as a complementary training in workshops and festivals such as the IFAC.

Interestingly, the design and construction of this pavilion served to assay the use of soil as a contemporary material, its combination with other materials, and to see if it can be easily adapted to contemporary architecture.

3 MATERIALS AND METHODS

3.1 *Historical basis*

The proposal is based on a vernacular construction system used both in Japan and in Latin America. The Japanese system was followed to build the tea houses or 'chashitsu', where the gatherings for the tea ceremonies took place. The Latin America system known as 'quincha', meaning 'wall' in Quechua dialect, was followed as a model to build small houses. Both construction systems are probed to be earthquake-resistant.

3.2 *Design of the pavilion*

The main concept for the design is a reinterpretation of the water tanks that appear as landmarks in the fields of Almeria. The project tries to give them a new meaning by creating a space for gathering people instead of gathering water.

The pavilion is a wooden structure formed by a sequence of 'mountain shaped' arches (Fig. 2) and packed with reed and a mix of clay, sand and straw (1:1:3%). Six people without previous experience have manually prepared these materials, with the use of elementary tools, taking only eight days to build the whole pavilion, and at an estimated cost of less than a hundred euro. All the materials have been obtained from the same valley, with the exception of the wood (Fig. 3).

3.3 *Process of construction*

3.3.1 *Main structure*

After doing the excavation, a truss at each level is placed into the ground. The main arches were designed with a single-double stick connection (Figs. 4-5), to be fixed to the trusses afterward.

The frames of the structure form different angles, where the 'quincha' would be developed. After the completion of the woodwork, materials needed for the construction were searched and collected from the surroundings. Canes, sand and straws were found in the wet and dry areas of the valley, respectively, and the soil was directly obtained from the near ground.

3.3.2 *Secondary structure*

The useful characteristics of the canes were high flexibility and strength. Clean canes were used inside each frame, placing the biggest ones in the perimeter and diagonals to make a rigid construction, and twisting the smaller ones to form a textile structure. 'quincha' was placed in most of the frames following a pre-conceived design. In this conceptual line, only some of these canes would be packed with mud (Fig. 6).

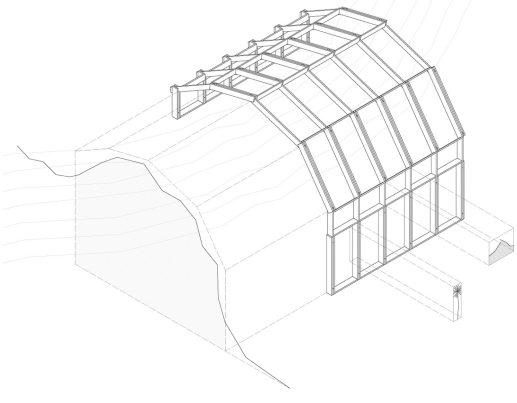


Figure 2. Axonometric view of the pavilion. Concept of the design and main wood structure with the 'mountain shaped' arches (Lucía Balboa, Antonio J. Jiménez).

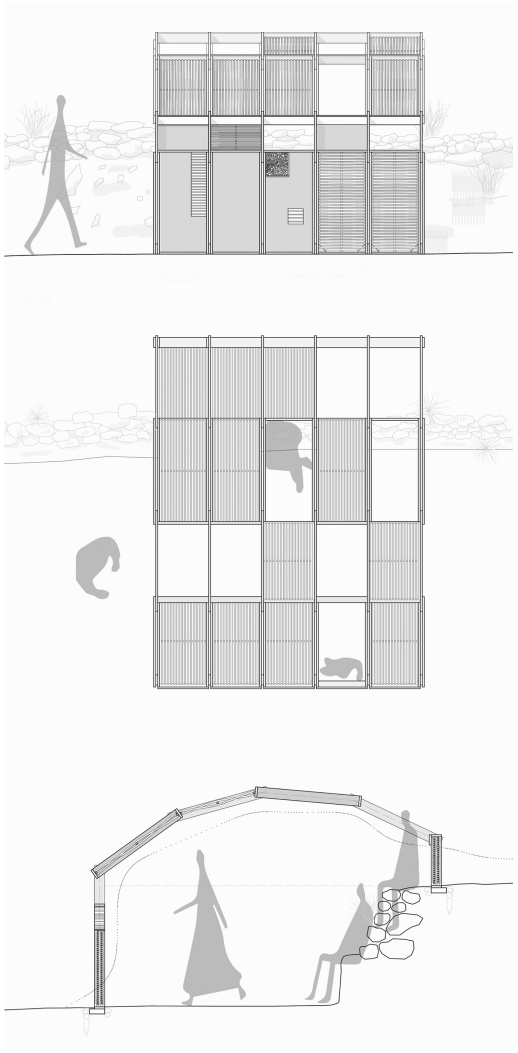


Figure 3. Elevation, plan and section of the pavilion (Lucía Balboa, Antonio J. Jiménez).



Figure 4. Main structure (Lucía Balboa).

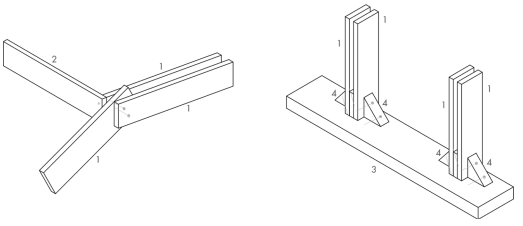


Figure 5. Connections. Left, single-double stick connection. Right, foundation connection (Lucía Balboa, Antonio J. Jiménez).



Figure 6. View of the secondary structure (Lucía Balboa).

3.3.3 *Mud packing*

Mud was made with the mix of one part of clay, another part of sand, 3% of straw, and the addition of water. The final composition of the mixture would depend on the type of materials used to make it, but the proportion of 1:1 and 3% of the above components is one of the most commonly used. The mixture was manually prepared, adding water in order to get a workable mud.

The packaging of the frames with mud should be done twice. First, mud should be placed directly with the hands throughout the secondary structure and cover it. It should be done from the bottom to the top. The mud surface should have rough texture to place the second layer. After the frame is completely covered, the operation is developed again starting by the down part. This would be the final layer of mud; which final surface would be smooth thanks to the use of special tools. (Fig. 7).

On the basis of the design, many combinations are possible to be developed in the different frames in order to understand the process of construction and to be able to compare and combine different materials (Figs. 8-9).



Figure 7. Packing with mud. Left, second layer. Right, view of the first layer (Lucía Balboa).



Figure 8. Main façade (Lucía Balboa).



Figure 9. Detail of the façade (Lucía Balboa).

4 RESULTS

The final result of this project is a space made with early-developed techniques that have been reinvented and designed in the 21st century. The Roly Poly shows its process of construction (Fig. 10).

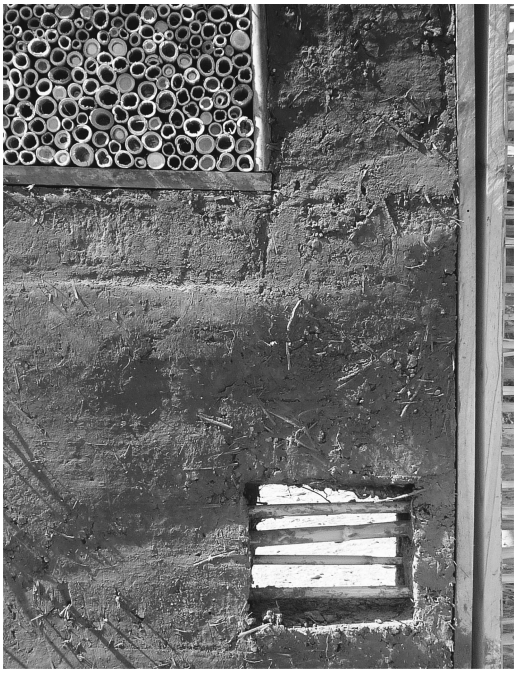


Figure 10. Final texture (Lucía Balboa).

The soil has been an easily workable material. The participants have learnt on how to made their own mixture, work with it and select the desirable texture of the final surface.

Those materials have shown us that the combination of early-developed techniques and contemporary ideas could be a possibility in modern times. This construction system could have been built centuries ago, but with this design, we add contemporary architecture qualities up and obtain an expandable, modifiable or removable project. As a result, a contemporary pavilion based on early-developed construction system is obtained.

5 CONCLUSION

The pavilion tries to demonstrate an innovative approach to sustainable development, focusing on the practice. The process includes participants at all stages of construction, which is key for a further education apart from architecture schools. Furthermore, there is no longer needed to be a specialist to work with earth.

The design exhibits new approaches to what temporary architecture can be. It shows the interrelationship with the landscape through an innovative use of local materials.

The pavilion is 100% recyclable, minimizing its ecological footprint. Using local and natural resources throughout their entire life cycle and managing them is an essential part of the design concept.

Architecture should not be only a matter of money, but a resource to be translated and useful to anyone, making it fast, affordable and available to everyone whom need it.

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A home with roots. Construction process of an adobe contemporanean house

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ABSTRACT: The study of the surroundings of the neighborhood of Valdefierro (Zaragoza) was determinant for the choice of the constructive technique of the structural wall with adobe for the realization of a single family house. In this research, it is compile the analysis and work that was done during the design, planning and construction of the dwelling to define the processes of elaboration and work of the vernacular materials (straw and soil) used. The house design and construction process is propose from a contemporary reading, maintaining the economic feasibility of construction.

1 INTRODUCTION

Valdefierro is a neighborhood in Zaragoza (Aragon, Spain) that was formed in the 1950s upon the arrival of a flood of immigrants from other parts of the country, mainly Extremadura and Andalusia.

Usually, they built single story houses, with poor concrete foundations, load bearing adobe walls and two-tiered Arab tile roofing.

The whole family participated in the manufacture of adobe bricks, using the soil of the plot of land itself. During the last decade of the twentieth century, real estate development economic interests and the permissions from Urban Regulations favor the destruction of the original neighborhood and replacing the single-family homes with four-story multi-family buildings.

In 2012, the architects Pedro Bel Anzué and Ignacio Abad Cayuela were commissioned to design a single-family home on 55 Marte Street in this neighborhood of Zaragoza.

As a starting point for the design of the house, the decision was to use the same materials with which the neighborhood was originally formed (soil, straw, wood, and glass).

The use of these materials produces a building (Fig. 1) that invites a free run for its different interior microclimates. The uses of the spaces have been conceived with a nomadic spirit in mind to inhabit them according to the seasonal climate. The materials reinforce the interpretation of the different areas. Soil tints the cool, sheltered, and static places, as opposed to the glass and wood that accompany the more luminous, sunny, dynamic, and open spaces in which boundaries and subdivisions are diluted.

From all the commonplace materials, soil is the only one that is neither marketed nor standardized as a building material. Its use required an in-depth analysis to respond to current regulations,

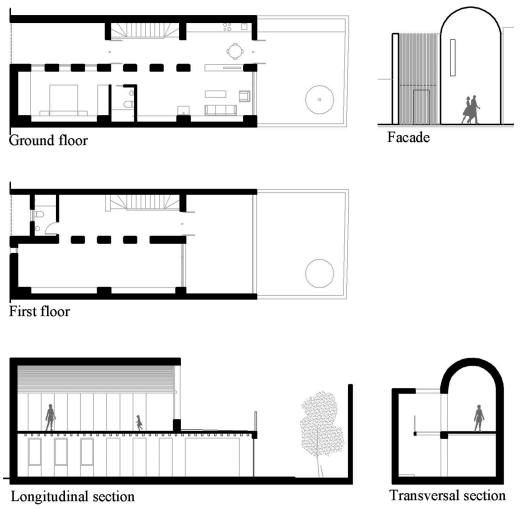


Figure 1. Floors, sections and facade of the home.

to present themselves economically viable and to adapt to the environment.

The aim of this paper is to document the decisions taken during the design, planning, and construction of the house so that they can be used as a reference and source of critical information on the construction system of adobe load-bearing walls for 21st century homes.

2 MATERIALS AND METHODS

2.1 *Materials*

2.1.1 *Soil*

Once identified the quarries present in a radius less than 20 km from the site, the soils were evaluated

initially by simple field trials (Minke 2012), and later in the laboratory by mechanical tests, X-ray diffraction (XRD) (Petschick 2010) and accelerated aging tests.

During the planning of the project, was found (according to specialized literature) an estimate of adobe mean compressive strength of 15 kg/cm^2. In the structural calculations of the ground plans, we decided to establish the minimum compressive resistance of the selected material to 24 kg/cm^2, ensuring compliance of minimum resistance with materials with a safety coefficient of 1.6, a factor typical of materials made manually.

The price of the raw material and the capacity of supply of each quarry to the work will be analyzed.

Selection criteria were technical, economic and related to the conditions of supply.

2.1.2 *Fibers*

For the fabrication of the adobes a great variation of fibers can be used, as many authors have already investigated with depth. (Xue et al. 2011, Parisi et al. 2015, Calatan et al. 2014). It is possible to classify the fibers into groups according to their origin: vegetable, animal, plastic, and metallic. Selection criteria were based on the environmental sustainability, economy, and availability of the resource.

2.1.3 *Additives and stabilizers*

Historically, many additives and stabilizers have been used to improve raw soil properties in outer layers or places with high propensity towards degradation (Quagliarini & Lenci 2010, Serrano et al. 2016). However, in the manufacture of adobes with merely mechanical use, like what occurs in popular architecture (such as the neighboring homes), the soil was used without additives because of economic factors, lack of availability and above all because of its redundancy, since adobe was already considered low quality. Instead of additives, the people simply increased the wall thickness. Again, our selection criteria were based on environmental sustainability, economy, and availability of the resources.

2.2 *Construction phases*

2.2.1 *Place of manufacture*

In Spain there are several companies that manufacture and market adobes, so the decision lie in auto-manufacturing the adobe bricks or acquiring them in the construction materials market.

Auto-manufacture of the adobes, had two possibilities: to make the adobes in the same plot of the construction site, or to rent a lot of greater size for mechanized manufacture and later transport the bricks to the site.

Selection criteria were ecological, economic, time needed and availability of resources.

2.2.2 *Mixing and kneading*

The process of mixing the materials is the most important for greater production yields, since it is the factor that needs the most time and work. Mixing can be done either mechanically or manually, so a detailed study of the factors involved was necessary to guarantee the economic viability of the construction project. In this case, the time and cost was put in proportion to the time dedicated by the laborers and their physical wear and tear. Selection criteria were economic and productivity.

2.2.3 *Molding and mold size*

The houses of the neighborhood and the majority of houses in the Community of Aragon are made with a mold or *adobero* which produces adobe bricks with dimensions 40 × 19 × 8 cm, regionally known as *adobas*.

The use of common materials reinterpreted for the construction of a modern house propelled us to study and optimize the dimensions of the mold connected with the work carried out.

Selection criteria were technical and economic.

2.2.4 *Construction*

Adobe placement in the brickwork required the choice of a bond and a design of the load-bearing walls that took into account the environmental conditions and protection against possible inclement weather. Selection criteria were technical and economic.

3 RESULTS

3.1 *Materials*

3.1.1 *Soil*

Once visited the quarries, taking representative samples of the soils considered by their appearance and quantity of clays the most appropriate for adobe brick elaboration.

From each quarry, four different types of soils were studied independently by simple field tests, selecting two bets soils proceeded from different quarries: one from Juslibol and the other from Garrapinilllos. Continuing improving the deficiencies, making new blends of soil from their respective quarries.

From this process was obtained 12 mixtures to continue testing. According to these basic but representative tests, two very good mixtures of earth, optimal for making adobes were obtained. The better performance of one of the two mixtures was not a deciding factor.

Neither was the economic factor significant choosing between the materials. The price ranged between 9.50 €/MT and 12.00 €/MT, and the difference of 1.50 €/MT on the estimated 80 MT of soil necessary for the finished construction of the house implies a material cost difference of 120€.

In this case, the supply option had the greatest influence in material selection. The material supply options for the Juslibol soil are very varied (big-bag, containers of 5.8 and 12 m^3 or even 30-ton trucks). The Garrapinillos quarry has an infrastructure better suited for large works, as it supplies material with trucks in loads of 20 or 30MT. As it is an urban work and a small plot, was considered more convenient to use the Juslibol quarry, which allowed us to have a container with the soil on the public road so that the soil could be incorporated into the construction piecemeal, keeping the site clearer and cleaner.

The results obtained by previous tests with the optimum mixtures of soils from the quarry of Juslibol were checked performing (Fig. 2) tensile, compression, and flexural-tensile tests in the laboratory, analyzed the presence of XRD expanded clays and evaluated a possible premature de-gradation of adobe by accelerated aging (with ice-thaw cycles).

The adobe bricks obtained a compressive strength average of 33.5 kg/cm^2. XRD tests resulted in a composition of 18% illite and a 2% presence of smectite. Furthermore, the bricks resisted 4 ice-thaw cycles. These data allow to verify a good material for the manufacture of adobes.

3.1.2 *Fibers*

The complete construction needed approximately 10 m^3 of fibers.

Metallic fibers, plastic fibers (polyethylene) or animal fibers (sheep's wool) have recently been incorporated into construction. However, the workability loss during mixture preparation, and the difficulty in the correct separation of materials during recycling tests, was decided not to use this type of fibers.

The vegetal fibers available in the environment were wheat straw, oats, and rye. The rye fibers were discarded because of their hardness and difficulty in cutting or molding in the wood. The oat was clearly the weakest fibers to tensile stresses.

The wheat fibers allowed good workability, adapting to the shape of the mold with simplicity. Its tensile strength was also remarkable and was the most available product. It is possible find several farmers with models of old harvesting machinery and who continued packing with old format (100 × 40 × 35 cm) obtaining bales of approximately 30 kg, easily manageable in the work. The price was 2 €/bale.

3.1.3 *Additives and stabilizers*

Once discarded the more expensive additives as well as those difficult to obtain or store in the work according to hygienic-sanitary regulations, including blood, egg, manure and linseed or olive oil. Studies were focused with ashes and commercial hydrated lime (CL-90-Q according to the Spanish Standard UNE-EN 459-1 (AENOR 2011)).

Ashes must be of completely vegetable origin for health reasons, and sifted to avoid pieces of intact wood. Ashes with these specifications were scarce, due to lack of commercial use. The addition of ash improve the compactness and strength of a mixture, was decided not to use this additive had strength in laboratory tests.

From an economic point of view, the cost of aerial lime supplied on site would have been 120 €, an acceptable increase in budget.

Different proportions of lime (5%, 10% and 15%) were tested and accelerated the curing process in an accelerated curing chamber (Fig. 3) checking the state of carbonation inside the mixture with the use of phenophthalein.

Flexural strength, traction, and compression tests were performed and observed that the resistance with 5% lime was lower and the resistance with 10% was very similar to the average resistance obtained without additive. The compressive strength obtained with the 15% addition of lime was only 17% higher, finally was decided not to use any additive.

3.2 *Construction phases*

3.2.1 *Adobe manufacture*

Two companies offered adobe bricks, one located in Amayuelas (Palencia) and another in Guadix (Granada) with an average price of 0.85 €/unit, plus the cost of transport. The weight to be transported required approximately 5 truck trips, increasing the costs approximately 0.25 €/unit, with a final cost of 1.10 €/unit. Approximately 95 kg of CO_2 per journey was produced. For economic and environmental reasons, was studied the feasibility of making the adobes in Zaragoza.

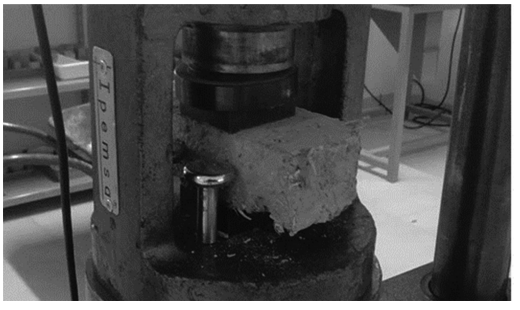


Figure 2. Test of soil from the quarry of Juslibol.



Figure 3. Carbonation test with phenolphthalein.

The production of the adobes in the same plot was complex because of the small size of the plot. A plot with a free area greater than 300 m^2 would allow partial mechanization, generating larger productions of adobes per day, with sufficient space available for drying.

In our case, daily adobe productions were programmed to optimize the 141,75 m^2 available in the plot to the maximum. According to the calculated work-performance rates, a person could produce 200 complete units per working day organicing the work area into 4 parts: a mixing and kneading area (8 m^2), a molding area of fresh state of adobe (35 m^2), a drying area with adobe of the previous 2 days (60 m^2), and an area of piled dry adobes (30 m^2).

3.2.2 *Mixing and kneading*

Total mechanization of the process would be of interest to a large production of continuous adobe and a large work surface. In our case, the adobes were produced beforehand in a period of 5 months with a single worker, with a total cost of 2,000 €/month.

In the rental market, was not found a machine suitable for the mixing of the adobe. From the production point of view, a mixer could increase the daily production of adobes, but the limitations in the dimensions of the plot of 141.75 m^2 alone allowed a maximum production of 200 adobes per day, a quantity easily produced through a fully manual process in an 8-hour working day by one person. The use of mixing machines to accelerate the process would not lead to an improvement in production times. Thus, because investment in mixing and kneading machinery was neither economically advantageous nor an improvement on the production times of the adobes, was decided to make the mixtures manually.

Tests with a large capacity concrete mixer allowed us to discard the possibility of use as a kneader. The work put into loading and cleaning the sticks adhering to the concrete mixer was greater than manually kneading the mixture with a hoe. The concrete mixer also had an added disadvantage of the high level of sound produced.

The methodology for the production of the adobe mass consisted in mixing the soil and the straw by sequentially pouring carts of soil in the mixing bowl and intercalating them with the corresponding proportion of straw, obtaining a sandwich of pre-mixed layers (Fig. 4). After six full carts of soil, the mixture was kneaded. Later, with a shovel, the worker turned the mixture until it was homogeneous. Regardless of the volume to be mixed, four turns were needed.

Water was poured, according to the mixture needed to prepare the mass for the next procedure.

According to the experience of local men who had built in the traditional style with adobe (Pepe Rodrigo from Burbáguena and Jesus Juan Lacambra from San Mateo de Gállego) the mixture was "amerando" (soaking) at least two hours or the day before using.



Figure 4. Mixing the soil and the straw for adobe.

Soaking dissolved lumps of clay and improved the smoothness and homogeneity of the mixture, which resulted in an improvement of quality during the demolding and an overall improvement in the production.

This procedure generate adobes for a total price of 0.65 €/unit, including raw, materials and handwork.

3.2.3 *Molding, the size of the mold*

The small dimensions of the plot forced to reduce the thickness of the load walls to the minimum possible within structural security. The values that resulted from the structural calculation determined a minimum load wall thickness of 22 cm, was decided to make a 24 cm adobe brick in order to be able to make the wall with one foot of thickness.

As in all bricks, the relationship between the noose and the blight determines this measure. The size of the adobe used was $24 \times 11.5 \times 8$ cm, which, in addition to being useful for the economy of the space occupied by the wall, was also useful in optimizing the tons of soil displaced by the workers during the construction. The mold had holes of $25 \times 12.1 \times 8$ cm. The difference in measurement between the hollow portion of the mold and the resulting piece is due to two reasons: the swelling of the wood that makes up the mold during the work and the retraction that the adobe experiences during drying.

3.2.4 *Construction*

The bond selection was focused on constructive simplicity and maximum separation between vertical joints. Were found both aspects in the Flemish bond (Fig. 5) that was used.

On the ground floor was obtained very competitive yields per square meter 0.6 hours of first



Figure 5. Flemish bond made with adobe.

officer and 0.3 hours of assistant. In first floor, the low machinery present in the work and the weight of the material to be transported decreased yields to 0.9 hours of first officer and 0.5 hours of assistant.

The material used between adobe bricks was an aerated lime mortar with a 1:4 ratio, allowing flexibility in case of wall deformations. During the execution of the walls, it was necessary to stop construction on numerous occasions due to rain and low temperatures typical of Zaragoza during the winter months. The warmest months had been dedicated to the manufacture of adobes. A great effort was made to protect the walls with awnings to prevent frost damaged.

4 DISCUSSION

4.1 *Supervision of the process by a specialist*

The current technical safety requirements needed during the design, planning and execution of the work demonstrate that carrying out a construction of raw earth, particularly adobe, in Spain requires a person specialized in the field and capable of coordinating the process to ensure its successful completion.

4.2 *Required quality controls*

Previous tests for the soil analysis were representative for choosing and improving the types of soil to be used and their quantities. Laboratory tests served to corroborate the results obtained previously.

Granulometric analysis was not used as a selection parameter. Correct granulometry was the consequence of improving the organoleptic properties.

During the construction of the adobe bricks, it is necessary to maintain a quality control of the soil received from the quarry to ensure homogeneity and correspondence with the soil analyzed at the beginning and to make the necessary corrections in the case of significant differences.

4.3 *Improvement of properties with additives*

The low cost of the soil supplied on site, and the high availability of quarries allowed us to be selective with the raw material, avoiding the use of additives.

The use of an additive incorporated into the mixture of the adobe supposes a production cost of material and manpower with a result that rarely justifies the means. The stabilization of adobes with lime should not be standardized as an improvement, but should be analyzed to understand its interactions with the predominant clay minerals.

4.4 *Economic viability*

Soil from excavating the foundations added into the mixture does not save money. Its preparation (extraction and crushing) is more expensive than acquiring the same amount of soil from a quarry.

The mixing process requires further study. Faced with a high demand for adobe and a large working surface, it is advisable to automate this phase. In a reduced production area (less than 300 m^2) the profitability of automation is doubtful, due to the necessity of daily productions of small quantities to be dried.

In our case, the final price for a finished adobe was 0.65 €/unit. A prefabricated, perforated brick made of cement called *gero* with the same size ($24 \times 11, 5 \times 7$ cm) supplied on site costs 0.43 €/unit, which in a housing of 20,000 adobes the impact on the final budget is 4400 € more expensive to build with adobes than with blocks of precast concrete.

The final price difference of adobe with the estimation of the use of *thermo-clay* (a commonly used brick of $30 \times 24 \times 19$ cm) was 6300 €.

These are acceptable price differences within housing budgets of 150,000 €, as they only represent an increase of 4%. In our case, this increase was expected to be absorbed with the placement of a pavement with more basic quality.

4.5 *Hardness of physical work*

Construction an adobe house involved the following movements: emptying the truck or container (1), mixing the adobe + straw + water (6), the molding (1), turning it in a sealed way (3), to the stack (1) at the foot of the wall (1), positioning it on the wall (1).

This means carrying out 14 displacements with 80 MT, equivalent to displacing 1,120 MT. (approximately 6 blue whales), a physical work that was exhausting for workers accustomed to the conventional work.

4.6 *Duration of the work*

The completion of the almost 20,000 adobes used in the construction of the single-family dwelling



Figure 6. Free courses for interested people.



Figure 7. Adobe contemporanean house finished in Zaragoza.

required 5 months of work, making adobes prior to the beginning of the project, dilating the execution process. To take advantage of the working months for the drying of the April-October adobes and avoid accumulating delays.

4.7 *Cleanliness of the work*

During the construction of adobe and the construction of adobe walls there was no residue or debris. All the remains of broken parts, broken pieces were re-kneaded to form new adobes, a very remarkable difference from the rest of baked clay materials such as bricks which during construction always produce several containers worth of waste.

4.8 *Training and dissemination*

Throughout the construction, several "conventional" masons were invited to ask and learn about the alternative the construction system. As a result of these events, were conducted a series of free courses for interested people, construction professionals, and technical professionals. More than 80 people went through these courses.

5 CONCLUSIONS

An adobe construction implies greater effort in planning, technical control, and difficulties carried out by a conventional construction made of concrete or brick. To meet work deadlines, work rhythms must be planned to coordinate with the weather. The selection of raw materials, soil ratio mixtures, and management of the work call for a person specialized in construction systems with raw soil.

The use of adobe must be re-examined according to the particular conditions of each construction, the available raw materials and environmental conditions to meet the current demand. The economic viability of adobe systems depends on good planning. Ground floors in the houses are normally smaller in height.

Critically analyzing these aspects, it is possible to build a modern home (Fig. 7) with adobes while still meeting the expectations of quality and costs of the twenty-first century.

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A minus carbon eco-cycle earthen refugee shelter: A feasibility study

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ABSTRACT: Forced migration due to wars and political conflicts create an urgent need for temporary shelters in hosting countries. Constructing new housing projects is not only economically burdensome but also requires a great deal of time and, most important, represents an environmental burden when the shelter reaches its end of life. This study discusses a design proposal for a 37 m^2 eco-cycle earthen refugee shelter that could be built with the help of seven people in 11 working days. The study has adopted an experimental, participatory and living lab methodology for a physical prototype as a proof of concept. The key idea of this eco-cycle shelter is to reach net minus carbon emissions during material extraction, building construction, operation and after end of life. As this project is still ongoing, this paper will confine itself to discussing the project's main idea for reducing carbon emission and will focus on the feasibility of an earthen wall structure skeleton as a minus carbon agent. The prototype is designed for the cold climate of Sweden but the methodology can be applied in different climates. Beneficiaries of this project need not be confined to refugees. It can be extended to house the majority of the world's urban poor.

1 INTRODUCTION

Conflict and war have become some of the leading reasons why people are forced to leave their homes nowadays, alongside natural disasters (Aquilino 2011). The public and private sectors in hosting countries are struggling to offer humanitarian emergency relief shelter and services (Ros-García 2013). Emergency tents are the most common form of temporary shelter, yet these are generally expensive to make, do not offer adequate indoor thermal comfort and deteriorate quickly (Dabaieh & Borham 2015). Their inefficiency is compounded by the additional environmental burdens that come from demolishing such temporary shelters as the majority of the common materials used are not recyclable (Obyn et al. 2015). Sweden experienced such a rapid influx of refugees during the years 2015 and 2016 that it became difficult to offer them immediate accommodation. It is apparent that innovative, cost efficient and time efficient solutions are needed to accommodate asylum seekers in temporary housing, and that this should have minimal impact on the environment after the temporary situation is over.

Reducing carbon emission from buildings during a complete life cycle from cradle to cradle is always a big challenge. It has been found that approximate 25% of global raw material extractions go into buildings (Unep 2009). The residential building sector in Sweden accounts for 40% of the country's total energy use (Swedish Energy Agency, 2016). Earlier, drawing their findings from working on single-unit dwellings case studies in Sweden, Adalberth (1997, n.d.) have shown that 85% of the total CO_2 emissions occurred during the operational building phase, while the energy used in manufacturing the construction building materials, then in the building construction and demolition phases accounted for the rest of the 15%. That is confirmed by a more recent study by Peng (2016) that showed that a building's construction stages accounted for 12.6% of the total carbon emission and approximately 2% during the demolition stage, while the rest of the 85.4% was produced during operation time. A study on low energy buildings by Blengini and Di Carlo (2010) showed that the major impacts and CO_2 emissions come during the building main structure manufacturing and during the maintenance phases. Equipment, construction and transportation had only a minor impact. In the same study, the authors highlighted the important role of the building material being recyclable (Blengini & Di Carlo 2010). Even if the percentage of CO_2 emissions during building construction is minimal compared to the emissions during the building operation, according to Peng (2016) this impact should not be dismissed because the average carbon emissions of non-operational stages per working area per annum are still far greater than those during the use phase. Cabeza et al. (2013) have discussed the potential to reduce carbon emissions by using building materials and building techniques with low embodied carbon during manufacturing. It has also been proved that a proper choice of materials affects the

primary energy use (Gustavsson & Joelsson 2010). As temporary shelters have a short life cycle, normally from 2 to 15 years, it definitely worthwhile reducing the embodied carbon and energy during the extraction, production, transportation and construction phases.

This study discusses an ongoing experimental living lab test to design and construct a 37 m^2 minus carbon temporary earth shelter in Sweden. The mission is to build a low cost and time efficient shelter in 7 working days with the help of 11 persons, with the intention of a having minimal impact on the environment after the building's end of life. The building timescale was calculated based on the needs of three family members (two adults and one child), the workers' productivity per hour and outdoor weather limitations. Several innovative solutions were adopted for this project in order to reach a minus carbon shelter for the building's intended full life cycle. This shelter house was designed through the application of the eco-cycle home concept, and equipped with the standard necessary everyday features. The building's main skeleton is made from lightweight materials, mainly in the form of clay reinforced with the plant based fibers of straw and reeds, using lime plaster for water resistance. The natural materials are available in the local environment where the shelter will be built, which ensures minimal embodied carbon during material extraction and transportation. The design of the building is intended to eliminate the energy demands for heating and cooling to act beyond the current passive buildings standards. The house is energy self-sufficient and is equipped with renewable energy sources. It is calculated to produce more energy than it consumes and to transport the excess back to the national energy grid for later use, should there be a deficiency in energy production.

The idea behind the design of the shelter is also based on the 5 Rs concept (Refuse, Reduce, Reuse, Recycle and Rot). Mainly the idea is to Refuse to use any toxic industrial material for building construction; to Reduce the use of all energy and carbon intensive materials or construction techniques; to Reuse all waste outcomes from the shelter during its time of operation and equally to Reuse the construction waste after the shelter's end of life so as to close the loop and achieve a full eco-cycle shelter over its lifetime; to Recycle the waste products that cannot be reused; and finally, at the end of the building's life cycle, it should decompose back to nature as Rot, with minimal if not zero impact on the environment, apart from what can be reused as building material.

The different low tech wall compositions have been selected to achieve minimal carbon emission during extraction, manufacturing and construction while still taking into account the availability of the material, its feasibility for construction and its cost efficiency. The thermal performance of the proposed walls is also being taken into account as that affects the building's total energy consumption for heating and cooling loads during the building's operation. The main materials proposed for the building's skeleton, which are all capable of contributing to the minus carbon effect after the building's end of life are clay, lime and three plant based materials: straw, reeds and wood. The project idea also tried to work on previous problems in exiting shelters specially when it comes to maintenance or the need for replacements and repairs. In addition, it integrated lessons from vernacular and local architecture building methods in Scania region in Sweden. As this project still ongoing, this paper will be just focusing on the design stage of the building's main skeleton wall structure and the calculations to reach a minus carbon outcome.

2 METHODOLOGY

2.1 *Investigative survey analysis*

The process started in this study by investigative analysis for possible building materials and techniques for the shelter prototype building skeleton. First the investigative study was made in the Scania region in Sweden to search for traditional vernacular building techniques and natural building materials available for possible current use. This phase incorporated both literature search and site visits for museums and existing vernacular sites. The main aim was to assess what features could be learned from vernacular techniques while trying to improve such techniques for more resilient and climatic adaptable solutions for a temporary refugee shelter.

2.2 *Wall cross section design alternatives*

Based on the investigative study, several wall composition alternatives were designed applying the eco-effectiveness concept discussed by Braungart et al. (2007). That would be achieved by designing a shelter skeleton with less waste and toxicity with possible recyclability or reuse and at the same time suiting social and economic constraints. Straw bale with reeds and a coating layer from clay plastering and lime render were the main elements in the wall skeleton design. The layers were alternated in different orders and with different thickness to reach the optimal thermal performance, U value and the least probabilities for moisture content and summer heat protection. Passive house premium standard was the target to reach. Five different solutions

were designed using the U-Wert web tool. Calculations were made for U-values for the wall structure proposals and were compared to each other to choose the best applicable and feasible ones.

2.3 *Carbon life cycle calculation during construction*

The total amount of CO_2 emissions during the building stage of the refugee shelter, including the emissions from the material production, transportation and construction, were calculated following the same method of calculation as Peng (2016). However, the equation he used in his study was developed to suit this project case for calculating the total carbon emissions.

$$C_{total} = C_e + C_p + C_t + C_c - C_s \quad (1)$$

where C_{total} is the total CO_2 emissions generated during building process, C_e is the total CO_2 emissions from building material extraction, C_p from material production, C_t from material transportation, and C_c from construction; C_s is the total carbon sequestration by the plant based material during growing process. All the units are in kg and the amount of material used is calculated for the whole building. All figures are obtained from field investigations for this specific case. This phase will be followed by calculations for the financial and energy payback period for the chosen alternative. Then a proof of concept test cell for a wall sample will be constructed in an urban living lab. Material lab tests for compression, tension strength and water resistivity will be performed. This part will not be discussed in this paper.

3 RESULTS

3.1 *Literature study and site survey outcome*

The investigative study revealed that several vernacular construction techniques were applied in the past in Scania using natural local materials such as mud bricks, straw, reeds, stone and wood. Earth techniques such as adobe, pisé and cast lime mortar were the main methods in use between the 1750s and the 1950s in Sweden (Palmgren 2003). Several lessons were derived from the traditional vernacular systems that exist in Scania region and were confirmed by looking at the availability of local natural resources (clay, lime, reeds and straw). Different types of clay are abundant and of very good quality suitable for use as abode, rammed earth and cast earth. The same for reeds and straw, which can be used for both roof and wall construction. Reed is an available material in the southern part of Sweden, growing around the region's lakes and rivers however, it is seldom used. On the other hand, straw is more often used in straw bale structures though on a limited scale. Lime is mainly used in final render; mixed with plaster as a binding material, in construction techniques such as cast lime-mortar buildings, or it is capable of being moulded into slag lime buildings. Lime is still used in Scania in conservation and restoration processes for both old buildings and on a limited scale as a plaster in contemporary ones. One factory was found in Scania that still produces good quality of lime in the traditional way.

3.2 *Design alternatives and best design outcome*

For the parametric alternatives for the wall composition, the five different alternatives are shown in Table (1). Different thicknesses for the straw, reeds, clay and lime plastering layers were tested.

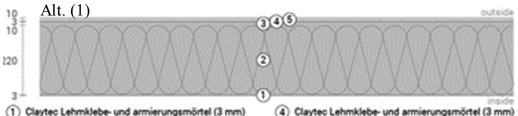
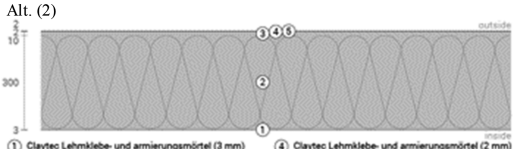
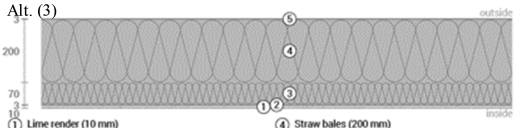
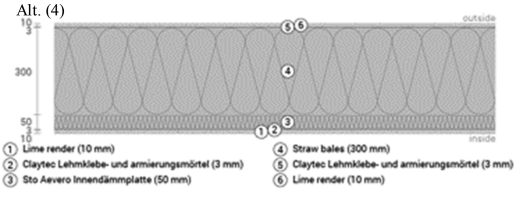
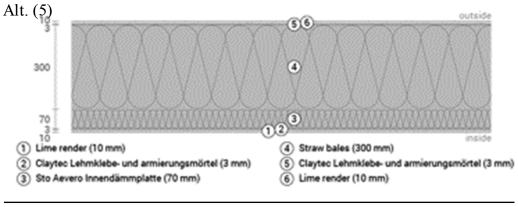


Figure 1. Example of an earth building from the early 18th century in Sweden (Karin Blent. Courtesy Upplands Museum).



Figure 2. Vernacular buildings constructed from Adobe and plastered with lime in Scania, Sweden.

Table 1. The five-proposed wall cross sections using the U-Wert web tool showing the layers, wall thickness and total U value of each.

Alt. (1)  ① Claytec Lehmklebe- und armierungsmörtel (3 mm) ② Straw bales (220 mm) ③ Sto Aevero Innendämmplatte (10 mm) ④ Claytec Lehmklebe- und armierungsmörtel (3 mm) ⑤ Lime render (10 mm)
U value = 0,200 W/m^{2}K / Thickness = 24.6 cm
Alt. (2)  ① Claytec Lehmklebe- und armierungsmörtel (3 mm) ② Straw bales (300 mm) ③ Sto Aevero Innendämmplatte (10 mm) ④ Claytec Lehmklebe- und armierungsmörtel (2 mm) ⑤ Lime render (2 mm)
U value = 0,153 W/m^{2}K / Thickness = 31.7 cm
Alt. (3)  ① Lime render (10 mm) ② Claytec Lehmklebe- und armierungsmörtel (3 mm) ③ Sto Aevero Innendämmplatte (70 mm) ④ Straw bales (200 mm) ⑤ Claytec Lehmklebe- und armierungsmörtel (3 mm)
U value = 0,123 W/m^{2}K / Thickness = 28.6 cm
Alt. (4)  ① Lime render (10 mm) ② Claytec Lehmklebe- und armierungsmörtel (3 mm) ③ Sto Aevero Innendämmplatte (50 mm) ④ Straw bales (300 mm) ⑤ Claytec Lehmklebe- und armierungsmörtel (3 mm) ⑥ Lime render (10 mm)
U value = 0,112 W/m^{2}K / Thickness = 37.6 cm
Alt. (5)  ① Lime render (10 mm) ② Claytec Lehmklebe- und armierungsmörtel (3 mm) ③ Sto Aevero Innendämmplatte (70 mm) ④ Straw bales (300 mm) ⑤ Claytec Lehmklebe- und armierungsmörtel (3 mm) ⑥ Lime render (10 mm)
U value = 0,099 W/m^{2}K / Thickness = 39.6 cm

The worst alternative with highest U value of 0.200 W/m^{2}K and the highest moisture content were the ones when the straw layer had a minimum thickness of 220 mm. After increasing the straw bale thickness to 300 mm and reducing the lime render from 10 mm to 2 mm the U value was improved to 0.153 W/m^{2}K. When the reed layer was increased to a thickness of 70 mm, instead of 10 mm in the alternatives one and two, while the straw bale was again reduced to 220 mm, the U value was cut to 0.123 W/m^{2}K.

Adding another internal clay plastering layer of 3 mm and reducing the reed thickness to 50 mm improved the U value to 0.112 W/m^{2}K. The best U value obtained was 0.099 W/m^{2}K, when the reed layer was 70 mm. The first alternative was the only alternative that showed a problem with moisture content as it produced condensation of 1,14 kg/m^2, but the other four alternatives showed no possibility for condensation occurring if the indoor temperature was a minimum 19.5°C and the outdoor a minimum 5°C, leading to a relative humidity of 52% to 51%. The time lag ranged from 12 hours in the first alternative to 20 hours in alternative five.

3.3 *Life cycle carbon emission calculation and minus carbon potential*

The total carbon emission of the wall structure calculated for the different building materials during extraction, production, transportation and manufacturing then subtracted from carbon sequestration using eq1 (1). The total emissions calculated for transportation of the clay, straw and reeds are based on calculating the actual emission using vehicles from the neighbouring farms to the proposed site for this project within a 2-km proximity. As for lime the figures calculated for extraction, manufacturing and production were obtained from the lime factory and the CO_2 emissions are calculated for the transportation from the factory to the site over a distance of 49 km. The CO_2 emissions of the plant based material were calculated during their growth as well for their carbon reduction potential. The calculations for production were made for the cutting and piling of reeds and straw. The total results of carbon emissions is minus 82.5 kg CO_2/m^2 of the shelter prototype.

4 DISCUSSION

This study has targeted carbon emission reduction possibilities during the construction of refugee shelters. This was achieved by using natural material with low embodied energy and carbon throughout the whole building process with a minus carbon potential as a net outcome. Normally temporary crisis shelters are constructed to last for short periods; the time varies from 2 to 15 years, after which they are demolished, leaving environmental burdens from construction wastes. These features occur in addition to the relatively poor

thermal performance and quality of construction. To contrast with this approach, in this project local indigenous natural materials were favoured to create the pilot building for the same end use as this offers low impact environmental qualities and will reduce the construction waste at the building's end of life. Additional advantages are that the indoor air quality is good because the walls are from a natural non-hazardous material; similarly with thermal properties that made the house more energy efficient in terms of heating and cooling demands. One of the benefits is that the techniques are easy to learn, which opens the possibility of involving the refugees in the construction process, a development which would potentially reduce labour costs and energy for labour transportation.

The proposed main wall skeleton in this shelter consists of mixed composite layers of straw, reeds, clay and lime, a combination which has shown a good performance reaching a U value of 0.99 W/m^2K, which complies with passive house standards. Both straw and reeds also serve as thermal and sound insulation materials in addition to acting as a main structure element. Reeds are an especially useful material as they allow air flow, which reduces moisture content (Dabaieh & Sakr 2015). Both are breathable materials so they enhance indoor air quality and reduce the possibility for moisture or moulds to occur. Reeds when bundled with steel mesh wires enhance the stability of the walls and act as structural support, shown in Figure (3). When it comes to carbon reduction, straw and reeds, being plant based materials, absorb CO_2 during their growth, a process that continues when they are mixed with wet clay as the resultant material decomposes partially into cellulose which, in turn, acts as a binding agent.

Lime takes in CO_2 throughout the construction process and building operation where there



Figure 3. A traditional machine for making reed mats with steel wire mesh in Scania, Sweden.

in an increase in indoor air humidity. It will even increase the carbon sequestration potential if calculated over the operation time along the lifetime of the temporary shelter. As a traditional material, lime has proved to be soft and succulent to apply. It is even more durable when mixed with sand. As for maintenance, a lime-plastered wall will need to be maintained twice over a life span of 15 years, which is done by plastering the external walls with lime wash to increase its resistance to rain and snow.

This study has contributed in showing how choosing the proper material can reduce the embodied carbon during building construction and can reach a minus carbon outcome. There is a potential in using the suggested wall constructed from natural materials as that will reduce the energy and carbon emissions when dealing with construction waste after the shelter's end of life. Early studies have shown that reducing an operation's energy increases the energy for material production (Keoleian et al. 2001, Thormark 2002); however, the argument in this study is that reducing the material energy production with enhanced thermal properties will consequently reduce the operating energy. However according to Peng (2016) approximately 85.4% of total carbon emissions are generated during a building's operation. Thus, this study is intended to be followed by another intensive study in carbon reduction strategies during building operation. As the preliminary results of this study have shown, there is a potential for energy consumption reduction especially for heating and cooling (which is the most energy consuming element during a building's operation) because of the U value of the proposed wall. A further potential yet exists for reduction of the total carbon emissions during the operating phase of this shelter prototype. Moreover, using resource efficient materials and low tech solutions offers adequate adaptation to the local conditions and when acute situations arise to offer low cost and quick shelters with the addition of dignified habitability. The results of this study provide an insight into the effect of using renewable materials like straw and reeds together with clay and lime on the total CO_2 emissions and the relevance of carbon storage potential to reach a minus carbon outcome. One of the indirect benefits of this project is also to revitalize some of the traditional building technologies in Scania, that are on the verge of disappearing as many other places in the world.

5 CONCLUSION

Building wall design can affect the environmental impacts of the various life stages of building.

The proposed wall construction solutions in this study are a first step for the project shelter design. They have shown how vernacular material and traditional techniques when developed have the potential for a better-quality emergency shelter. The choice of renewable energy-based raw materials and reduction of fossil fuel use in material production and construction can contribute significantly in reducing primary energy and CO_2 emissions through a building's life cycle. The project has also a high potential for reversibility, reuse and/or recycling with minimal impact on the environment. There is a great deal more to be done for the complete design of the project to be followed in the coming research steps.

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Net Zero Energy straw bale & rammed earth design; cold climate case study

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ABSTRACT: Canadian housing has several unique challenges which are presented by predominantly cold climates, century old patterns of development, conventional material preferences, and finally by comparatively inexpensive energy costs for building operations, as compared to European nations. Current industry standards and codes do not address full lifecycle or effect of materials on carbon footprint and energy consumption. Green building certification systems such as Net Zero Energy (NZE) may address operational energy, but provide a basis only for energy reduction and generation in the built environment. This paper examines the merits and valuation of straw bale construction as a feasible construction technique, specifically when striving to meet a NZE standard. The basis of determining feasibility is focused on a home in central Alberta and premised on the UN World Conference's concept of the three pillars of sustainability: environment, social and economic impacts (people, planet, and profit).

1 INTRODUCTION

1.1 *Context*

The Canadian climate often presents unique challenges to meeting ambitious sustainability goals, such as Net Zero Energy (NZE). Canadian households use an average of 11,000 KWh of electricity per year (2010)… comparatively France uses (5760 KWh and Germany 3505 KWh. (Government of Canada 2016). It is noteworthy that much of Canada's population resides near the 50th parallel. The specific focus of this paper is the community of White Sands, Alberta, which is located precisely at 52.47° N, akin to Berlin (52.52° N) or Amsterdam (52.37° N).

In 2011, the Canadian census (Government of Canada 2011) revealed that of 13,320,610 households, 7,329,150 were single family, detached homes (over 55%). It is clear that not only climactic conditions, but also development patterns and construction preferences, contribute to increased household energy consumption in Canada.

1.2 *Background*

Historically, homes in Alberta have been constructed using readily available resources in the province. As a result, the prairies were settled by homesteaders who built with earth, sod, or logs (dependent on socioeconomic status and region). As industry evolved, dimensional lumber became the method of choice and has remained largely unchanged since.

Despite minimal changes to structural concepts, there have been substantial changes to materials used and insulation techniques leading up to 2017. Advancements in insulation and air tightness of homes have led to new challenges associated with the building envelope, and excessive or trapped moisture has been established as a major threat to the health and durability of a home. Provincial codes and regulations have addressed some of these issues but lack in addressing the full impact of buildings on both greenhouse gas emissions (GHG) and carbon footprints.

2 MEASURABLE IMPACT

The 2005 United Nations (UN) World Summit Outcome (section 48) addresses what has become known as the three Pillars of sustainability (United Nations 2005) recognizing interdependence of social equity, the environment and the economy in order to achieve measurable success in sustainable endeavours (Fig. 1). The strategy provides a useful evaluation tool and decision making criteria for sustainably driven projects (construction or otherwise). More than ten years after the UN Outcome report was released, it is clear that no certification system has had significant market impact or achieved the industry transformation required to meet emission targets. In 2011, Canada formally withdrew from the Kyoto Protocol which aimed to reduce emissions to 6% less than levels in 1990 (UNFCCC 2008).

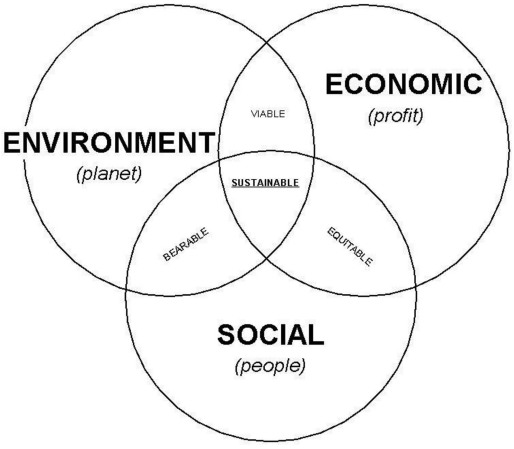


Figure 1. Venn diagram representing the three pillars of sustainability (Johann Dréo 2006).

Weighing a Net-Zero Energy (NZE) standard using the three pillars criteria, one will note that NZE addresses only the environment in its approach; produce at least as much energy as is consumed on a per annum basis.

Homeowners, L. Olson and W. Wright, elected to construct their NZE retirement home in White Sands, Alberta, comprised primarily of straw bale and rammed earth thereby addressing the social and economic impacts of their project voluntarily. Partnering with the Southern Alberta Institute of Technology's Green Building Technology (GBT) research team, the family aimed to achieve harmony between embodied and operational energy, aesthetics, occupant health and happiness, and budget. Known fondly as *Pelican Perch,* the home forms the basis for this case study, which aims to create a foundation of reasoning for use of straw bale construction in detached single family, NZE construction.

3 ENVIRONMENT

3.1 *Embodied energy*

Unfortunately, codes and standards have not kept pace with industry research and knowledge regarding energy efficient building principles and best practices. It was not until October, 2016 that Alberta adopted the National Energy Code for Buildings (NECB) which addresses minimum effective (not nominal) RSI (thermal resistance) value of assemblies, continuous insulation requirements, air tightness and mechanical efficiency (etc.). The changes have brought an increased awareness to building energy performance; however selection of materials used to achieve code compliance remains up to consumers and builders. The focus of the NECB is on operational energy use reduction, but overlooks the critical aspect of embodied energy in new construction and retrofits of existing housing stock.

An analysis of embodied energy in conventional building materials reveals that modern homes have as much, if not more environmental impact prior to occupancy than throughout their operational life, especially when constructing to a NZE standard. Many of the conventional materials used pose concerns for occupant health (see Social section) and end of life options for waste products.

The primary wall system employed in this project includes a load bearing, insulated exterior post-and-beam frame with an internal straw bale non-bearing wall (Fig. 2). The decision criteria weighed thermal performance, embodied energy and local content, design flexibility, and ease of permitting. The selection of this wall system did not negate the need entirely for conventional materials; however through salvaged material re-use and considerate design, their use was minimized as much as possible.

Embodied energy in conventional housing has increased due to new materials/technology, globalization (accessibility to foreign markets), and modernized, fossil fuel intensive industrial practices for material extraction, processing and transportation; after which the construction process consumes additional energy for machinery, power tools and transportation of people, goods and waste. A more accurate picture of energy use in the built envi-

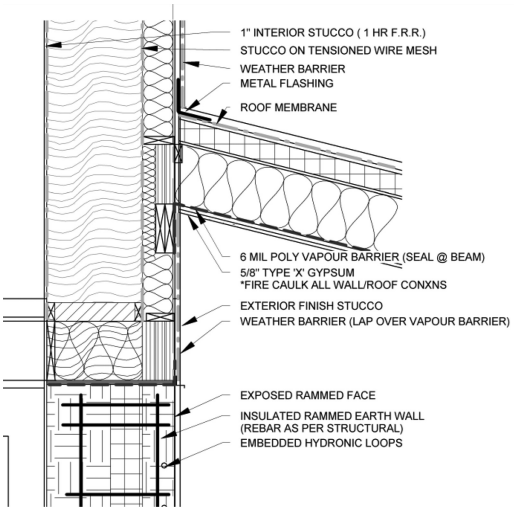


Figure 2. Pelican Perch straw bale wall and rammed earth connection detail. (SAIT GBT 2015). Note that fire rating is minimum value only and will be exceeded by assembly.

Table 1. Relation between wall types, embodied energy and embodied carbon.

Wall type*	Embodied energy MJ/m^2	Embodied carbon kg CO^2/m^2
Masonry	1429.69	105.32
Straw 1**	202.61	15.99
Straw 2***	74.84	3.98

* Inclusive of all assembly components, including finishing
**Non-load bearing straw bale assembly w/ softwood frame
***Load bearing straw bale assembly

Table 2. Relation between wall types, embodied energy and embodied carbon.

Wall type*	Embodied energy MJ/m^2	Embodied carbon kg CO^2/m^2
Compound straw*	283.25	21.03

* Adapted from Table 1., refer to Figure 2 for assembly detail.

ronment is a lifecycle analysis which analyzes all aspects of energy consumption pre, during and post occupancy.

Embodied energy is inherently varied by location of construction, however a study produced by the Kaunas University of Technology (Milutienė 2010) evaluates one square metre of three complete, finished assemblies: load bearing straw bale, non-load bearing straw bale and masonry construction in their complete assemblies (Table 1).

The results of the study have been extrapolated for the purposes of this paper to reflect the Pelican Perch compound wall assembly using mineral wool of 4.8 kg/m2 density, and the adjusted values are represented in Table 2.

A study published by Canadian Architect emphasizes the importance of recurring embodied energy, or the energy which is required in the replacement and maintenance of components over the building lifecycle. Recurring energy provides a measure of building durability, by recognizing that materials which may have lower initial embodied energy may need more frequent replacement making them an inherently less sustainable choice over a building lifespan (i.e. asphalt shingle vs. galvanized metal roofing). Based on precedent straw bale buildings, particularly those in Nebraska (often credited as the longest standing straw bale buildings), there is reasonable certainty that given the extensive knowledge attributed to this project from prior research and lessons learned, that Pelican Perch will survive more than 100 years as well.

Canadian Architect published a list of industry accepted values for embodied energy of individual construction products. The thermal materials evaluated in this study, are highlighted in Table 3 and establish that straw bale as an insulating material contains substantially less initial embodied energy (at minimum 72.4% and up to less than 0.1%). Straw bale should also have minimal recurring embodied energy which makes it a strong environmental product choice.

Table 3. Relation between insulation material and embodied energy.

Insulation material	Embodied energy* MJ/m^3
Straw bale	31
Cellulose	112
Mineral wool	139
Fibreglass	970
Polystyrene	3770

* (Canadian Architect n.d.)

3.2 *Material performance*

Substantial research has been conducted to evaluate the performance and applicability of straw bale construction in the Canadian climate. Much of this research has been provided by the Canada Mortgage and Housing Corporation (CMHC), and was carried out by Research Contractor, Habib Gonzalez—a key participant contracted in the design and construction of Pelican Perch. Successive testing and research regarding thermal performance of straw bale has been carried out to meet revised test methods and procedures (standard ASTM C1363), and the industry accepted value of R1.45 per inch as documented by Oak Ridge National Laboratory in 1998. (Commins & Stone 1998). At roughly 23" wide per bale, the Pelican Perch wall assembly achieves R33.35 before mineral wool insulation, which adds an additional R 22. The continuous insulation of the straw bale at the interior face, negates almost all thermal bridging in the home (except fenestration locations) and provides a much higher effective R Value which was modelled at minimum R40 to minimize heat loss through the envelope.

Building grade bales are recommended to be from 100–130 kg/m^3 and no more than 18% moisture content at installation (Black et al. 2011). Bales for Pelican Perch were sourced from a local barley farmer less than three hours away. In designing a compound wall assembly, natural breathable materials were preferred to mitigate the risk of trapping moisture in the assembly and counteracting the natural behaviours of straw bale assemblies. "The vapour permeance for 25 mm (one inch) thick cement-based stucco tends to lie in the range of 200 to 500 metric perms (ng/Pa s m^2) or 4 to 9 US perms … in the winter the equilibrium moisture



Figure 3. Construction photo of rammed earth walls at Pelican Perch site in central Alberta, post form removal. (Olson 2016).

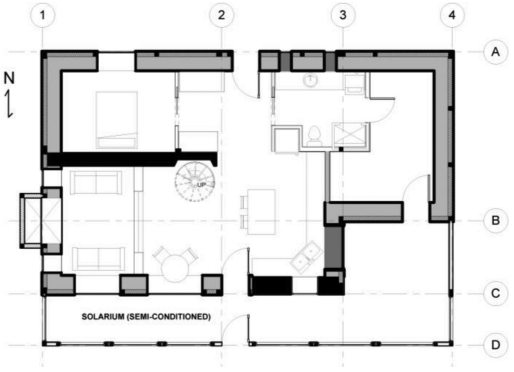


Figure 4. Floor plan of Pelican Perch, main level. Grey walls denote straw bale, black denote rammed earth (SAIT GBT 2016).

content (of bales) will be about 8–12% moisture content by dry weight, and the moisture content can rise to at least 20% before moisture problems begin." (Straube 2009)

At end of life, straw bale assemblies can be largely de-composed, recycled or repurposed adding little to no landfill waste and with no toxic effects during decomposition and reprocessing.

At Pelican Perch, rammed earth (both insulated and solid mass) were used in select areas, and although not the focus of this paper, have inherently similar characteristics and environmental rationale for their inclusion in the project (Fig 3).

4 SOCIAL

4.1 *Human health and happiness*

Further to energy consumption, building materials are undeniably linked to human health throughout their lifecycle. Exposure during material creation, construction, occupancy, and end of use options all have potential to create adverse health effects. Current research (Koulis et al. 2016) on indoor air quality of homes has shown a direct correlation between air tightness, material selection, ventilation rates and occupant health. A careful balance must be achieved between all aspects of design in order to adequately remove air pollutants, or prevent their introduction into the home. The result of an imbalance can have ranging effects on human health.

Currently, manufacturers can voluntarily undertake product lifecycle analyses and report findings in an Environmental Product Declaration (EPD) or Health Product Declaration (HPD). Not all EPDs and HPDs are third party verified, and many manufacturers choose not to undertake the research involved in producing them at all.

Materials such as expanded polystyrene (EPS), polyisocyanurate (Polyisco) and other rigid foam products are rapidly becoming staples of high performance buildings because of relatively high R values and ease of installation for continuous thermal layers. These manufactured products have several inherent chemical properties which are hazardous to human health as identified by the Living Future Institute and documented on their Red List (LFI 2016). Comparatively, the only adverse health effects notable in use of straw bale construction are potential exposure to pesticides and dust particles. Lime cement stucco, mineral wool, dimensional lumber and drywall can all be readily available without any chemicals of concern intentionally added to those products.

At Pelican Perch, the air-tightness of the home is counteracted with active ventilation systems which prevent poor indoor air quality and reduce risk of moisture accumulation in the bale walls. A heat recovery ventilator (HRV) takes in pre-heated air from the solarium at the south face to supplement the fresh air requirement and to reduce heating demands. (Fig 4) The solarium also adds valuable living area and a connection to the outdoors which is sheltered from prevailing winds and extends the outdoor living season, which is otherwise limited to only a few months per year in central Alberta.

4.2 *Community*

The construction of the home itself has been a community initiative, led by Habib Gonzalez. Students studying at the Southern Alberta Institute of Technology (SAIT) in various programs were given the opportunity to learn the construction method and participate in the build, along with other homeowners, neighbours, family members, researchers and industry professionals bringing a greater sense of awareness and understanding to both NZE concepts and merits of straw bale build-



Figure 5. Volunteer & community bale wall construction, led by Habib Gonzalez. (SAIT GBT 2016).

ing. Through the process of volunteer build days and collaborative research with SAIT GBT team, straw bale construction has been introduced into curriculum based activities for students and faculty. Pelican perch serves as an important case study using comparative values derived from homes built using conventional materials, yet meeting equivalent certification requirements (NZE).

5 ECONOMIC

5.1 *Cost of straw bale assemblies*

Straw bale walls are conventionally built using low tech tools and techniques, making the process accessible to even the most inexperienced builders and average homeowners. One way in which straw bale homes can keep costs relatively low, is to reduce labour and construct the walls themselves. This approach to a community barn raising (Fig 5), or family build can reduce construction costs by 50% (Mack & Magwood 2002) and foster stronger community connections, further supporting positive social impacts.

It is notable that the cost of an individual bale is typically $3–5 CAD, however that does not signify a "cheap" building. The construction method is labour intensive in itself, and if a homeowner were to pay for labour the cost difference compared to conventional construction is negligible (Mack & Magwood 2002). This analysis holds true in the case of Pelican Perch, where completed construction should cost between $275–300 CAD per ft^2 ($2962–3231 per m^2)of finished floor area; this is within the expected range for an average custom home. However, the value per dollar spent has more impact in a straw bale home, where improved energy performance has been measured at 20% less than conventional construction in 9 of 11 homes (CMHC n.d.). The study is since out of date and Gonzalez has independently verified in correspondence, "Clients are now reporting anecdotally a) average monthly winter energy cost for the Mill Creek Flex Home east apartment of $30 CAD/month, 2) a two story four bedroom Battle Lake Design home in Summerland, BC reportedly uses less than 1 cord of wood per winter. There are more examples which could be reference and they need to be properly collected and compared with other wall assemblies in their bio-regions." Straw bale homes are not likely to become a primary building material in the region, however their adoption in a niche market of environmentally conscious individuals is anticipated to continue (particularly in rural areas).

5.2 *Cost of NZE*

NZE homes have not absorbed the market share of new construction, largely in part to higher upfront costs to the consumer for upgraded materials, mechanical systems and renewable energy technology (i.e. solar photovoltaics or solar thermal heating systems). Return on Investment (ROI), based on current electricity and natural gas rates, puts payback periods over 10 years in most cases but is heavily dependent on site factors, design and occupant behavioural patterns. In the case of Pelican Perch, the home was modeled to be between 10–12 years depending on actual energy consumption and variable energy costs. This makes NZE homes a tough sell to average consumers buying from a developer. It is also a tough sell to builders who associate a NZE product with higher risk, partly due to considerable effort required to re-educate trades on new methods and materials. In reality, research shows that it is economically feasible with less than 15% incremental costs, and less than one additional construction week (SAIT GBT and Mattamy Homes research outcomes 2016, unpublished).

Based on current policy regarding electricity generation in Alberta (phasing out coal fired power plants) and a newly implemented carbon tax in 2017, it is reasonable to assume that electricity prices are going to increase over the next decade, thereby lowering the payback period and hopefully adding additional financial incentives or rebates to homeowners for inclusion of building integrated renewable energy (program to be release by Provincial government in Spring 2017). The carbon tax also affects products, adding additional costs to most products which require fossil fuels in their production, manufacturing and shipping; another financial incentive to source local, natural and low embodied energy products to keep material costs low.

All costs considered, straw bale construction should not be discredited as a viable option for NZE construction based on a financial standpoint.

The evidence suggests that upfront costs are comparable to conventional construction built to the same performance standards, and the value proposition is favourable given the health, environmental and social benefits of such an assembly.

6 CONCLUSION

Buildings accounted for 10.3% of emissions in Canada in 2013 according to Canada's National Inventory Report to the UNFCC. Electricity generation accounted for 12.1% and transportation accounted for 25.2%. It is clear, that activities related to building construction, operation and decommissioning are both directly and indirectly related to nearly half of Canada's emissions. (Parliamentary Budget Officer 2016) A new approach to home construction is required to substantially curb emissions going forward.

While there are multiple certification systems available for sustainable buildings at all phases of construction, operation, and retrofit, a simple, accurate measure is reflective of the three pillars of sustainability: people, planet, and profit. Without recognizable value to the economic, environmental or societal factors, the success of any sustainable endeavour will be limited.

While unconventional, straw bale construction has been demonstrated as an effective building material to achieve high thermal performance standards, meet challenging building envelope concerns, and provide added value for occupants and local industry. A straw bale home does not cost substantially more than one built of conventional materials and when coupled with NZE strategies and renewable technology, reduces operational energy and costs throughout occupancy.

In a global economy of rapidly depleting natural resources, both fossil fuels and commodities, strawbale construction is a viable option to support local economies, live in healthy indoor environments, and reduce carbon emissions and footprints throughout the lifecycle of a home.

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Natural clay plasters: Checking regulations to characterization tests

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ABSTRACT: This experimental search is based on the application of the existing rules for natural earth mortars coatings. It is checked the characterization values of natural prepared clay plasters that exist in the construction industry and verified the suitability of the regulation. To establish the application of these mortars, there are planned study strategies, to evaluate its main features and apply criteria of use. A series of tests to establish the stabilization with lime addition, values of checking mechanical resistance, adhesion degrees, humidity effects, erosion and improvements. These tests allow checking if the used normative references are applicable and detect specific cases for the application of this construction. In the experimental methodology, it is used as a reference the normative regulatory in Spain that describes the coating mortars specifications. The obtained results allow establishing more successful conditions to use this product, recommend testing methodologies and establish guidelines for testing for characterization.

1 INTRODUCTION

1.1 *Objectives*

The main purpose of this research project is to characterize clay mortars for plasters, as a prepared and predosed product. The characteristics of that type of natural mortars must be known, making that product a relevant option in the construction of continuous coating. Consequently, it is necessary to stablish the contextualized frame of raw materials within our proximal environment, quantify the reference values of the product and, specially, stablish the application possibilities and its usage guidelines.

1.2 *Traditional construction*

The new approaches to traditional trades and the use of natural materials in vernacular architecture are increasing and, due to the upgrades in matter of coatings mortars, it is crucial to analyse the situation of this materials regarding their own application and actual constructive process.

The establishing of technical guidelines of the product allows the evaluation of its suitability as an option in terms of application within these coatings in a specific design. There is a lack of knowledge in terms of manipulation, dosing, preparation and application, although there are required few and simple steps, which can allow solving the emplacement of the continuous coating with basic recourses and unspecific instrumental.

Clay mortars are nontoxic products, which enable the execution of a non-impermeable, porous and breathable coating. These properties give it the ability of regulate the environmental humidity and absorb polluting substances in the air. Furthermore, its correct thermic and acoustic insulation is proved. (Bryce 2015).

1.3 *Materials*

In the Spanish construction industry there are few local firms which provide plaster mortars, dosed with natural clays, as a prepared and predosed product.

One of them is Ecoclay Company which use the selected clays for the prepared mortars originate from operating clay quarries in Teruel, a province in the North of Spain. The predosed and prepared mortars of Ecoclay offer several mineralogical characteristics and a varied range of colours, although they all proceed from operations of the same quarry.

1.4 *Natural clay plasters*

Currently, clay plasters are non-standardized products, despite the fact that they are used as coating with the designation of "natural finishes", whether they have additives in their composition or not, they could be combined with other materials in order to stabilize and improve their mechanical, physical, or even aesthetical, properties.

Given the natural components of clay mortars without additives, they are non-polluting and reusable products because of their recycling capacity. This feature enters them, from the energy saving point of view, in the current tendency of recovering traditional techniques and materials in order to apply them in new designs and in erected architectural heritage interventions.

In the technical context, it is required regulation and prescription requirements of the products used in the construction. The quality control of the raw material and the production process, force the

manufacturer to ensure its characteristics and to depict them, specifically, in data sheets, where the minimum guidelines for its application and its suitability with other materials can be understood.

In our country, mortars for plasters and renders operate under the norm UNE-EN 998-1: 2010 *Especificaciones de los morteros para albañilería. Parte 1: Morteros para revoco y enlucido*. Nonetheless, the regulatory control of the usage of the earth within the different constructive systems is still an unfinished business in our context. In Germany, there are published norms about clay plasters DIN 18947. Moreover, they difference between exterior mortars, in DIN 18550-1, and clay interior mortars in DIN 18550-2: 2014-10 (Schroeder 2015). This regulation has been updated as a continuation of all the references in constructive systems where earth is used as a constructive material.

2 METODOLOGY

2.1 *Characterization of prepared natural clay plasters*

Based on the 12 types of prepared clay mortars, which are traded in Spain by the firm Ecoclay, it is made a selection of 4, which are mainly classified by dosing, mineralogical characteristics and colour. It is chosen the fiber base coat, which named with acronym BF, and others three used as plaster and renders, with three different colours, under the same traded chromatic range, differentiated as A2, G4 and R1.

2.2 *Dosage of the samples*

Besides the fiber base coat (BF), for each type of mortar prepared for plasters, 4 different dosages were designed for each of them: 1 without additive and the other 3 with non-hydraulic lime (CL-90), hydraulic lime (HL3.5) and lime putty (SPL) addition, using several percentages (Table 1)

2.3 *Sample preparation*

For each testing, several test pieces were made, following the instructions of the UNE regulations, applied for each situation. Some dimensions and types of referenced samples were adjusted in some tests. In other tests was proposed a different geometric piece than the standardized Moreover, the procedure of some tests was adjusted in order to satisfy the possibilities of execution that this sort of product allows. For instance, there were established different bases in the test of absorption by capillarity towards the placement of the samples, and there were amplified the measurement cycles, so as to the test of steam permeability.

Figure 1 shows the principal samples of different tests. Thus, the relevant variations for mortars for plasters were verified with regard to the prescriptions of the current regulation, which were drafted exclusively for clay and cement mortars.

Table 1. Dosage prepared for the test phase.

Code plasters	Yellow	Grey	Red
Without additives____	A2	G4	R1
Code additives_____	CL	HL	SPL
Dosage additives_____	4%	12%	20%

3 EXPERIMENTAL PHASE

3.1 *Tests planning*

The test planning is designed taking into account the characteristic values which must be specifies in the products used as plasters, according to the main requirements established by the construction market (AFAM 2006). Moreover, two basic field tests are developed with all the earth materials before being either applied or used for particular constructive systems (Neves 2009). In the case are made the drop ball and samples to evaluated retraction test and dry strength. Hereunder, the list of some tests of the experimental phase is described in the Table 2.

4 EXPERIMENTAL PHASE

Based on the obtained results, using as a reference the UNE norms for plasters, (UNE-EN 998-1: 2010), it is checked if it is necessary to raise an action and application protocol of technical and specific criteria in order to predose these products. Then, it is depicted a synthesis of the relevant aspects within the obtained results of some developed tests.

4.1 *Analysis of consistency and density results*

Regarding the consistency tests of the used mortars, the runoff values depend on the sort of clay. In order to stablish guideline values (UNE-EN 1015-3: 2000/A2: 2007), the characteristics of the type of

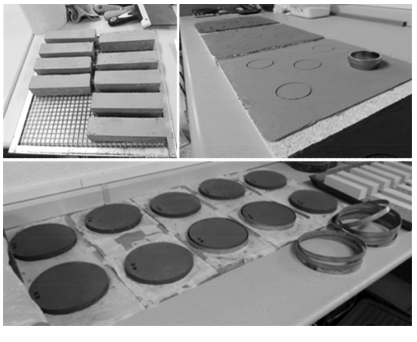


Figure 1. Samples of different tests: prismatic piece of 4 × 4 × 16 mm, samples of 300 × 300 × 5 mm applied over several sort of surfaces and circular test pieces of 160 × 1 mm.

Table 2. Test planning.

Field tests:	Drop ball
	Retraction test and dry strength
Tests of fresh mortar:	Consistency
	Apparent density
Tests of hardened mortar	
Behavior to water:	Capillary water absorption
	Water permeability
Mechanical behavior:	Flexural and compressive strength
	Compactness (ultrasonic transmission rate)

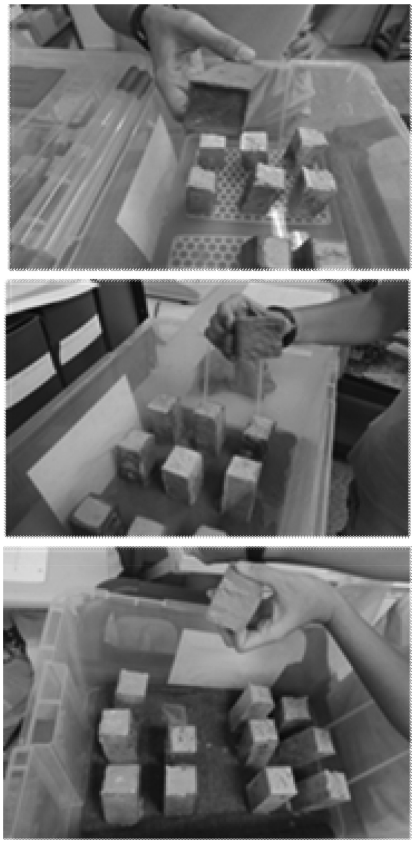


Figure 2. Capillary water absorption test. Stability with clay mortar samples (A2, G4 and R1) on different base surfaces.

clay which the dosing of the mortar contains, must be known, and it is crucial to verify if the resulting consistency gets the recommended average values.

The clay additions in the used dosages prove that the mortars with prevailing siliceous components improve their plasticity and, almost in every dosing, increase their density (UNE-EN 1015-6: 1999), if it is compared with the product without additives. Despite the fact that the retraction values are also high in dosages with clay additions, it should be related with the sort of surface and the environmental conditions taking into account to ensure a correct application of the product and adherence to the base material.

4.2 *Capillary water absorption*

After the application of the procedure of the reference test (UNE-EN 1015-18: 2003), it is checked that it is not effective for these sort of products. The samples of clay mortars must not be directly immerse in water; in order to complete the test, they require an absorptive holder which allows its stability for a certain period of time. The control and the tracking can be improved if the base of the samples is placed submerged into distilled water, one centimetre, over a layer of sand or a cotton cloth (Fig. 2).

The obtained values are not homogeneous; they vary according the type of clay, although it can be deduced that the dosages with non-hydraulic lime improve the reaction of the mortar, hence, its stabilization.

Furthermore, the procedure of this test needs to be reframed within the different cycles of control and measurement. In the reference norm, there are stablished only two measures: one at the tenth minute, and another one at the ninth minute. In this research, the criterion of increasing the measure periods is kept, and it is added a measure sequence of 24 hours for 4 more days. This modification ensures verifying that the absorption values can either fluctuate in some cases or stabilize in other dosages.

4.3 *Water permeability results*

The water permeability tests are applied in order to quantify the property of clay mortars to regulate the exchange of ambient humidity. In this case, the reference test (UNE-EN 1015-19: 1999/A1: 2005) does not allow the collecting of representative values. Therefore, it is also indispensable to stablish modification in the normative procedure. It is needed the evaluation of the product reaction to changing environments, not only its response to an atmosphere with constant temperature and humidity.

In Figure 3, it is showed the climatic chamber where the circular samples were placed. Half of the samples were tasted with saturated solutions of potassium nitrate (KNO_3), which provides a relative humidity of 93.2%, in order to control the pressure of the steam for smaller relative humilities. The other half of the samples was placed in a saturated solution of lithium chloride (LiCl), which generates a RH of 12,4%, towards control the pressure of the steam for higher relative humilities. Thus, it was obtained minimum and

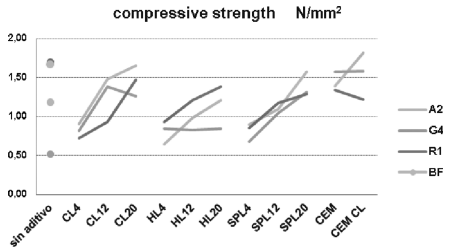


Figure 4. Compressive strength values of mortars tested.

maximum exchange values of steam for the three types of plaster mortars (A2, G4 and R1).

4.4 *Mechanical resistance values*

The norm UNE-EN 1015-11: 2000/A1: 2007 enables the establishment of mechanical resistant values to flexural and compressive strength of the plasters. Even so, compressive strength values are the most accurate for a product which is applied with few millimetres thick in a continuous surface. In such a case, Figure 4, every tested dose gives compressive strength values within the referenced values—DIN 18952 (Schroeder 2015), that means, between 0,4 and 1,5 N/mm^2 (Fig. 4).

The comparison between the obtained data for compressive strength values and the non-destructive test of compactness (measures with the ultrasonic transmission rate) allows valour the degree of cohesion, dimensional stability and placement of the discontinuities in the samples.

It can therefore be concluded that the additives do not modify the mortar compactness, but that dosages with 12% of clay are the most suitable. In the same way, dosages with more non-hydraulic lime provide better mechanical data.

5 CONCLUSIONS

It is important to define specific tests and procedures for clay mortars used as plasters and renders. It is necessary to adjust the conditions most appropriate to the service circumstances of these mortars. Therefore also, test piece or samples must be specific for this type of product.

Study strategies must be raised in order to facilitate the necessary evolution of the development of the product, the implementing methodology, control and maintenance. From this research, there are proposed several guidelines for the drafting of instructions towards the reception of the material in the building construction. Furthermore, there is suggested the necessity of defining the appropriate specifications for the different sorts of dosages, according to each type of clay or additive, in order to make them more suitable to certain uses and/or surface to be coated.

Hence, it is necessary to probate the manufacturing process and the application of clay plasters. That will lead to plan a correct and complementarian denomination and designation, in order to use it as a component in coating systems. Therefore, there must be prescribed the proper dosing for each sort of clay, and if additives, in this case limes, were also used, their compatibility with a particular type of lime.

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Terra nova—earthen architecture and modernity

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ABSTRACT: Earthen architecture can fully satisfy a series of functions, performances and aesthetic concerns. The efficiency of the material and of the technical and constructive historical know-how can be taken into consideration today to offer an adequate answer to the pressing needs for sustainable building strategies. A new central role that ratifies both its unexpected *technological modernity* and its responsible and innovative *compositive and linguistic-formal updating*. The interpretative passage from traditional building uses and configurative results to the new possibilities for technical manipulation and as technological-structural support permits defining new horizons for architectural creation. A central role in the contemporary landscape, marked by specific implications in environmental terms, but also of formal investigation: *terra nova*, not intended as a return to the picturesque or the vernacular, or as *rétro* nostalgia, but rather as a *different repetition*, paradoxical cultural and practical territory of another present, which is just as efficient and poetic.

1 CONTEMPORARY EARTHEN ARCHITECTURE: THE SURPRISING OXYMORON

Researching into the possible and full contemporaneity—technological, as well as in terms of performance and aesthetics—of an ancient constructive technique such as that of earthen architecture, constitutes the key to an educational research, caught between technology and composition, that has been pursued for some years now by the School of Architecture of the University of Florence. The guidelines are threefold: the main value as both threshold and bridge of the architectural project as critical thought naturally linking tradition and innovation; sustainability as strategy giving meaning and operative direction to the practices of transformation and shaping of the contemporary material world; compositional creativity as field of application free from any subjection, prejudice or discrimination regarding architectural styles.

It is rather the efficiently compliant modernity, glimpsed in the evolutive re-consideration of a technical-constructive knowledge that reaches our time from the ancestral depths of human society, which constitutes the unexpected and surprising oxymoron whose opportune and well-founded educational significance must be recognised. The recognition and understanding of these elementary and primary materials and methods may lead to their re-appropriation as an adequate field of expression and formal research, living and active, and therefore susceptible to updating. Not only: epochal cultural oxymoron as a result of the urgent need for innovation aimed at a proper and sustainable environmental development, which rediscovers precisely in the raw earthen material the agent better suited and proven to carry out an efficient suture of the ever widening gap between the natural environment and the unstoppable and expansive processes of anthropization. A boundary—temporal, technological and aesthetic—proposed and taken on as the frontier of possibilities for architectures aimed at full sustainability, in a balance between millenary knowledge, long forgotten or surpassed, and claims of a full and deserved cultural modernity: conceptual, technological, and formal-linguistic. Where a new energy, but also an aesthetic efficiency, the latter to be reinvented, can shape, through the use of the ancient tool, a new architectural landscape decidedly in consonance, not only concerning the field in question, with the needs and the spirit of the current age.

And ultimately, an intellectual and sentimental oxymoron, since it is also a symptom of the rediscovery by the society with the highest degree of technological processing and pervasiveness in the history of mankind, of a need to find a compensatory balance, with a deep and wise cultural and existential equality of distribution, in a sort of Jungian "return of the repressed", irresistibly bringing back to the surface the inhibited opposed principle, that is the recovery of the excessive imbalance between the founding polarities of a humanism which is instead both organic and complete. Or else, as in the contexts that traditionally take it into account—Africa, the Americas and the Far East –, in a trend of increasing re-consideration of a brilliant tradition which is, on the contrary, undervalued and scorned as a symbol of backwardness to be removed.

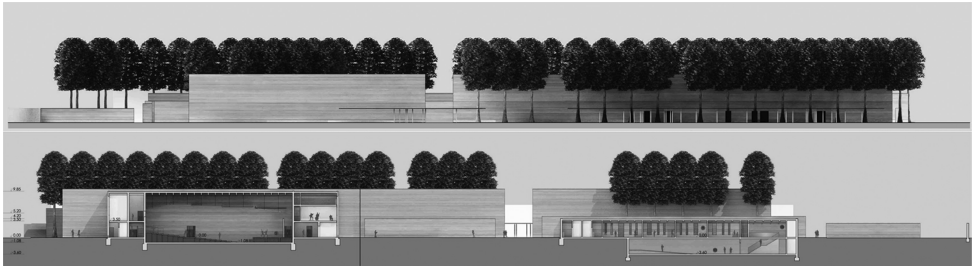


Figure 1. San Sperate Art and Cultural Center, Sardinia. Front and Section (A. Manca, E. Manca).

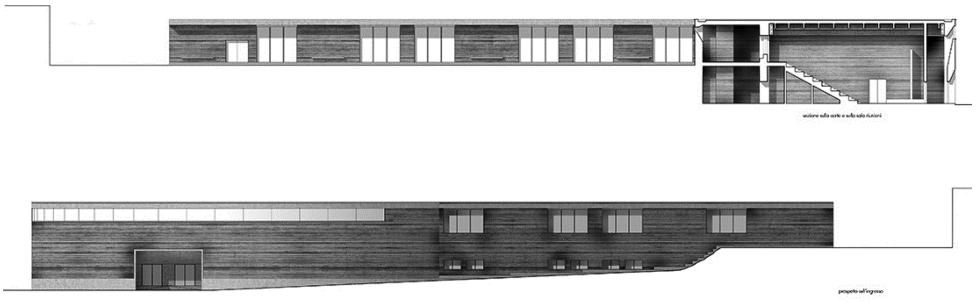


Figure 2. School in Incisa Valdarno, Tuscany. Section and front (E. Ventisette).

Thus, earthen architecture proposes itself, in an unexpected and paradoxical role, in opposition to the exponential, imperative, compressive and deforming one-sidedness of a technological hypertrophy derived from industry and from chemistry, assumed as the only universal and objectively progressive paths capable of guaranteeing modern standard values, affirmed as essential and unparalleled *vis-à-vis* other building methods and procedures. Homogeneous globalisation which can find an unexpected bulwark and an antidote in the gentle simplicity, ease, discretion and proximity of the *ante litteram* global archetypal building tradition of earthen architecture, now re-admitted even in the most advanced contexts, as paradigm of a sort of mitigating counterpoint. But also, deep down, of a rediscovered adhesion to a primary plan for material and cultural building that evokes the cyclic aspiration to a re-fusion of nature and architectural artifice, which has been present throughout the history of architecture, including some avant-garde movements.

2 CONTEMPORARY NATURE OF THE FEATURES

The building of architectural structures in raw earth is increasingly frequent, including the works of important authors in today's architectural scene, which have ratified their dependability and wide range of uses, both as efficient buildings and as bearers of formal representation (Rael 2008). In parallel, the Combined Laboratory and the Thematic Seminars on Architecture_Materials_ Environment of the School in Florence, founded upon the three disciplinary keys of architectural composition, technological design and the physics of buildings, have pursued the aim of the re-interpretative passage from traditional forms of treatment, constructive use and configuration results regarding raw earth, to new possibilities of technical management and technological and structural enhancement (Lorusso & Mecca 2015). They have tacked the final key in particular, the most uncertain and risky, but also the most prioritary: the assessment of the potential in terms of new horizons of compositive and linguistic updating (Özel et al. 2015). An formative commitment capable of liberating this architecture from falling into nostalgic regrets or picturesque and vernacular mimicry, conferring to it, on the contrary, full status as a key player with a renewed and well-justified role in the con-temporary world, with an adequate contemporary aesthetic identity (Figs. 1, 2). A contemporaneity, however, pursued in accordance with the most sub conferring to it, on the contrary, full status as a key player with a renewed and well-justified role in the con tle and sophisticated of its stances: that of being able to turn the cultural



Figure 3. San Sperate Art and Cultural Center, Sardinia. View (A. Manca, E. Manca).



Figure 4. San Sperate Art and Cultural Center, Sardinia. Hall (A. Manca, E. Manca).



Figure 5. San Sperate Art and Cultural Center, Sardinia. Gallery (A. Manca, E. Manca).



Figure 6. School in Incisa Valdarno, Tuscany. Inner courtyard (E. Ventisette).

platform for progressively impulsing and relaunching, while applying the methodological intelligence of the analogy, of deduction and transliteration, of the weaving together of the "iteration, alteration and revelation" of tools, methods, meanings, signs, representations of the original reference, and proceeding with their inclusion in new compliant forms (Figs. 3, 4, 5, 6).

It is thus that, in this interpretative key, the material, perceptive-sensory, geometric-dimensional, morphological and expressive features that systematically recur in traditional earthen architecture, giving structure to its alphabet, grammar and syntax, in accordance with a peculiar configurative lexicon—tectonic and linguistic –, have been identified and recognised as a possible compositive substance, functional especially in terms of a rediscovered desire, also of our day and age, for volumetric purity, for a re-evaluation of the mass, for the physical density and great thickness of walls for energy performance purposes, for the material nudity of primary building processes with a direct formal worth, for a minimalist reduction to a few quintessential dominant connotative traits. Polar rediscovery in retaliation to the opposed and dominant polarity, in current architectural literature, of the poetics of thinning, of dematerialisation, porosity, tunneling and luminescent rarefaction, or else of plastic redundancy, of hypertrophic volumetric modelling, as well as of hypertechnology and structural audacity. A dialectic aesthetic re-balancing, useful to the plurality of the material and existential landscape, in which the laconic beauty of the stratification of rammed earth, the texture of adobe, the homogeneous tactile and chromatic unity of the earth, the precise and strongly chiaroscuro subordination of the openings and gaps in relation to the massive, imposing quality of the whole.

An archaically elementary expressive palette which, critically re-processed, combined with new structural and technological devices and enlightened by socio-cultural references, turns to the opportunity of a more complex formal research, completely innovative and adapted to the new times. We are, in other words, in the field of the subtle exercise of "different repetition", in the sense of a genealogical instance which implies the conscious re-proposal of its difference from its origins because derived from it. Well-founded reinvention, which combines and weaves, as in any other vital practice, continuity and transformation, confirmation and adventure.

3 TERRA NOVA

The reform and compositional exploration of earthen architecture depends on the perfecting

of its components and of the building processes that have always been used in the construction of the most typical buildings: rammed earth, adobe, horizontal scaffold ing and occasionally lattices in wood or bamboo. But it depends even more on the collaboration of materials derived from contemporary structural systems such as reinforced concrete or steel, but especially plywood.

This is the preferred technical resource since it is an extraordinary evolution of the most ancient building element, as has been historically and empirically proven. Hidden or exposed, in layers, as pilasters or beams, as part of the shell or of the flooring, either homogeneous or in slabs, depending of local conditions or anti-seismic requirements, this technology permits obtaining ample spaces, has a good anti-seismic performance, and offers an aesthetic counterpoint capable of providing new developments in terms of composition and performance: geometric, volumetric, dimensional, linguistic. A modern and resolved break with the structural load-bearing role that, as a result, liberates traditional building practices from the direct responsibility of supporting the structure, using raw earth especially for the external walls, due to its high performance in terms of the physical-energetic efficiency of the building, but also, as said before, as unexpected matter for creative representation (Figs. 9, 10).

In addition to wood, also reinforced concrete has an organic and necessary role, both in terms of functionality and aesthetics, in the foundations and in the load-bearing shell, as a base to separate the walls from the ground to protect them from rising humidity and from rain-water: artificial stone of modernity which analogically replaces the stones or bricks of the past as technical device, but also in terms of aesthetic detail underlining, framing, decorating in a counterpunctual manner the streaked surface of the rammed earth or the material homogeneity of the earthen plaster that protects the adobe walls.

It is the rammed earth technique which seems to prevail in the formal choices both in terms of education and training and in the actual work of the architects who use it. The compact nature of the material and its grain, as well as the direct truth of its stratified use, so familiarly allusive to the aesthetics of apparent reinforced concrete, the trace of the texture of the formwork, the possible increase in terms of language with the use of earth of different colours, either natural or added to the mix, and the liberation from the protection of the plaster, thanks also to the occasional use of new compatible transparent protective substances, give it its aesthetic signature, its connotative identity and its poetic suggestiveness. And it is interesting to see how this primary poetry, so characteristic of rammed earth, is migrating, in a fascinating upside down movement of transliteration, in examples of architectural structures made of stratified rammed concrete (Dudler, 2014), a compressed cement conglomerate which replicates the aesthetic results in terms of thickness (Figs. 7,8), irregular and iterative superficial graphism, with the evident

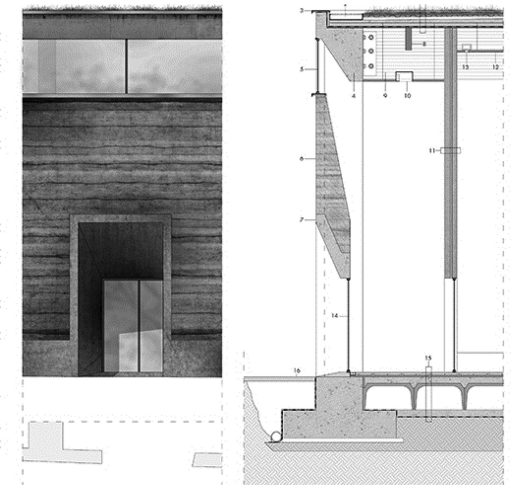


Figure 7. School in Incisa Valdarno, Tuscany. Building detail (E. Ventisette).

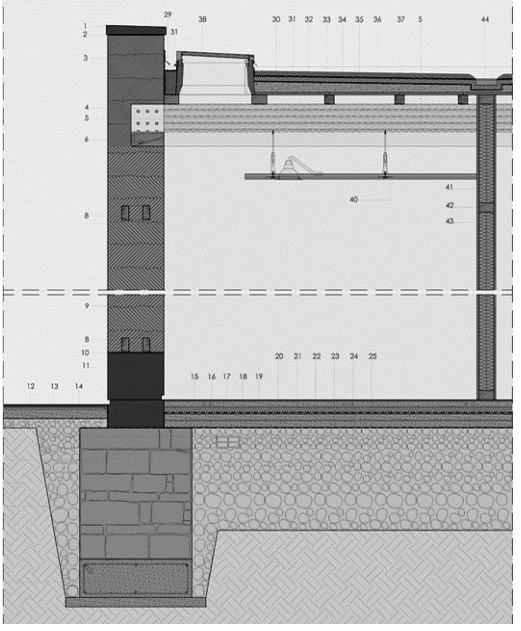
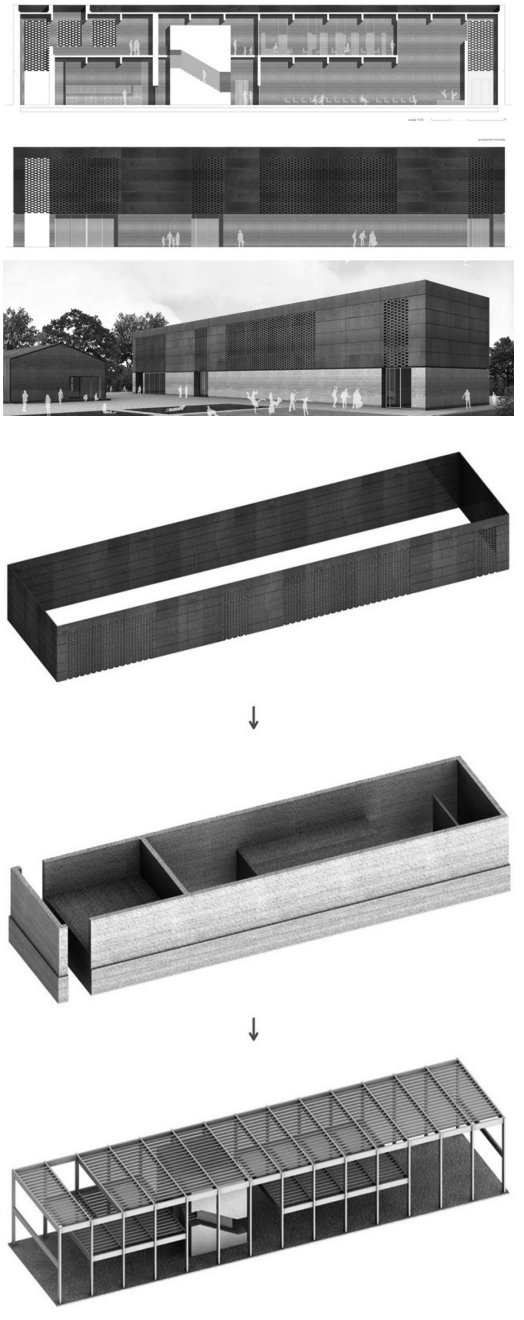


Figure 8. San Sperate Art and Cultural Center, Sardinia. Building detail (A. Manca, E. Manca).



Figures 9, 10. Ecoborgo in Cenaia, Tuscany. Cultural Center. Section, front, view, building scheme (G. Aguti, G. Boscherini).

appearance of the manual execution, colour variation and tactile ruggedness.

But not only: under the sign of a contamination/ hybridization that unites the extremes of historical tradition and contemporary innovation of the two materials, earth and cement, a surprising and paradigmatic synthesis has arrived between the ancient artisan technique of rammed earth in the formwork and the modern technological methodology of the pre-fabrication of modular components in cement. An operative torsion—methodological, instrumental and even ideological -, due to which the patient and coherent coincidence with the construction at hand of the ancient method is transformed in the procedural de-composition between the predisposition of mega-blocks of rammed earth and their subsequent mounting in combination with autonomous load-bearing structures in another material, in accordance with the modern industrial method (Herzog and de Meuron, 2014). Thus the adobe brick becomes a hypertrophic monolith which supports the dimensional and temporal scales of our age, showing an unexpected versatility in terms of adaptability of earthen material which opens new horizons for research and technical and aesthetic possibilities, rich in interpretations and compositive explorations.

It is on these levels that the educational experience developed through exams, and especially undergraduate theses, but also through a pilot project for Jericho in Palestine, has researched and manipulated terms and syntax inherent to traditional earthen architecture, resulting in new interpretations applied to buildings completely inscribed in contemporary functional and formal narratives: schools, nursing homes, residential houses, student housing, and mu-seums have verified and demonstrated the validity of an unusual building and creative approach, capable of brilliantly combining today's fundamental requirements in terms of environmental sustainability in construction, with a re-appreciated, renewed and tested knowledge which at the same time belongs to the ancient past and projects itself authoritatively in the present with a unique innovative role and an autonomous and accomplished beauty.

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The school of Baasneere, the process of international cooperation

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ABSTRACT: "L'Escola de Baasneere" (the school of Baasneere) is an international cooperation project that carries out the Valencian association Algemesí Solidari in a village in Burkina Faso. The construction of this secondary school is being executed with walls and vaults of compressed earth blocks (CEB). It has been hoped that the entire process followed for this project, from the definition of needs to the management of the execution, going through the drafting of the architectural project, will be carried out in a collaborative way and will also incorporate criteria of sustainability, the NGO's own objectives: awareness of situations of inequality and the promotion, in front of them, of solidarity actions.

1 THE COOPERATION PROJECT

The school in Baasneere is an international cooperation project consisting of the construction of a secondary school, which will be carried out on the initiative of the NGO Algemesí Solidari (Valencia, Spain) and the local association A3B, in the town of Baasneere (Burkina Faso).

Algemesí Soladarí is a small organisation which came into being in 1991 and which consists of 280 members with the objective of bringing to light the realities of injustice and inequality in the world and to achieve a world with more fraternity, justice and solidarity in general and in particular the decentralised cooperation and emergency aid. Therefore the priority field of work is located in Algemesí (Valencia) and currently also in the village of Baasneere, located north of Burkina Faso in the province of Samantenga.

The construction of the school is currently in the construction phase of the perimeter walls. The forecast is to finalize the construction of the first phase (classroom block) in the spring of 2017.

The long process from the realization for the need for a secondary school in the village, to its final construction, has been an exciting journey, one of learning and unlearning of passion and collaboration, in which many people and entities from different walks of life have participated with the common objective of helping those less fortunate then themselves.

The request for the construction of a secondary school came from the members of the town itself, organised in an association called A3B (the Buud-Bumbu association of Bao-Baasneere).

The town of Baasneere has various primary schools, however at 12 years of age the pupils are currently left with no option other than to move to the capital Kaya, 30 km away to continue their studies, a situation difficult to sustain for the majority of the towns families who struggle with basic needs and are therefore forced to abandon their education. The result of this is that the majority of the towns inhabitants who attend school only reach a level of basic education.

Taking all this into account the NGO set about making the school a reality based on the conditions that both the construction and the design should carried out according to the criteria of participation and sustainability and should spread the objectives of the organisation.

2 THE USE OF EARTH

The initial information that came to the organisation concerning alternative architecture with limited resources being carried out in Africa came to us through the media and talk of work being carried out by the local architect Diébédo Francis Kéré and his schools in Gando, Dano and Laongo.

Inspiration was taken from these projects which were being carried out in an area of close proximity to the future construction site of the school in Baasneere and an exchange visit was organised to initiate the process of research and training into the use of earth as a construction material.

During this learning process contact was made with the UNESCO Unitwin Chair Earthen Architecture, Building Cultures and Sustainable Developement, in Valencia under the supervision of Camilla Mileto and Fernando Vegas.

Under their guidance the world of earth architecture, its possibilities and advantages, and its perfect adaptation to the construction in countries with few technical and material means.

Once the decision was made to use earth as a working material, the compressed earth block technique (CEB) was chosen as it provided the following advantages for our project:

- The obvious economical and ease of manufacture: in Baasneere earth is free.
- It has a simple manufacturing and construction technique: the machinery is simple and it is easy to learn.
- It resembles traditional techniques already known: CEB is a technical improvement over the adobe used regularly in the village and surrounding area.
- The production of bricks and the execution of the work allow for the project to be carried out to the given timeframe.
- This system allows monitoring of the quality of the construction and its control: it can be corrected and rebuilt simply.
- The country's capital (Ouagadougu) has standardized CEB production.

This decision was accepted in Baasneere with interest, overcoming the initial skepticism as the technique did not at first seem as modern or resistant as the materials derived from cement, which have arrived in Africa along with so many other aspects of western culture. Although this tolerant attitude could be seen as the fruit of the legendary wait and see attitude of Africans towards western ideas.

3 THE ARCHITECTURAL PROJECT

The project was organized in July 2014, in collaboration with the UNESCO Chair Earthen Architecture, Building Cultures and Sustainable Developement, and the Higher Technical School of Architecture of the Universitat Politècnica de València, a workshop of ideas between students in order to propose adapted and sustainable solutions.

From this workshop, which involved 60 students, 12 proposals came out and an itinerant exhibition was held whith them in Valencia, at the Congress of Versus 2014, another in Algemesí, in a local museum, and another in Baasneere.

For the final drafting of the project, the professional services of architectural firm HAC-90 were recruited, which gathered the reflections of the workshop carried out in the architecture school, and which offered the collaboration to 10 students who had participated in that experience.

The final work has been the result of the joint work of technicians and students and has undergone different modifications to suit the educational program of Burkina Faso, which has been changing in recent years (especially after the political events of October 2014, which ended with the overthrow of President Compaoré).

The project includes the completion of a complete secondary school, composed of 3 classrooms and complementary buildings for the administration, a library and a science laboratory. In addition, the construction of 6 homes for teachers is included as are a sports field and well (Fig. 1).

In addition, thanks to the collaboration of the Arabist Ribera vocational training institute of Carcaixent, a village near Algemesí, through a project carried out by volunteer teachers and students, the new school will also be provided with electric power by means of solar panels.

The architectural design is based on the maximization of modularity, to allow its progressive implementation in phases that are economically viable given the financing characteristics of this project.

The constructive technique chosen is that of CEB block loading walls, covered with a canopy of barrel vault arches over concrete supports; And on these vaults, steel plate covers supported by triangular structures of tubular steel bars.

The structures will be surrounded by a perimeter made of stone masonry, which will raise the level of access in order to protect them from the torrential waters of the rainy season.

All the planned constructive techniques have been tested in situ with available equipment.

4 TRAINING AND RESEARCH

4.1 *Courses-training workshops*

The community of Baasneere lives according to a subsistence economy. The weakness of this structure of survival leads the population to endure important daily hardships.

One of the objectives of the cooperation project was therefore that the construction of the building should be a means of developing within the community of Baasneere a vocational training system that would enable the villagers to build their own houses or community buildings through the use of compressed blocks, and to be able to do so even

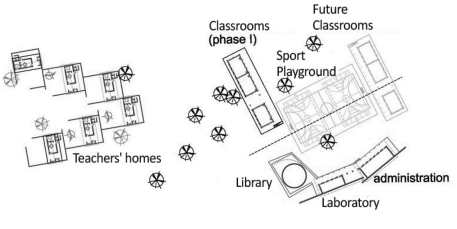


Figure 1. General project plan.

in neighboring communities, so that the technical improvement brought about by this construction method would also become aid improvement at the individual and social level of the population.

To gain an understanding of the material and the manufacturing process, two workshops were organized in Algemesí with the invaluable aid of CEDATERRA which were overseen by M.Rocha.

One of these workshops carried out in the month of July 2015 included a group of young people with elementary studies of a disadvantaged neighborhood in the city; and the other, between August and October 2016, with the participation of the City Council, aimed at unemployed young people from the same neighborhood, to formalize the production of CEB and to manufacture the 17,000 blocks needed for the future construction of another one of our projects: a school library in the Raval district of Sant Roc in our city. From the experience of this last workshop, a specific document is developed at this congress.

In the first phase of the construction of the school, it has been decided not to organize the training workshops for the manufacture of CEB in the village and bricks used for construction have been obtained directly in Ouagadougou, where there is an important factory (Zi Materiaux) which produces good quality blocks with a group of Terstaram-type hand presses.

The reason for this strategy was, on the one hand, our inability to organize simultaneously the management of the work and the training workshops, and on the other hand, the guarantee to offer employment in the first stage of the project, availability of reliable materials iat the offset of the project.

4.2 *ConBurkina research project*

One of the latest projects linked to the Baasneere school project is the one that represents the research work that will be carried out during the years 2017 and 2018 through the project ConBurkina granted in the framework of ADSIDEO—Centro de Cooperación al Desarrollo de la Universitat Politècnica of València, by a group of researchers that integrates the heads and members of the UNESCO Chair Earthen Architecture, building cultures and sustainable of the Universitat Politècnica de València and the members of the Association Algemesí Solidari.

The project "ConBurkina" is designed to reinforce the project under way from three fundamental aspects: the scientific-technical support necessary for the construction of the school and the improvement of the building from the point of view of sustainability (environmental, socio-cultural and socio-economic); the support in the process of technical training of young people aimed both at the empowerment of the population of Baasneere and at the specific training of engineering students at the nearby Ecole Supérieure Polytechnique de Kaya (ESPK) through the organization of theoretical and "hands on" workshops; The participation of the population in the process of building the school through participatory workshops for adults, youth and children.

5 PROJECT MANAGEMENT

For the organization and management of the work carried out in Burkina Faso, different trips have been made in 2015 and 2016.

They were contacted (with the support of the consulate of Burkina in Valencia) with the different administrations involved or that could collaborate with the project. Visits were made to the education ministry, the Kaya Council (municipality which includes Baasneere), and the Kaya Polytechnic, which trains engineers; as well as with the different tribal chiefs of the surrounding villages, to whom the students of the new school belong.

In all the meetings the project was explained by means of plans and a 3d model. Out of all the expositions without a doubt the most endearing was that celebrated with the heads and the town inhabitants, under a canopy in the market of Baasneere, with translation into French and the native language, *mooré*.

Several local construction companies were approached for the construction of the buildings. One of them had extensive experience in of the CEB construction.

The land was ceded by the community of Baasneere.

As for the direction of the work, in one of the trips that took place for the organization of the construction, contact was made with the Catalan architect Albert Faus.

Albert Faus has lived and worked in Burkina Faso for many years. There he has demonstrated his interesting in numerous pre-eminent projects, which demonstrate his interest and commitment to modern architecture and a commitment to the society in which it is exists, such as the Katiou library in Komsliga, the Kisito children's home, the School integration center both in Ouagadougou, or the recent maternity unit in Guiba.

But in addition to the strict professional involvement of the architect, the management of the school's work has also become a learning process in earth construction techniques while at the same time raising awareness of the situation in which these African men and women live. With this objective in mind, a workshop was organized for volunteers: from October 2016 to February 2017, 8 young people, students and professionals, lived with the community of Baasneere and collaborated in the direction of the construction process (Fig. 2).

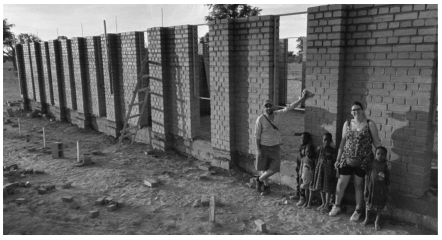


Figure 2. State of de work (January 2017).

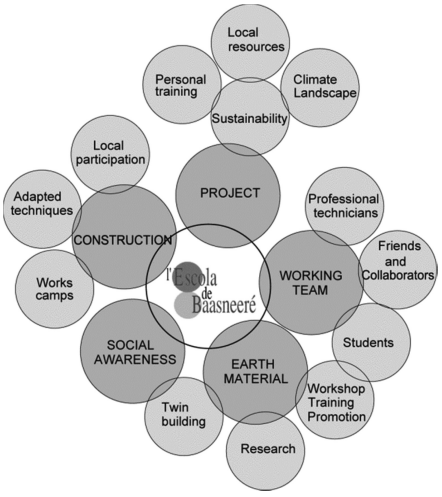


Figure 3. General organization chart of the cooperation project.

Regarding the participation of the town in the project, it had initially been limited to the participation of a few locals as members of the work team and it was agreed with the whole of the village that the participation would materialize in the construction of the perimeter base of the buildings, for which the community would collect stones and sand, with their own means, materials and labour.

This activity was organized by the leaders of the community and developed in different stages, taking advantage of the seasons of less workload in the field or with the cattle. After a lot of work carried out with small carts pulled by donkeys or motorcycles, and with collaboration of local men, women and children, today, next to the site, are piles of materials have been gathered ready for use.

6 CONCLUSIONS

As can be seen from this report, cooperation projects are complex and costly both economically and at a personal level. That is why it is essential that all the effort taken in the management and development is an integral part of the project's objective. Thus, in the event that it is not possible to complete the projects objectives 100%, the route traveled has, in itself, been a positive action, both for the group and for the community that supports it (Fig. 3).

In this case, the main source of inspiration for the architectural design has been the monitoring of the sustainability, in its different aspects:

– Socio-economic sustainability; related to the reduction of execution and maintenance costs. Use of materials and means inspired locals. Low energy consumption in the construction process.
– Social and cultural sustainability; arising from the cultural foundations of the community to which the work is intended; and empowerment of the community as a whole.
– Environmental sustainability; which takes care of the unique conditions of the environment in which the architecture is intended. Processes with low environmental impact. Landscape and climatic integration.

In order to cover these criteria, Earth block architecture is particularly appropriate. Also, due to its low cost, it is ideal for its implantation in communities with little technological development, and therefore, very suitable for cooperation projects.

At the professional level, we have had to unlearn part of our working methods, and adapt ourselves to new conditions, which were previously unknown and often hostile, however adaptation is one of the indispensable stages of cooperation. That is why we have had to learn to adapt the project as the knowledge of the place where it was destined and of the people with whom we were going to work with became more apparent.

However, we have rediscovered, after years of professional practice, the true social function of architecture, so forgotten in our societies, and yet it should remain its true purpose. We have finally come to the conclusion that in this type of project, as Kavafis has already shown us in his poem Ithaca, the path can be as important as the goal.

NOTE

This work is part of the research project "ConBurkina", funded by the ADSIDEO Programme of UPV's Development Cooperation Center.

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CEB Factory for seismic resistant earthen architecture design in Nepal

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ABSTRACT: The consequences of the earthquakes of Spring 2015 in Nepal, are still being felt a year later. Reconstruction projects funded by NGOs and international groups have been insufficient to deal with reconstruction throughout the country. Providing appropriate solutions, self-managed by the local population, is the only sustainable course of action. The geological and cultural characteristics of Nepal make earthen architecture a real and effective response to this need. But the proposed solutions must be rigorously studied, adapted and designed for each specific area. A cooperative factory of Compressed Earth Block (CEB) run by women has been the central axis of the reconstruction project developed in Nuwakot. The objective is to promote the local micro-economy and provide a way to reconstruct village dwellings. The design of the CEBs, laboratory tests, the quality control of the blocks and the design of the load bearing-walls have been carefully studied to ensure good seismic resistance.

1 INTRODUCTION

In Nuwakot, one of the most affected regions, an international project was proposed with the aim of rebuilding the Chandeswhory Blind Hostel—a residence for blind children. The project was sponsored by the Petit Mon NGO (www.petitmon.org) and received contributions from other bodies, including the technicians from the Recoop Nepal (www.recoopnepal.org), an International Cooperation Project run together by three NGOs: Nousol (www.nousol.org), Moviment Nòmada (www.movimentnomada.org) and Terram (www.terram.cat).

Ninety per cent of the buildings in Akkare Bazar, the town where the Hostel is located, had collapsed and required full reconstruction.

The shortage of resources and rising prices of construction materials made it virtually impossible for the overwhelming majority of inhabitants to take any initiatives to reconstruct their affected houses or businesses.

Public buildings throughout Nepal were already featured in the aid plans of international and national NGOs. However, few plans, not even those of the government, offered any direct solutions to families who had lost everything.

Given this scenario, it was decided to go one step further and to use the construction of the Hostel as a means of empowering the population. Advocating the use of low-cost locally available materials also helped to boost the area' economy.

2 BACKGROUND

2.1 *ABARI and its seismic resistant building prototype made with earth and bamboo*

ABARI (www.abari.earth) is a firm of Nepalese architects based in Kathmandu who have been working for years on the development of sustainable construction with earth and bamboo. After the earthquakes, their activity was focused almost exclusively on developing seismic resistant projects for reconstruction. Their efforts paid off and set a precedent when, in January 2016, they obtained government approval for a seismic resistant prototype for a classroom built entirely with earth load-bearing walls and a bamboo roof structure.

2.2 *Conscious Impact NGO, Auroville and its AURAM 300 press machine*

Some NGOs, including *Conscious Impact* (www.consciousimpact.org) elected to run reconstruction projects using CEB. Critically, *Conscious Impact* decided to acquire the AURAM 3000 machine, manufactured in Auroville, India. This versatile machine produces blocks with various finishes that are designed to facilitate the construction of reinforced load-bearing walls. In the months following the earthquakes, workshops on the use of these blocks in earthquake constructions were held in Auroville,

3 THE CEB DESIGN AND THE PRESS MACHINE FOR PRODUCING THEM

The physiognomy of the CEB was specifically designed for this project. The objective: to facilitate the construction of reinforced load-bearing walls and to maintain a solid block so as not to diminish its mechanical properties.

The manufactured blocks dimensions are 255 × 125 × 70 mm (Fig. 2). Their unique features



Figure 1. CEB press machine.

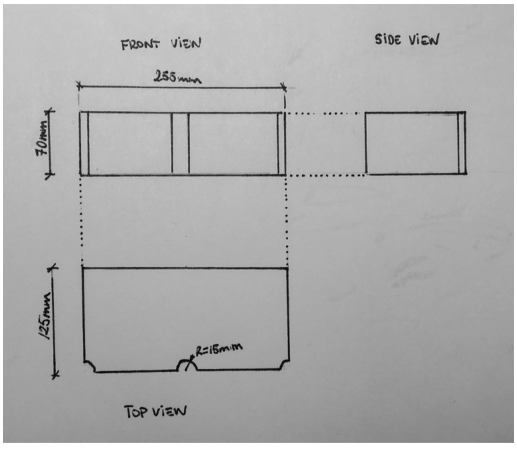


Figure 2. CEB Sketch of the design.

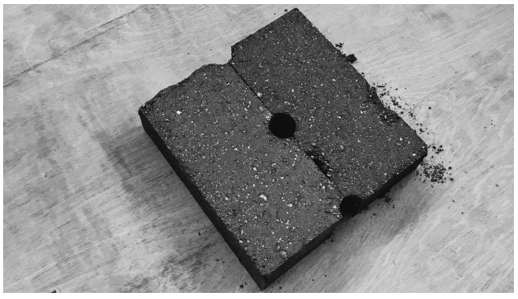


Figure 3. Two CEB at right position to create the vertical holes on the center of the wall.

are the three curvilinear channels caste into the internal side edges i.e. perpendicular to the top/bottom faces. These 3 channels are located at the centre and at each of the two corners. The radius of each cylinder is 15 mm. When the blocks are placed edge to edge inside a double wall, vertical holes of 30 mm in diameter are created in the centre of the wall to distribute the reinforcement (Fig. 3).

The press used is produced entirely by a metal manufacturing company in Pokhara, Nepal. (Fig. 1) This factor is relevant because the costs are much lower than imported machines (by a ratio of 1: 4), avoiding problematic and costly border management. Ultimately, it makes a technology available to the entire country´s population. The original design comes from a free model available on the internet taken from assembly drawings provided by ABARI. During several months, different tests and modifications were made to the original model until a machine was obtained that fulfilled the minimum requirements that we had demanded.

4 THE LABORATORY

In collaboration with ABARI, a small laboratory was created to perform soil and aggregate analyses. A partnership agreement with the Universities of Kathmandu and Pulchowk enabled the use of their facilities to carry out more complex testing samples of earth and bamboo structures. This is an unprecedented project in Nepal that is still at an early stage.

5 CLAY SOIL AND ITS CARACTERITZATION

The land on which the town was erected was rich in clay. The location on the banks of the Trisuli river had generated the formation of significant alluvial deposits for centuries. Although it was possible

to corroborate the presence of clays with simple visual and organoleptic analyses in situ, a scientific process of soil characterization was followed in order to quantify its proportions.

A representative sample of soil was obtained from a plot with the possibility of starting a small quarry. The complete grading curve was analysed by the sieve test for wetting, sieving and drying and Sedimentometry test with and without chemical dispersant. The bulk density was determined by the pycnometer test and its grading curve was improved by adding other aggregates from the area i.e. sand and gravel. The test methods followed were based on Indian reference standards (BIS/CED 43), the Brockville Laboratory Exercises (Teutonico 1988) and the methodology of the author of this article (Masso & Barbeta 2014).

The texture of the sample was determined according to the ternary soil classification diagram as Sandy Loam. The amount of clay was quantified by 17% (Figs. 4 & 5).

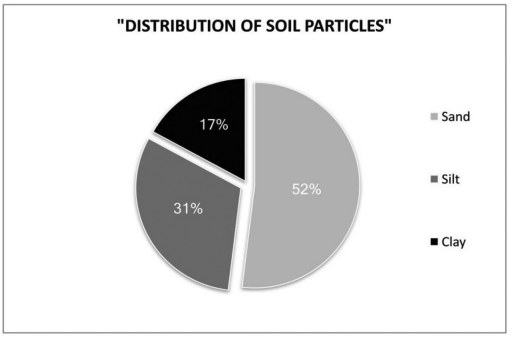


Figure 4. Soil particle size distribution.

6 THE CEB FACTORY

The CEB factory was designed as the backbone of the project. Its implementation was the first action on site. A team of local workers, mostly women, was trained in machine management and CEB production. During the first stage, they had to produce the necessary blocks to build the walls of the Hostel. This period was dependent on and financed by the Petit Mon NGO. However, after the first stage, the workers´ cooperative could then start producing bricks for their own homes and/or for sale, but always cooperatively self-managing their own performance and profit.

The factory has different areas for stacking and sieving clay soil and aggregates, two simultaneous mixing spaces, a closed workshop where the manual press operates and a covered but ventilated area for the curing and drying of the blocks. The clay soil quarry has been located at 500 m from the factory, exactly at the point where the test samples were obtained. The clay is extracted by hand and transported by truck to the stacking area.

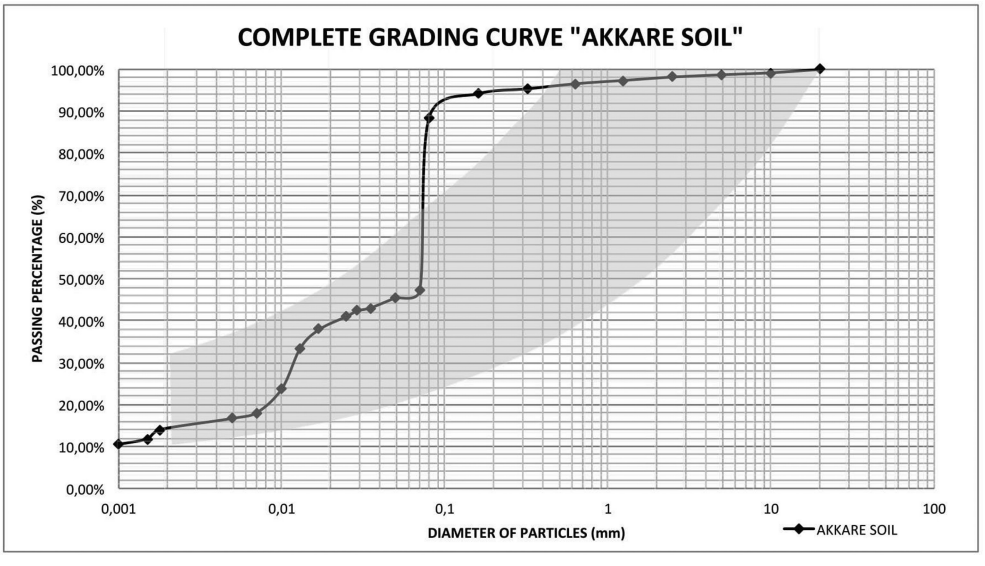


Figure 5. Grading curve graphic of clay soil sample.

7 THE BLOCKS PRODUCED: COMPOSITION, ANALYSIS AND RESULTS

From the grading improvements theoretically studied during the soil analysis, five different compositions were proposed to be tested for the manufacture of the blocks. These combined different percentages and types of physical and chemical stabilization. Physical stabilization based on aggregates characterized i.e. sand and gravel, and the chemistry based on the contribution of 5% to 8% of Ordinary Portland Cement (OPC). List of compositions.

A1: 65% Clay soil + 30% Gravel + 5% OPC
A2: 55% Clay soil + 40% Gravel + 5% OPC
A3: 63% Clay soil + 29% Gravel + 8% OPC
A4: 55% Clay soil + 40% Sand + 5% OPC
A5: 53% Clay soil + 39% Sand + 8% OPC

A representative sample of each composition was tested for compression breakage at Pulchowk University. For the test, a manually operated hydraulic press was used. Samples were transported to Kathmandu and cured for 28 days at constant temperature and humidity before being tested. To perform the test, the blocks were divided into two halves by a circular saw with diamond disk. Between 4 and 5 samples (each block half sample) were tested for each composition.

The test was carried out according to the procedure of Spanish reference standard UNE EN 772. The values of the normalized compression resistance obtained proved that the composition *A5* with 4.19 N/mm^2 was the best combination (Fig. 7). Consequently, this has been used for the manufacture of all blocks. This result corroborated our minimum forecast of 3.2 N/mm^2 applied during the structural calculations of the load bearing-walls. (BIS/CED 39 2005).



Figure 6. Compression breakage testing machine.

composition nomenclature	density	resistance capacity - standarized levels
A1	1.80 g/cm³	3.25 N/mm²
A2	1.81 g/cm³	2.18 N/mm²
A3	1.82 g/cm³	3.41 N/mm²
A4	1.75 g/cm³	3.52 N/mm²
A5	1.89 g/cm³	4.19 N/mm²

Figure 7. Levels obtained under compression.

8 THE BUILDING SEISMIC RESISTANT DESIGN

In order for the walls to meet the necessary seismic resistant requirements, it was not enough to produce a good quality CEB with a high compressive strength. The conception of the building and its commissioning were of vital importance (Minke 2005).

The buildings were designed with square and symmetrical floors, in single-level constructions. The walls were provided with pilasters at the corners and longer sections. A vertical assembly was arranged every two metres on the axis of the whole wall and three perimeter rings for reinforcement at different heights. One ring or brace at the base, another at the bottom half or window sill and a third ring or hoop at the top which acts as a lintel and support for the cover structure. The rings can be made with reinforced concrete or, following a low-tech system, making a sandwich of two or three courses of bricks enclosed by wire mesh or chicken wire and creating a thicker, horizontal joint to distribute another small reinforcement.



Figure 8. CEB samples ready to be tested under compression.

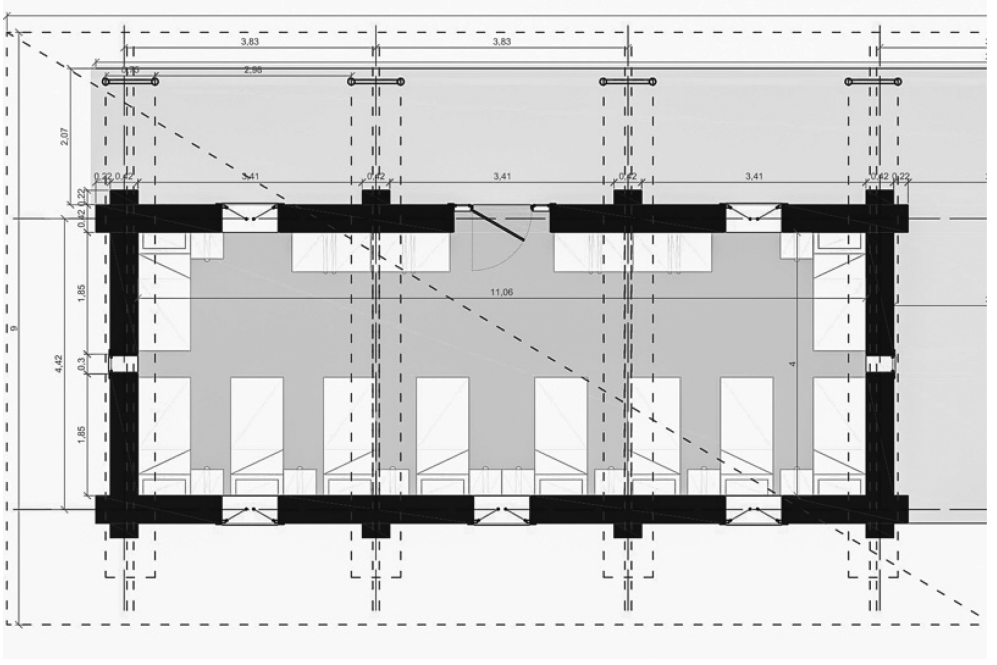


Figure 9. Floor plant for one of the Chandeswhory residence's rooms. In black the perimeter of the load bearing-wall.



Figure 10. The workers of the CEB factory preparing the quarry to obtain clay soil.



Figure 11. Workers shoveling the clay soil on the truck to be transported.



Figure 12. Front view of the CEB factory.



Figure 13. Operating the CEB machine.

9 CONCLUSION

The analytical process followed in this project has set a precedent in Nepal. The author of this article in collaboration with ABARI has analysed six further different soil samples for another six reconstruction projects whose main material is clay soil.

Clay soil and CEB have met the standards raised during the design and structural calculation of the load bearing-walls.

The CEB factory is a reality: it works and the workers are increasingly effective and committed. the psychological effect that the factory has generated. It has provided a window of hope to people who had lost everything.

The Hostel is still under construction but is expected to be completed soon.

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CEB production in social insertion workshops. An experience in Algemesí (Spain)

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ABSTRACT: "Earthen blocks to build a future" is a social insertion project focused on the construction of a public library in Raval de Sant Roc, a slum area in the city of Algemesí (Spain), through the development of participatory activities with the local community. This initiative included the organization of two CEB production workshops, the first one aimed at volunteers and the second aimed at youths in risk of social exclusion. The project also considered the subsequent contracting of the latter to manufacture the blocks with which the new library for their community will be built. This article gathers the results of this experience and offers some considerations about the characteristics that make the CEB a material of a great interest for the construction of collective buildings in disadvantaged communities.

1 INTRODUCTION

When properly selected, earth is a material that barely needs any preparation between its extraction and its use in construction. Moreover, building techniques using earth offer remarkable mechanical and bioclimatic qualities while requiring very few support facilities and a big but unskilled workforce.

These features turn earth into a highly valuable resource when developing construction projects in poor or socially disadvantaged communities. Its use in this kind of initiatives allows a lower investment in building material while bigger resources are allocated to hiring manpower that can be local, due to the low technic requirements of the work. By doing so, the investment is focused in the local community who gets involved in the project and becomes responsive to it from its very beginning.

This article gathers the project "Earthen blocks to build a future", a social insertion experience developed in Raval de Sant Roc, a priority action area in the city of Algemesí (Valencia). Within this initiative, eight youths at risk of social exclusion took part in an educational workshop in which they were trained in the production of compressed earth blocks (CEB). Afterwards, they were part-time hired during three months for the manufacturing of 17,000 blocks that would be used to build a public library in their own community.

This project met several social problems in the neighbourhood and was supported by the City Council of Algemesí, the Public School Salvador Andrés and the local NGO Algemesí Solidari (AS).

2 CASE STUDY CONTEXT

2.1 *The neighbourhood of raval de sant roc in algemesí*

Located in the city of Algemesí (Spain), Raval de Sant Roc is a vicinity that presents a general state of vulnerability and risk of social exclusion. The high rates of school drop-out hinder the access of the local population to the labour market and produce a lasting unemployment problem that hampers the social regeneration of the community.

For these problems to be solved, it is essential the development of public actions aimed to the refurbishment of the community and to the academic and professional training of the neighbours. If these policies are implemented, their life conditions will improve and their job placement will be easier.

2.2 *The new public library in raval de sant roc*

The project for the new municipal library comes up from the joint effort of different entities.

- The City Council of Algemesí included its construction as a priority action in the Comprehensive Community Action Plan in the District of Raval de Sant Roc (17–20).
- The Public School Salvador Andrés, that will employ the new building to implement actions with the local educational community within a process of inclusive and intercultural transformation set up in the project IN-CLUD-ED, tabled in the European Parliament in December 2011.
- The NGO Algemesí Solidari (AS) has taken charge of the organisation and supervision of the workshop. This entity was stablished in 1991 with the aim of raising social awareness in the city.

The new building will hold 100 m^2 of facilities and will be entirely constructed employing CEB as the main material both in its walls and its roof. Its horizontal structure will be defined by four barrel vaults with a 3.40 m span.

3 THE COMPRESSED EARTH BLOCK (CEB)

The compressed earth block (CEB) is a building material employed in the construction of earthen masonry elements. It is produced by compacting in a press a volume of earth commonly stabilized with between 5% and 8% of cement (Amàco 2015) (Fig. 1).

The resulting piece is a modular item that can be easily handled by one single worker due to its small size and short weight. In addition, the constructive technique for CEB masonry is similar to brickwork, so it does not require specialised manpower.

Regarding its characteristics, the pressing process drops the CEB porosity. Their compactness and the stabilisation of the earth with a small amount of cement make them present higher water resistance than most of earthen building techniques (Gómez-Patrocinio et al. 2016). Additionally, CEB is a product with high density and thermal inertia that generates insulating and breathable architectural elements that provide large hygro-thermal comfort to the spaces built with them (Barbeta & Navarrete 2015).

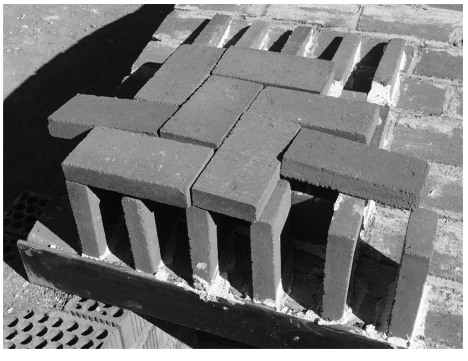


Figure 1. Compressed Earth Blocks (CEB).

Their fair compression resistance allow their use in the construction of bearing elements of any kind. The value of their compressive strength is normalised up to 5 MPa in the Spanish standard UNE 4140, but can reach values significantly higher (Walker 2004).

Most soils are susceptible to their use in CEB production with small corrections and the pieces can be manufactured using small manual blockers. Thanks to these features, it is possible to produce the blocks near the construction site, using local raw materials and disregarding the use of fuel or any other source of energy.

CEB constitutes a reliable constructive material that opens a wide range of possibilities for the development of low environmental footprint projects or buildings located in non-industrialised areas.

4 THE CEB WORKSHOP

The project "Earth blocks to build a future" has taken place between June 2015 and August 2016 and has included different activities directed particularly to the fulfilment that fulfilled either of its educational or productive objectives.

4.1 *Training*

Two training workshops were held by Cedacterra, a company specialised in technical consulting about earthen architectural solutions.

The first course took place in June 2015 with the attendance of 25 professionals, university students and volunteers from Algemesí Solidari (Fig. 2). This activity was focused on the CEB production and its use in construction and involved both the Algemesí City Council and the UNESCO Chair "Earthen architectures, constructive cultures and sustainable development" in the Universitat Politècnica de València.

In May 2016, a second experience was held with the attendance of eight young men at risk of social exclusion from Raval de Sant Roc. This course was focused on the manufacturing of the blocks and the development of positive attitudes towards work. The activity aimed to train these youths towards their later employment and took place in the facilities that afterwards would be used to produce the CEB for the library.



Figure 2. Training course for professionals, university students and volunteers.



Figure 3. Dosage and blending of the mixture.



Figure 4. Pressing process.



Figure 5. CEB storage for the construction of the public library.

4.2 *Production*

During the months of June, July and August 2016, the eight disadvantaged young men who attended the second training course were hired for the production of the CEB with which the public library in Raval de Sant Roc would later be built.

The manufacturing process started with the preparation, screening and crushing of the earth. Once this material had been prepared, it was dry-mixed with cement and finally blended with the proper water dosage (Fig. 3).

This mixture was pressed by means of a manual blocker, producing earthen blocks that would be left to dry 24 to 74 hours (Fig. 4). After this drying process, the CEB were packed in pallets containing 100 or 120 units and carried to the warehouse.

Work conditions were hard due to the physical demand of the process and to the high temperatures reached during the months in which the production was developed. In order to ease the work and maximise the performance of the blocker, workers were divided in two teams that alternate in four-hour shifts.

Production increased as workers gained experienced and teams grew more efficient. During the last month a weekly production of 1000 units per team was reached. After the three months of work 17,600 CEB had been produced enough material to build the public library was stored (Fig. 5).

While the manufacturing process was carried out, each worker was overseen in the development of social and occupational skills such as punctuality, absenteeism, perseverance or social interaction.

5 WORKSHOP RESULTS

"Earth blocks to build a future" has been considered a sheer success considering both its training and labour objectives.

The first course, held in June 2015, brought the CEB technic closer to university students and construction professionals. In this way, it contributed to spread and raise awareness about the existence of socially and environmentally sustainable alternatives for the construction of new buildings.

Moreover, some of the attendants would lately volunteer in the construction of the public library in Raval de Sant Roc or a high school in the city

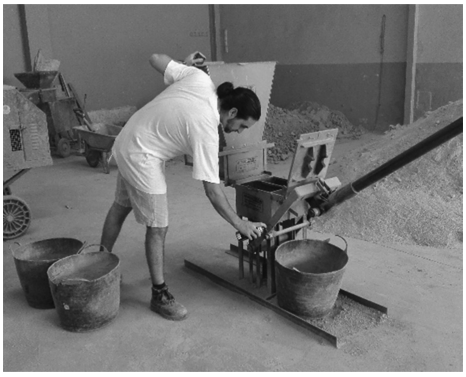


Figure 6. Cleaning and maintenance of the blocker.

of Baasneeré (Burkina Fasso), within a cooperation project that Algemesí Solidari is holding in the town and that involves the use of CEB (Maravilla & Ferragud 2017).

The second course, held in May 2016, qualified eight disadvantaged youths for a specific job and allowed them to access to a temporary job. Six of the workers had never got a working contract before.

The small manual blocker used in the manufacturing process turned out to be inappropriate for such a constant use. It had to be repaired in several occasions with the subsequent interruption of the work (Fig. 6).

Besides that, the workspace dimension were limited and didn't allow long drying periods. Therefore, it was necessary to pack the blocks manufactured every 24 hours in pallets that were moved to the storehouse. Thus the amount of broken pieces was bigger than expected.

However, the manufacturing processes fulfilled the established production objectives within the expected period. The work schedule also considered time for working on the social skills of the employees and on the development of a favourable attitude towards work.

The workshop has also fostered the involvement of the local community of Raval de Sant Roc in the public library project, arising a plain interest in the progress of the construction works and early acceptance of the new facility.

Finally, the organisation and development of the workshop has allowed the members of Algemesí Solidari to learn about CEB manufacturing and using the blocks in construction. The experience gained will be of a great value during the construction of the high school in Baasneeré using the same material.

6 CONCLUSIONS

The experience gathered in this article shows that the compressed earth blocks offer a viable and technically reliable alternative for the construction of buildings with a very low environmental footprint or located in disadvantaged and non-industrialised areas.

CEB does not require skilled workmanship during their manufacturing nor use in construction. Besides, the blocks can be processed from local inexpensive materials and fuel is not needed in their production. Therefore, they are very cheap to produce if there is enough access to manpower. Due to the low requirements of the fabrication, local workforce can be used and economic resources that otherwise would be spent in materials can be allocated in the same disadvantaged community or priority action area.

The initiative that took place in Raval de Sant Roc also demonstrates that involving the local community in the manufacturing process can also increase the labour profile and working prospects of the neighbours and raise receptiveness towards the educational actions that will be held in the new CEB building that they already feel as theirs.

NOTE

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A case-study project of reinterpretation of local traditional techniques

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ABSTRACT: The project concerns a building extension of a traditional rural house, in a village of Castilla la Mancha, a region located in the inner areas of Spain. The building that dates back to the end of the 19th century is characterised by a simple layout, thick stone walls and whitewashing finishing. The project's aim is to maintain the outline of the house and its energy performances but, at the same time, the architects have decided to distinguish the materials used in the new extension of the building. In this case the challenge is to find a construction solution aimed at the maintenance of thermal inertia and the compatibility between the old structure and the new one. For this reason, a new wing of the house has been built with rammed earth and lime walls, also reinforced with stones. Thick modules have been designed, considering the capability of their thermal mass to regulate the thermal gradient in the summer and in the winter. The village, for instance, is characterised by extreme temperature ranges, with huge differences between daytime and nighttime, and also between summer and winter temperatures. Rammed earth walls are a good answer for these problems, also considering the local building culture and use of raw materials, thus this area has usually presented mixed structures, both with rammed earth walls or stone structures.

1 ORIGIN OF THE PROJECT

There are architectural projects that arise from deep personal ties with a certain environment: living in it, knowing it firsthand, and for that reason being able to evaluate potentialities, resources, as well as problems and difficulties that may appear. The project outlined below was brought forward by a private developer, and at the same time it relates to the research trajectory of the authors (Ruiz & Cristini 2014). Working on it has truly provided an opportunity to deepen the local and vernacular construction lexicon of Manchuela, a region of the province of Cuenca in Castilla la Mancha (Noguerón 2011, Fernández 2005, Serna 1985).

1.1 *The local construction characteristics: The area of the Manchuela conquense*

The context of the project is an abrupt transition zone between La Mancha plain and the Serranía de Cuenca. Commonly known as Manchuela, it is characterised by plenty of conifer forests, and more specifically Maritime and Austrian pine forests, which until a few years ago fostered an important timber and resin industry in the region. This area features the southernmost foothills of the Iberian System, in transition between the Serranía de Cuenca and La Mancha, two regions it ultimately does not resemble; it is too hilly compared to La Mancha, but it is also too flat to be properly considered Serranía.

The climate can be broadly described as Continental Mediterranean, whose temperatures are characterised by their extremes (Neila 2000–2002). In fact, it is typical of the area to have a tremendous contrast between the summer and winter seasons, as well as regular storms, which are responsible for the green of its pastures and plains, which in turn feed the transhumant cattle and sheep, stimulate forest growth, and foster wicker and cereal cultivation. Long hot seasons with dry weather alternate with hail and snowfall in winter.

For all these reasons related to the environment and the territory, the traditional architecture of the area relies on varied resources, typical of the heterogeneous geology and landscape variety (Goldfinger 1970). There really is not a predominant material in the area, but rather construction demands and requirements to deal with the climate and abrupt territory. The houses, whitewashed, are usually facing south, and are enhanced by thick masonry walls, to ensure optimal thermal inertia (Jerez 2000–2002, Serrano 2006). The living spaces are quite small, with protection systems, with roller blinds or louvres, all complemented by filtering elements such as patios and grapevines. Interdomes isolate the roofs and foundations of the houses, and are typically used for storage, thus creating an optimal separation from the inhabited spaces.

1.2 *The preliminary draft and its fundamental purpose*

The project is based on proposing an alteration, extension and general accessibility improvements to a modest rural house (Fig. 1) close to Motilla



Figure 1. The building before the intervention (authors).

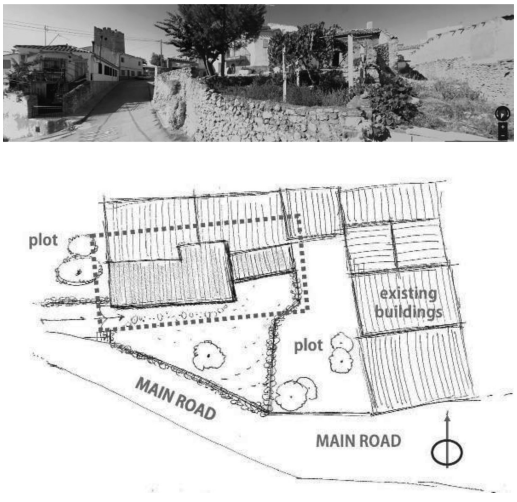


Figure 2. Sketch of the rocky pen with the old building (west flank) and the warehouse (east flank) in relation with the existing buildings (authors).

del Palancar, a village located in Castilla la Mancha. The small building, before the intervention, measured only 45 m² (three rooms and living room) with an added 20 m² of auxiliary and service spaces (kitchen, store, pantry, bathroom and hall).

The functional programme thus adapts and reconverts this space into a second residence (Fig. 2), to be used by a family which has grown over the years and that, due to the advanced age of some of its members, needs to improve the overall accessibility.

The fact of being used intermittently, from a minimum of two to a maximum of ten people of different ages (elderly, adults, children, adolescents, babies.) requires flexible and agile construction solutions. In addition, given the climatic zone with strong thermal changes, the project insists on specific construction proposals based on a great thermal inertia and a low conductivity of the materials to be employed.

2 THE CONSTRUCTION TRADITION AND ITS ADAPTATION

As indicated, the existing construction is very modest, but has good potential. Located in a large rocky pen of 160 m² facing southwards, the building to be reformed is a compact and regular structure with small openings in a masonry wall 60 cm thick with lime-based continuous coating. In the north perimeter, a dividing wall 20 cm thick features a construction system with a base of adobe bricks and wood framing. The house to be remodelled presents an inhabited main floor of about 65 m², as indicated, plus an attic and a half-buried space, both used as wood storage and general storage areas.

Naturally, with these premises the design parameters cannot be met, so the developer decides to extend the dwelling, built at the end of the 19th century, with another 50 m² made *ex novo*, integrating a new volume in the open-plan space of the pen. This new building aims to respect the preexistent structure, but also connects to it, with a ramp access (Fig. 3).

In fact, the difference in height between the access to the pen and the house is approximately 7 m, covered by a set of stairs that do not meet any habitability standards at all. Therefore, one of the objectives of the project is also to try to bridge this gap by using a ramp, integrated in the 15-metre front of the exterior wall.



Figure 3. South façade: work in progress (authors).

In the new module, the dimensions of the existing construction elements are maintained and the wall is executed with a 60 cm thick rammed earth wall system, replicating the distribution of existing openings in the façade.

Between the two modules (the existing volume and the new one), the new service area is developed (access to the covered terrace and entrance hall) which serves two independent sleeping areas, facing east and west, with 3 and 2 rooms respectively.

The north side, that connects with the dividing walls, is improved with the creation of a patio, which serves as an enclosed patio and exit for the double-use kitchen. In addition, insulation gaps are being employed in the foundation and in the attic, both being used as storage and service spaces.

The design of the new volume, its orientation, the use of filters, as well as of the local construction techniques all respect the tradition and blend into it, as it is outlined below in a few more detailed aspects of the developed project.

2.1 *The walls*

The construction system on the south wall of the extension is based on rammed earth whose module size is 1.60 × 60 cm and 80 cm high. In the area of the Manchuela, as previously mentioned, the load-bearing walls are built with various methods and solutions (Feduchi 1976, Fisac 1985).

There is a relative variety of options: mortar, improved rammed earth wall, adobes, mixed solutions. Traditionally all of these are implemented with the purpose of guaranteeing a solid thickness of the wall. Considering this background, we opted for the construction of the south wall with formwork, an inexpensive local solution, since the developer already has a tamper, and also a quick one when it comes to providing raw material.

For this purpose, the formwork is filled with local limestone, hydraulic lime, clay and aggregate (with a mixture ratio of 60% lime, 20% clay and 20% sand, Fig. 4). This technique provides the load-bearing wall with a great thermal inertia and an extraordinary barrier against the strong sun exposure during the summer months (Givoni 1968–1998).

As for the other two flanks (East and North), less exposed, the solution involves a thermal clay brickwork 30 cm thick, due to its excellent thermal behaviour. In both cases, the continuous coatings (both exterior and interior) are executed with a base of hydraulic lime mortar. In the interior, it is lined with plaster; on the outside, it is finished with two layers, the first using lime mortar and conventional aggregate (1:3 ratio), while the second layer using lime mortar and marble powder (1:2 ratio), and blue tint. This way the exterior painting isn't necessary and the hygrothermal behavior of the whole is improved, giving a nod to the finishes and the original colour scheme of the towns in the region.



Figure 4. Formwork is filled with local limestone, hydraulic lime, clay and aggregate. This solution has been chosen for the new façade of the east wing (authors).

2.2 *The roof and the paneled ceiling*

In line with the local construction tradition, and given the difficulty of supplying and arranging heavy materials, for the upper frame we use a panelled ceiling made from 9 × 15 cm pine wood scantlings produced at the Cuenca City Hall sawmill (Figs. 5–6).

In receiving these scantlings, we follow the criteria established in the CTE-DB-SE-M, especially regarding moisture content and drying process.



Figure 5. Panelled ceiling made from pine wood scantlings.



Figure 6. Panelled ceiling: final result (authors).

As for the roof system, the same inclination is maintained, using salvaged tiles to cover the extension. Specific systems are installed to secure the photovoltaic panels for the production and sale of electricity to the grid.

As for the insulation system, the thickness of thermal insulation based on fiberglass and vapour barrier is doubled. 9 × 15 cm wood scantlings, spaced every 55 cm, are also employed in the supporting structure. In this case the beam filling is covered with boards of 10 cm arranged transversely to the direction of the beams. Anticipating possible breakage and as a temporary solution, we also install an Onduline roofing system under the tiles.

2.3 *The openings and filters*

In keeping with the choice of using local materials with the least possible impact, a new carpentry with pine wood section is installed in the openings. Unfortunately the house lacks historical carpentry, since it was replaced with metal frames and exogenous solutions during the 1960s.

Since there are no references to the original openings, we choose a new, restrained, 6 + 6 + 6 double-glazed design with low emissivity glass in all instances.

Also, in order to alleviate the strong sun exposure of the summer months, passive protection systems are applied in such a way that all the openings are protected by external rolling shutters.

In the case of the covered terrace, a large extendable awning has been installed so that the space is perfectly protected against the sun and the rain, and lastly it is also useful as a closing element when the dwelling is not inhabited.

The distribution of openings in the extension improves cross ventilation, and that in turn facilitates thermal energy dissipation during the summer season. The new patio and terrace facilitate ventilation, and the two, being protected and sheltered (Fig. 7), are buffer spaces that in winter and summer lend themselves to be enjoyed, respectively in the warmer hours of the day.



Figure 7. Details: terrace and openings, before and after the intervention in the west wing (authors).

3 CONCLUSIONS

The *raison d'être* of traditional architecture is indissolubly connected with the territory and climate of a given environment.

Thousands of details suggest clues to understand how nothing is left to chance in these buildings (Oliver 2003, Vellinga 2007).

For example, this case study, in line with others studied by the authors, underlines how the volume of a building, its orientation and its functional programme, its colour or geometry, all respond to specific requirements of the site and the various weather conditions which may affect it (Ruiz Cristini et al. 2014).

In addition, the spaces, the openings, the materials and their implementation respond to rules that provide for the adaptation of a building to a particular environment.

The identity of this project (Fig. 8) is rooted in the understanding of all these mechanisms. It has been a matter of identifying principles, understanding them without straining, and applying them to the renovation project of a rural house.

To all these factors is added the difficulty of having a single façade to manage the composition of the project, orientation and ventilation. All the others elevations are blind and this point underlines the complexity of the project. The north façade is blinded by a couple of party walls, meanwhile the east and west flanks have not openings, to respect existing plots. For this reason, the new terrace has a strong potentiality for the functional and hygrothermic program of the building (Fig. 9).

Low budget is not a constraint (Fathy 1986). The use of local construction solutions and construction prin-ciples known to the local workers helps to execute the work, containing its cost. Also, the constant reference to tradition (Fig. 10) does not limit other important aspects of the project, such as the correct implementation of the facilities.

In this case it should be noted how the installation of photovoltaic panels on the roof and their

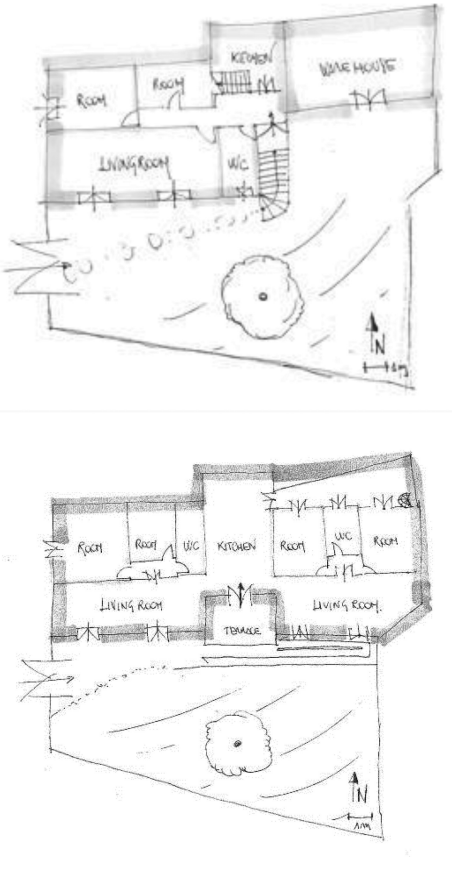


Figure 8. Sketches of layouts: before and after the project.



Figure 9. View from the terrace, towards the poplars (authors).



Figure 10. Winking at tradition: the ramp, completed by ancient tiles, recycled (authors).

connection to the grid has been planned for possible sale (IDEA 2012).

This has allowed to support the heating system based on radiators, since the energy produced allows to compensate the power consumption. Additionally, two stoves fuelled by forest waste products from family-owned farms contribute to the thermal comfort.

At any rate, LED lighting and energy class-A devices and appliances have been employed, complementing the project with particular attention towards essential energy requirements.

NOTE

This work is part of the research project "Restoration and rehabilitation of traditional earthen architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention", funded by the Spanish Ministry of Science and Innovation (Ref.: BIA2014-55924-R; main researchers: Camilla Mileto and Fernando Vegas López-Manzanares).

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Restoration of monumental earthen architecture



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Restoration method on the southern wall of the Medieval access road to the Generalife

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ABSTRACT: The southern wall of the Medieval access road to the Generalife is part of a set of earthen structures that make up the Large Orchard of the Generalife. Parts of these structures, which have barely been touched ever since they were built, are clearly in a poor state of conservation. In 2004 a study, supported by the Getty Institute, began on these walls. In collaboration with Universidad de Granada, restoration works were carried out in 2005 to consolidate the walls by means of the high-pressure earth mortar injection system. The study analyses this and other repairs of different periods from different points of view, as well as the current stage of restoration works, in order to establish evaluative criteria based on real models of the aging of different techniques. The present study comprises research into the optimum strategy regarding the general restoration of earthen structures in the Alhambra palace complex.

1 INTRODUCTION

1.1 *The Royal Orchard of the Generalife*

To the north-east of the Alhambra and beyond its borders lies the Nasrid estate of the Generalife, which, although independent, maintains a close geographical relationship with the palaces, underlined by a striking direct communication between the two: the medieval access road to the Generalife.

The Generalife was a Nasrid royal pleasure estate, that is to say, an estate that was at once residential and agricultural, with a palatial building set amid a vast expanse of cultivated land and pastures. Its location on a steep hill meant that the arable lands were divided from the beginning, by way of terraces, into four large orchards. Their names have changed over time, but today they are known as Colorada, Grande, de la Mercería and de Fuente Peña. We know that the Grande or Large Orchard, of which the wall we are studying defines the northern limit, has retained the same name since at least the 16th century (AHPAG 1571).

Among the various medieval access routes to the Generalife, the one closest to the Alhambra, as mentioned above, is a path that ascends between the walls separating the orchards, directly communicating both palatine areas.

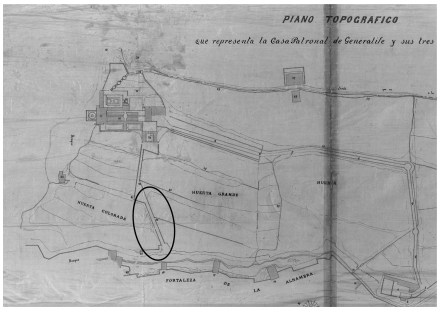


Figure 1. Topographical partial map of the master's house in the Generalife and three of its orchards. Salvador Amador, 1847. (AHPAG 99). In red, the zone where the restoration work was performed.

1.2 *Situation of the earthen walls delimit the Huerta Grande*

Extending to the south-west of the palatine enclosure and below its gardens, the Large Orchard offers, among other architectural values, and apart from its ecological importance—the result of practically uninterrupted cultivation since the Nasrid period—one unique feature: the dividing walls of the orchards, which are considered in some literature to be the true defensive walls of the Alhambra (Bermúdez Pareja 1965).



Figure 2. Initial phase of the restoration in February 2015 (López Martínez).

Built to formalise and regularise large terraced areas, these walls have, despite their natural deterioration over centuries of being exposed to the elements, retained the essential nature of their stonework.

Of the four terraces that make up the cultivated fields of the orchard, the upper part today forms part of the theatre of the Generalife and its adjoining gardens. The next terrace is contained by what we have called "Wall 1", and in which our team carried out restoration works between 2009 and 2012. The rest of the terraces have not yet been touched by any restoration work, although we know that they must have been repaired since at least the sixteenth century, particularly after the uprising of the Moriscos which left the Royal Orchards in a deplorable condition (Tito and Casares 2011); additionally, the archaeological studies that we have conducted on Walls 1 and 2 have convinced us of the continuous reparation and reinforcement processes that were already necessary in the Nasrid era to assure the stability of the walls despite the movements of the earth beneath the different terraces.

A different situation is presented by the wall that determines the northern limit of the three lower terraces, which we have called "Wall 2", and which also forms the south wall of the medieval access road to the Generalife. This has been the subject of numerous repairs over the course of time. In particular, the wall underwent reconstructions between 1934 and 1935, under the supervision of Torres Balbás (1970), and again in 1970 under Prieto Moreno (Prieto 1972).

At present, the wall shows traces of all these procedures, but it also presents serious stability problems, mainly due to the presence of a large hackberry tree (which has since been removed) whose roots took advantage of the discontinuity caused by the wall being built in fact of two parallel, but not adjoining walls, to penetrate the interior of the earthen wall. As a consequence, the outer wall—the weaker of the two because of its thinness—was

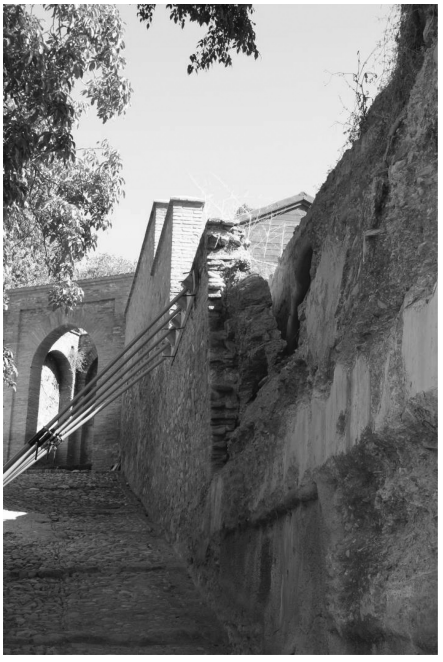


Figure 3. The warping of the rammed earth wall reinforced with lime strata together with the cover of the restoration of Torres Balbás (Bestué Cardiel).

gradually fragmented as it became warped until it was no longer straight, either in the horizontal or vertical axes. Even the restoration work carried out by Torres Balbás, which had tried to alleviate the deformation of the wall, has been compromised, due to the continual warping process.

2 RESTORATION WORK ON THE SOUTH WALL OF THE MEDIEVAL ACCESS PATH TO THE GENERALIFE

2.1 *Data provided by archaeology regarding the repairs*

In the different phases of restoration on the Generalife walls, archaeological work has provided valuable information that has made it possible to understand more precisely not only the construction process of the orchard walls, but also their evolution over time throughout the various alterations and repairs that were undertaken from the very beginning in order to adapt the construction to the topographical needs of the slope and to the stresses and forces that the earth deposits have generated on the wall.

In particular, with Wall 2, we find the construction of two parallel structures: the first one made entirely of double-sided rammed earth reinforced

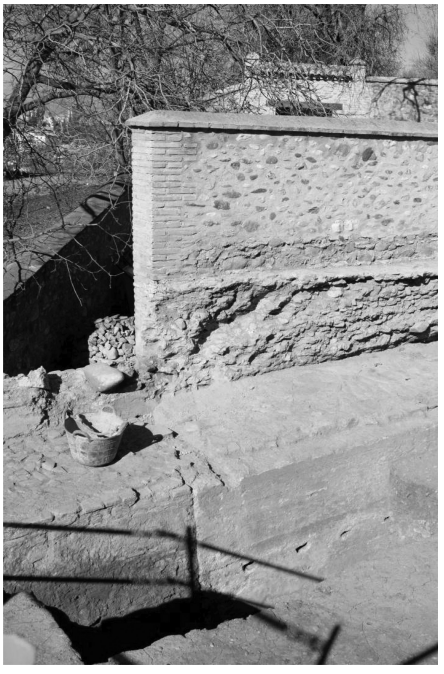


Figure 4. Wall added to the southern side of the rammed earth wall that delimits the medieval road. First stage: rammed earth reinforced with lime strata; second phase: belted masonry wall. On the first wall, the facia added recently by Torres Balbás (Cañones).

by lime strata, with a width of approximately 75 cm; this is the wall that faces the medieval passage. On the south side, a second wall was later added which, in the first phase, was also built of rammed earth reinforced by lime strata, and which was later repaired by belted-masonry rammed earth on one face.

This stronger structure has a width of 145 cm and must have remained a few cm below the coping of the previous wall.

A stratigraphic reading of the walls indicates that at some point the exterior wall suffered serious damage and was possibly repaired, beginning at the north-west corner and ascending to the east, with a rammed earth structure that encompasses both walls, obtaining a final structure of 220 cm in width and a joint coping at a single height. On top of this coping, several rows of fragments of brick and various ceramics were added without any apparent order.

2.2 *Historical restorations*

The Historical Archive of the Alhambra and Generalife has preserved numerous files from the 16th century that refer to specific repairs of the Large Orchard walls, the opening or closing of doors, the construction of houses for settlers, etc. All this gives us an idea of a space in continuous use and transformation over the course of time.

In the 20th century, once the settlers ceded the land of the Royal Orchards to the Alhambra in 1921, a new era began for the Generalife, one characterised by a vision of the entirety of the space and its use, which would partly be dedicated to the enjoyment of visitors.

Early on, the conservation architects of the Alhambra and the Generalife became aware of the value of the Generalife gardens as a perennial agricultural space.

Leopoldo Torres Balbás was the first conservation architect of the Generalife under the General Directorate of Fine Arts. In his work diary from 1925 to 1936, the architect describes briefly but accurately the works being carried out on the



Figure 5. Coping of Wall 2, at its north-east corner. Reparation of the rammed-earth wall that encompasses both walls, and the coping finished with rows of ceramic pieces of various origins (Bestué Cardiel).



Figure 6. View of the Generalife and its orchards around 1923 (AHPAG).

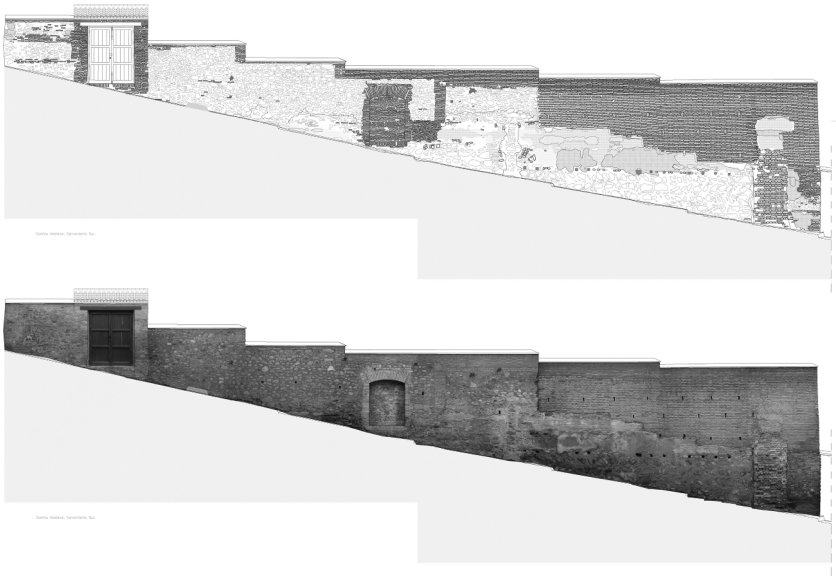


Figure 7. Restoration project on Wall 2 with an indication of the different repairs carried out between the twentieth and twenty-first centuries (Designs: Urbistondo).

medieval road. His notes mention the orchard entrances and the walls on the side of the alley being rebuilt with masonry. These reconstructions sometimes covered the very deteriorated earthwork, which had lost much of its substance; at other times, they are attached to the lime reinforced rammed earth wall in the same plane, filling in the gaps.

After the archaeological excavation, the architect discovered the beginnings of the double door and the trough in the middle of the alley. Torres Balbás rebuilt the intermediate access ensemble using bricks from an easily recognisable manufacturer. He restored and covered the old drain, built new platforms to carry water to an irrigation channel along the sides of the road, and rebuilt the masonry along the entire slope.

Figure 6 is an image from 1923 showing the condition of Wall 2 before the intervention of Torres Balbás.

Around 1970, Prieto Moreno picked up the restoration of the medieval alley again, this time covering large surfaces of the access to the medieval road with brickwork. This masonry does not merely rest on the lime reinforced rammed earth wall, but completely covers it, creating a facia that hides the original structure.

Finally, in the year 2000, as part of works carried out to reorganise the gardens of the Generalife, layers of brickwork are also laid into the structures built by Torres Balbás and Prieto Moreno, thus completing a mosaic of restoration works from which it is possible to draw conclusions.

2.3 *Current repair attempts*

In 2005, within the previous study for the restoration of earthen walls of the Alhambra and Generalife led by this institution with the support of the Getty Institute and the collaboration of the University of Granada, an experimental technique was put into practice for repairing rammed earth walls by injecting earth and lime mortar under pressure.

The purpose of this trial was to validate the starting hypotheses that predicted good adhesion to the disintegrated stratum of the earth wall and excellent cohesion of the material deposit. The intention was to determine its viability in heritage structures where other equally important criteria, such as the reversibility of the technique, its harmlessness towards the original substrate, the suitability of the finish, the appearance and colour of the sacrificed surfaces, etc., also come into play. To this end, the mixture was applied to the cavities in the wall, remaining 3 cm short of the overall surface, and then several finishes were made: washing the final surface with a sponge; leaving it as it was; smoothing it with the trowel; and applying dry earth in a larger diameter. The projection was left to dry and carbonate naturally, and several samples were taken in 2012 to analyse the aging process and the resistance of the procedure.



Figure 8. Wall 2, in which rammed earth walls with lime strata can be observed. In the lower part, the attempts to inject the mortar at pressure into earth can be seen with their different finishes1 (Bestué Cardiel).

Around the same time, restoration work began on Wall 1 of the Large Orchard, where restoration techniques more in line with existing approaches of repairing earthen walls were applied (López & Bestué 2014).

3 TEST RESULTS

3.1 *Adhesion and cohesion of the mixture*

Thanks to the previous studies carried out in 2004, we knew the original earth composition of the wall as well as its mechanical characteristics. In this way, we knew of its high resistance to compression, around 110 kp/cm^2. Its material composition had a high silica content, 66.3%, with a slaked lime content of 18.8%. This proportion would be equivalent to an approximate dosage of one part of lime to four of aggregates (gravels, sands and fine aggregates). The density and porosity obtained for these samples were average.

The tests performed with the pressurised earth mortar tried to respect, as far as possible, the dosages and gradings extracted from the material characterisation of the rammed earth walls. However, the results were not as encouraging as had been anticipated.

In terms of adhesion, it is true that in the innermost layers of the application, where the new mass impacted on the old one, the adhesion proved to be optimal. However, for large applications this solution is not practical since the adhesion must be carried out on other layers of pressurised earth mortar which have not yet dried and which are necessarily applied with a higher degree of humidity than the usual mixtures of earth applied to rammed earth walls. This causes the newer masses to fall away and horizontal cracks and fissures to appear, as well as weak points emerging in the perimeter areas where the original rammed earth wall and the new contributions meet.

There are similar problems with the cohesion and resistance of the pressurised earth mortar. From the specimens extracted, and the experience gained, during the removal of these applications at the beginning of 2017, we found a disintegrated and barely carbonated mass, despite the passage of several years (2005–2017). Only the innermost layers of the mixture, those which were in direct contact with the original surface of the wall, had an acceptable degree of cohesion, and the entire mass lacked the resistance to high compression that the original mixture provided.

By contrast, the removal of the sample made in 2005 has been much simpler than expected. The lack of a greater cohesion of the material has allowed the removal of all the mixture without causing noticeable damage to the original material.

3.2 *Finishes and external appearance. Manipulation of the mixture*

Regarding the external finish that could be obtained on the pressurised mortar samples, optimum results were limited by the initial setting time of the mixture and its greater humidity, which made it impossible to perform some types of finishes. In addition, the pressurised application has one fundamental disadvantage compared with traditional techniques: a lack of precision.

Applying mortar at high pressure naturally makes it impossible to adequately profile the contours or make careful contact with old walls, and drastically limits the control needed when placing a new material over a pre-existing one.

In this sense, it seems that one of the benefits this technique offers is to freeze the extreme degradation of a rammed earth structure with minimal alteration of its state.

3.3 *Other techniques to be used*

After this last experiment, which was carried out on a small portion of the medieval wall of the Generalife and has now been removed, we carried out another experiment on the nearby Wall 1 of the same Orchard, with very different results.



Figure 9. Application of the traditional technique of rammed earth construction on Wall 1 (Bestué Cardiel).

In this case, we used traditional techniques to produce and install lime reinforced rammed earth walls that allowed us to adapt to the different causes of degradation in these walls.

The main problems to be solved do not differ dramatically from the ones usually found in earthen structures: loss of mass and volume, erosion and disintegration of the coping of the walls, detachment of the crust with the consequent weakening of the surface of rammed earth walls, and in this case in particular, a pronounced collapse of the upper parts of the wall that calls for new solutions other than those already used in the repairs made in the early twentieth century.

In all these cases, we believe that the technique that must be used would preserve the original method of work, by depositing a compressed mass that stabilizes the structure.

4 CONCLUSIONS

Wall 2 of the access path to the medieval road of the Generalife has been restored over time using different solutions. Of these, the historical repairs of Torres Balbás and Prieto Moreno were based on depositing material using a technique that differed from the one originally used to build the wall. Torres Balbás opted for a traditional system that had been used since ancient times in Granada's rammed earth walls, and in particular in the Alhambra, which consists of replacing the gaps of lime reinforced rammed earth with masonry or belted masonry that aims for evenness with the surface of the external face of the original rammed earth walls. This technique solves the problem of the stability and integrity of the rammed earth wall, allowing the observer to recognise the original parts of the wall. In the 1970s Prieto Moreno took a different tack by facing the walls with brickwork. This solution, which did not involve any excavation, ensured the survival of the original remnants, and completely hides the rammed earth walls that are covered by new structures that sometimes advance on the façade line of the walls, altering the original architectural readings.

The application of techniques such as the pressurised injection of earth and lime mortar, can pose problems of precision, and involve not only a modification of the structural building system of rammed earth walls, but also a lack of absolute control over the material added and of the finished result due to the difference in the time required for the mixtures to set and dry. It seems that this solution should only be considered when the state of deterioration of the original material and the urgency of action does not allow for other methods of traditional intervention that, in our opinion, remain the optimal solution to be applied in the restoration of raw earthen structures.

NOTE

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The keep of the Alcázar of Carmona (Sevilla, Spain). Materials for the restoration of rammed earth walls

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ABSTRACT: The Alcázar of King Peter is a representative building of Spanish military architecture from the 12th to the 15th century. Built with rammed earth, it has been restored on several occasions, for which reason its restoration required a comprehensive historical and constructive analysis. For this purpose, the materials that make up the rammed earth walls of the keep have been physically and mechanically characterised, which allowed for assessing their condition and establishing guidelines for their proper restoration.

1 INTRODUCTION

This project synthesises a study of the characterisation of the materials in the stonework of the keep of the Alcázar de Arriba or Puerta de Carmona of King Peter in Carmona, Seville, an archaeological site declared a Monument in 1931 and catalogued as an Asset of Cultural Interest (BIC). It was carried out by a multi-disciplinary team from the University of Seville (Spain) on the occasion of the works carried out in 2016, which followed a project by architect Pablo Diáñez Rubio commissioned by the Instituto de Patrimonio Cultural de España (IPCE), attached to the Dirección General de Bellas Artes y Bienes Culturales y de Archivos y Bibliotecas del Ministerio de Educación, Cultura y Deporte del Gobierno de España. During these works, the company Ánfora Gestión Integral del Patrimonio, S.L., under the technical leadership of Olga Guerrero Chamero, carried out preventive archaeological and earthwork operations.

The differences of opinion among researchers regarding the origin of the remains were settled during the 2008/09 and 2012 campaigns, which evidenced the existence of Caliphate and Almohad structures with successive modifications of the interior space taking place until the modern era. In fact, after reconquering Carmona, in the mid-14th century, Peter I rebuilt it, with later additions being made during the time of the Catholic Kings, in the late 15th century, with three well differentiated spaces: the central one, of a residential and palatial nature, located between two defensive ones, one to the North and the other one, the current Parador, to the South.

The effects of the earthquakes of 1504 and 1755 contributed to the deterioration of the complex (Guerrero & García 2016), which has reached our time with isolated emerging elements and a situation of constructive disorganisation, as well as widespread structural precariousness.

As shown in the plan of the Alcázar (Fig. 1), made by English archaeologist George Bonsor in 1856 for *Historia de Carmona* by Manuel Fernández López, the Alcázar, surrounded by a moat on its N and W façades, had a perimeter enclosure where the Artillery Emplacement and the Guardhouse in the NW corner can be highlighted and, within it, there was a palatial space and two Weapons Squares: the Northern one immediately next to the Keep and the Southern one where, in the mid-70s, a Parador Nacional was built (opened in 1976). The palatial enclosure, with a rectangular shape, presented rectangular towers at its corners, all surrounded by a barbican. The Keep (connected with the Hall of Balconies on its southern façade) is the NE tower. The SE tower is called Torre de la Piedad; the NW one is called Torre Menor; and the SW one is called Torre de la Pólvora. It also

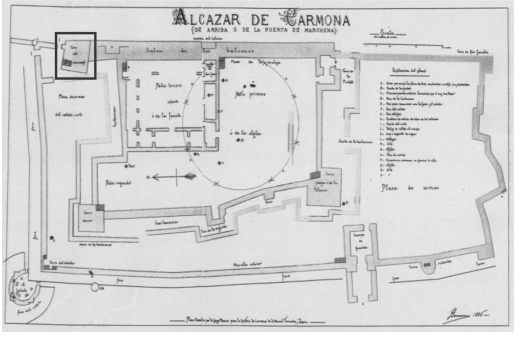


Figure 1. Plan of the Alcázar de Carmona. In red, situation of the keep J. Bonsor, 1856.

featured two other smaller towers located in the Western façade, the largest of which is known as the Torre de los Infantes. Different open spaces or courtyards were included within the palatial enclosure, which Bonsor called the first courtyard or patio de los Aljibes, the second courtyard and the third courtyard or patio de la Fuente.

2 DESCRIPTION OF THE REMAINS OF THE TOWER. DAMAGE AND RISKS

The object of this study are the remains of the keep that raises over a basement of Caliphal origin. The keep is located on the northeast corner of the Alcázar enclosure and emerges as the highest point.

Description of the remains. Originally, the keep featured a square plan with a height of over 10 metres above the caliphal base. Only two walls currently stand: the eastern and the southern ones, which are also now disconnected because the corner has also been lost (Fig. 2).

Constructive analysis. Even though the Alcázar is a conglomerate and an overlap of Caliphal, Almohad and Christian stonework, the studied of the keep studied may correspond to the early 16th century (Guerrero & García 2016). The constructive system used in the walls displays techniques associated with these periods. The height of the rammed-earth module (95 cm), the constructive type (type 11, wooden area with stone lines and triple string courses in brick, (Graciani & Tabales 2008)), the flat section of the putlocks (7 × 3 cm), the separation of the putlocks holes (>80 cm) and the existence of a thick layer of lime mortar in the horizontal joints are evidence of a Christian construction technique with a few Almohad touches (Canivell & Graciani 2015; Graciani & Tabales 2008).

Current condition. One of the objectives of the restoration phase (Diañez 2013) was to consolidate the walls of the Keep due to its preservation status being poor, going so far as to jeopardise its structural stability. Damage has been classified as material, structural and superficial (Canivell 2011) according to whether it affects the cohesion of the mass, its structural stability or the outermost layer.

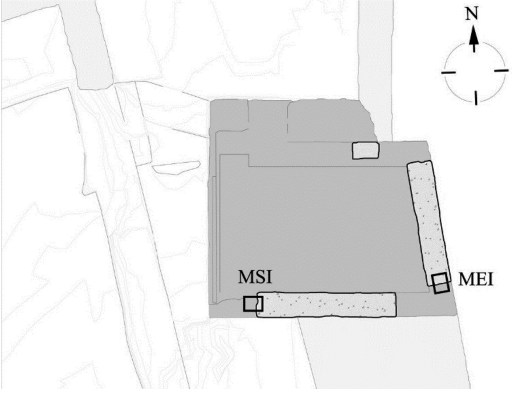


Figure 2. Plan of the keep and the points of extraction of samples.

Material damage. The mass of the rammed earth formwork has eroded, mostly due to the action of water, wind and birds. Erosion is widespread and has resulted in superficial washing, becoming more pronounced due to ponding of rainwater in places such as the putlog holes, at the top of the walls, the joints and the cracks. Even though the cohesion of the mass is acceptable, the interior of the boxes that has been more exposed displays a lower degree of cohesion, reaching a certain degree sanding once the layer of dirt is cleared. Furthermore, as shown in the tests carried out, the rammed earth is not of the highest quality, for which reason the starting point was a more porous mass sensitive to erosion. There are no mass losses, which is the next degree of erosion and would require a replacement of rammed earth mass on one or both sides. In this respect, the only existing cavities have not been caused by erosion or by a lack of cohesion in the mass but by the imprints of constructive elements on the internal surface of the keep, such as beams, floor structures, stairs or openings for doors and windows. In fact, these cavities have already been repaired in the wall.

Structural damage. The eastern wall does not display structural damage. However, the southern wall is slanted 4 degrees to the west, which entails a significant loss of stability, even more so when considering that a large portion of the basement of the keep has been lost in this area. With all of this, images from over 50 years ago show the keep in almost the same condition, for which reason, despite its criticality, collapse is not imminent. The same wall also displays a crack across it, significantly inclined to the west, which runs through all its rammed-earth boxes. This has been repaired recently, along with a small underpinning, and no signs of progression were detected.

Superficial damage. As a consequence of the high exposure of walls and a lack of maintenance, dirt and crusting are widespread on all surfaces. However, a more developed crust can be observed in the southern and western sides, which correspond to the prevailing winds in the region.

For all these reasons, the condition of structural damage is considered serious and, along with a certain risk of collapse for the southern wall, it makes structural stability critical. Regarding the stability and cohesion of the mass, even though it is not ideal, the progression of erosion and mass losses do not represent a high risk.

3 CHARACTERIZATION

3.1 *Materials*

The study carried out in this unique place consisted in characterising two samples of rammed earth stonework (compacted earth area). The designation employed was MSI (southern inner wall), taken from the first line of rammed earth at the level of the north-south wall that encloses the Palace on its eastern surface and MEI (eastern inner wall) in the sixth line, according to Figure 2.

3.2 *Methodology*

An elemental chemical analysis through XRF using an X-ray fluorescence spectrometer by Panalytical (AXIOS model) with an Rh tube and a mineralogical analysis using XRD through a diffractometer by Bruker-AXS of the D8 Advance model were carried out. The determination of carbonates (expressed as $CaCO_3$) has been carried out through a stoichiometric estimate, considering that the CaO analysed is mainly from $CaCO_3$ (confirmed by the results of the XRD mineralogical analysis). This parameter is valid to estimate the original lime content in the rammed earth, since it carbonates over time and transforms into $CaCO_3$. However, it should be noted that the earth used in its construction may naturally obtain carbonated fractions, for which reason not all of the carbonate content can always be attributed to the addition of lime.

The porosity to water was calculated using the aspiration method, in accordance with UNE-EN-1936:07 (2007). To determine mechanical compressive strength, three specimens were carved out from the Eastern Inner Wall, with an approximately cubic geometry. They were later faced with sulphur and their surfaces were calculated with precision prior to breaking, following the method proposed by Alejandre et al. (2012).

The granulometry study of the rammed earth was carried out through a hydrochloric acid 1:1 attack, thereby eliminating the limestone matrix that acts as a binder for the particles and grains in the rammed earth. The result of this process was obtaining the siliceous-silicate fraction that makes up the rammed earth in a disaggregated manner, thereby allowing for its granulometric classification. As a drawback of this technique, it should be mentioned that if the earth has, in addition to the siliceous-silicate fraction, a carbonated fraction, the second one is eliminated during the attack, which may lead to changes in the granulometry curves obtained. The mesh width of the sieves used were: 0.063 mm, 0.125 mm, 0.25 mm, 0.5 mm, 1 mm, 2 mm, 4 mm, 8 mm, 16 mm, 31.5 mm and 63 mm *UNE-EN 933*-1:2012 (2012).

4 RESULTS AND DISCUSSION

4.1 *Chemical analysis through XRF*

The results of the chemical analysis are those that would be expected in these samples, with a medium content of SiO_2 attributable to quartz and silicates in the aggregate/soil and a high content of CaO and calcination loss CL attributable to $CaCO_3$ from the limestone and/or the carbonated fraction of the aggregate (Table 1), with no significant differences being found between the two sections of rammed earth walls.

Regarding SO_3 content, the values found were low, therefore having little relevance and indicating that gypsum (calcium sulphate dihydrate, $CaSO_4 \cdot 2H_2O$) was not used in their construction.

4.2 *Carbonate content*

The carbonate content found in the samples is shown in Table 2 and that in reference mortars in Table 3.

Both samples of rammed earth yielded values greater than 75% for $CaCO_3$. If compared to

Table 1. Chemical composition of majority and minority elements in samples.

Sample	MSI	MEI
SiO_2 (%)	15.62	17.60
Al_2O_3 (%)	2.23	2.22
Fe_2O_3 (%)	1.13	1.13
MgO (%)	0.55	0.50
CaO (%)	42.46	44.57
Na_2O (%)	0.23	0.13
K_2O (%)	1.12	0.88
Ti_2O (%)	0.08	0.08
P_2O_5 (%)	0.79	0.64
SO_3 (%)	0.28	0.30
LOI (%)	34.50	30.93
Total (%)	99.82	99.11

Table 2. Carbonate percentage in the samples.

Sample	MSI	MEI
$CaCO_3$ (%)	75.8	79.6

Table 3. Carbonate percentage (%) of reference mortars (Martín-del-Río et al. 2008).

Dosage by weight (lime:sand)	$CaCO_3$ (%)
1:1	57.5
1:2	40.3
1:3	31.0

reference mortars, it could be established that the lime dosage in construction may have been much higher than 1:1 by weight, which is not very likely as the calcareous nature of the soil (biocalcarenites) where the Alcázar de Carmona is located indicates that a large percentage of the carbonate analysed may come from the earth/soil used in construction, which would indicate actual dosages lower in lime.

4.3 *Mineralogical analysis*

Most mineral phases identified in both samples (Fig. 3 and Table 4) were those that would be expected, taking into account the nature of their components and noting that the high calcite content could come from both the aggregate (biocalcarenites) and the lime used in construction.

Quartz, feldspars and clay minerals in the clay come from the earth used in construction. The mineral concentration in the clay found in the semiquantification carried out indicates medium levels (<15%), for which reason they did not use very clayey soils. No significant differences were found between the two sections of rammed earth from a mineralogical standpoint.

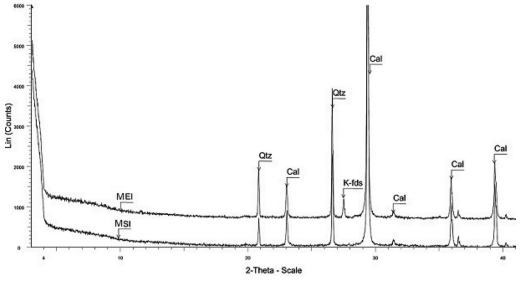


Figure 3. Comparative diffractograms of the two samples using the powder method. Qtz. Quartz; Cal: Calcite; K-fdp: Potassium feldspars.

Table 4. Semi-quantitative mineralogical composition of the rammed earth walls.

Minerals	MSI	MEI
Calcite (Cal)	++++	++++
Quartz (Qtz)	++	++
Clay minerals	++	++
Feldspars	--	+
Gypsum	--	+

++++. Very abundant; +++: Abundant; ++: Middle, +: Traces; --: None detected.

4.4 *Physical properties*

4.4.1 *Porosity and density*

Porosity values may constitute a criterion to determine the quality, preservation status and durability of the rammed earth walls. Table 5 shows the different physical properties found.

The real density values obtained are those that would be expected, taking into account the real density of the majority minerals composing them: quartz at 2.62 g/cm^3 and calcite at 2.71 g/cm^3. As would be expected, these being very porous materials, apparent density is much lower than real density.

Regarding porosity, the rammed earth sections usually present high values of open porosity, in the range of 30%–50% and usually above 35%, for which reason they can generally be classified as very porous materials. The origin of this high porosity can probably be justified by the presence of a high percentage of fine particles with Ø < 0,063 mm (lime, calcite, clay minerals, etc.), all of these being characterised by having a high specific surface with a high water absorption capacity. During mixing, they demand large amounts of water, which, after elimination through evaporation, causes a high level of open porosity in the rammed earth structure. In this study, rammed earth sections display porosity values within the usual range for materials of this type.

4.4.2 *Simple compressive strength test*

It was not possible to obtain data from the MSI sample as it was impossible to carve a sample for breaking. The compressive strength value for the MEI samples was 1.07 N/mm^2, obtained as the arithmetic mean of the breaking of 3 samples with a cubic shape and edges measuring 5 to 10 cm (1.261, 1.30 y 0.65 N/mm^2) (Fig. 4).

Strength was very low, below the usual range of values for rammed earth, at 2–15 N/mm^2 (Martín-Del-Río et al., 2008). Considering that compressive strength depends on multiple factors, such as the open porosity of the material (the lower the porosity, the higher the strength of the material and vice versa), lime content, aggregate compactness, level of deterioration, etc., it is reasonable to think that high levels of erosion, combined with high porosity in the material, have led to low mechanical strength in the walls of the keep of the Alcázar.

Table 5. Real and apparent density and porosity of rammed earth samples.

Sample	Real Dens. (g/cm^3)	Apparent Dens. (g/cm^3)	Porosity %
MSI	2.64	1.51	42.8
MEI	2.69	1.42	44.9



Figure 4. Break of sample MEI-1 under unconfined compressive strength test.

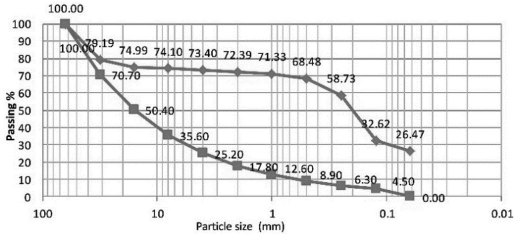


Figure 5. Particle size distribution curve of sample MSI.

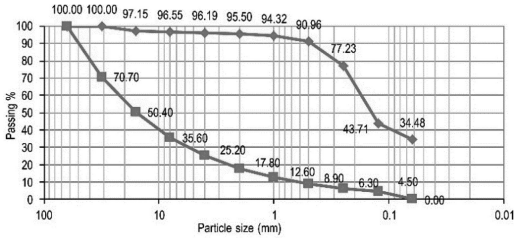


Figure 6. Particle size distribution curve of sample MEI.

4.4.3 *Grain size distribution*

The granulometry tables obtained from both the MSI and the MEI sections of rammed earth display a percentage of fines (% fines <0.063 mm) of 34.48% and 26.47%.

An analysis of Figure 5 shows that the MSI aggregate has a maximum size of 63 mm and a modulus of granulometry or fineness of 2.95.

The modulus of its corresponding Fuller curve has a value of 6.68, for which reason the modulus of the aggregate analysed is quite far from this value, making it an aggregate with low compactness and with a large quantity of fine particles. As seen in the graph, little aggregate is retained in each sieve, meaning that aggregates in all particle sizes are missing.

An analysis of Figure 6 shows that the MEI has a maximum size of 16 mm and a modulus of granulometry or fineness of 1.08. The modulus of its corresponding Fuller curve has a value of 4.79, it also being an aggregate with very little compactness and a large quantity of fine particles, ultimately being granulometries of bad compactness and with a high content of fine particles.

5 CONCLUSIONS

The conclusions that can be drawn from the study carried out are the following:

- The walls of the keep of King Peter in Carmona are made up of monolithic rammed earth containing lime throughout its mass. Even though the calcium carbonate contents analysed in the two samples are very high (>75%), their precise lime dosage (lime: aggregate) could not be determined due to the abundant presence of calcareous aggregate (biocalcarenites). In the mineralogical composition, it can be noted that the concentration of clay minerals ranged between 5% and 10%, which means that the rammed earth did not use very clayey soils.
- Regarding properties related to the structure, the porosity of the samples was found to range between 42% and 45%, values that, despite being high, are within the usual range for rammed earth, while compressive strength was very low, at 1.07 N/mm^2, below the usual values for rammed earth. Considering the multiple factors that may affect them, it is reasonable to think that high levels of erosion, combined with high porosity in the material, have led to low mechanical strength in the walls of the keep of the Alcázar.
- The material characteristics mentioned, i.e. low compressive strength and high porosity, along with the constructive characteristics—mixed construction with stone reinforcement and courses in brick—constitute evidence supporting a Christian origin (from the 15th century) of the stonework studied.
- Both the inspection of damage and the analysis of materials show very damaged rammed earth walls. The cause may be a combination of several factors: defective construction (little balanced dosage, excessive presence of fine particles with a low proportion of clays), intense

erosion and high exposure. Therefore, for the purpose of guaranteeing stability and preventing the progression of erosion, it would be necessary to consolidate the most exposed areas, bind the collapsed walls and further protect all structures.

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Rammed earth and formworks in Medieval fortifications in Castilla-La Mancha, Spain

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ABSTRACT: The use of plain rammed earth, lime-enriched rammed earth or limecrete, is a constant in medieval fortifications of the Iberian Peninsula. Its use was common throughout this period and spread through both the Islamic and Christian ages. Within the La Mancha region, there is an extensive list of fortifications where the use of formworks can be found. However, no catalogue or database for global study has been made to date. Our proposal aims to present an interdisciplinary project born at the University of Castilla-La Mancha in the framework of a collaboration of architects, engineers, historians, conservators and archaeologists. Three case studies are presented, paying special attention to the metrics, materials and formwork assembly. In addition, we analysed in detail the stratigraphic relationship of this technique with other constructions in order to be able to classify them chronologically and culturally.

1 INTRODUCTION

1.1 *Background and objectives*

The presence of earthen structures or earth-lime concretes is a constant in the medieval fortifications of the Iberian Peninsula. The use of earth-lime concretes was common during the Andalusi period, but it also stood out in the Christian kingdoms either by the widespread use of Mudejar labourers in construction or by its own development, especially in border areas. Within the region of La Mancha, an extensive list of fortifications is documented where the use of formwork (*tapial*) is present to a greater or lesser extent. To date, a comprehensive study of these has not been carried out. For research and conservation purposes, we depend on specific works referring to the buildings or constructions that are the object of archaeological intervention, as recorded in the collective books published by the Junta de Comunidades de Castilla-La Mancha (2004, 2007, 2011). Usually, these walls are rarely studied in a monographic and individualized way. In addition, there is a lack of comparative and overall views on this issue.

Our aim therefore is to make a catalogue of rammed earth works of various types and chronology in fortified buildings of medieval times in the Castilla-La Mancha region that once analysed and contrasted would allow us to reach relevant and significant conclusions which can serve as a benchmark in other regions. Additionally, we intend to study the typologies, traditional modes of execution and composition of the aforementioned walls, analysing their components and their current pathologies so that they can serve as support for the various preventive conservation and consolidation actions in these buildings.

This work is part of a line of research that has been trying for years to systematize the study of earthen walls, especially those of the Middle Ages. Authors such as De Boüard (1981), Bazzana and Guichard (1987), Azuar (1995) and Malpica (1998), among others, laid the foundations for the chronological characterization of the formworks in the medieval period. For more specific geographical areas, we have examples such as the recent study of Canivell and Graciani (2015), in which an evolutionary proposal has been made of these structures in the Sevillian zone from the 12th to 17th century. In the Levantine area, the aforementioned Azuar stands out, mainly for the Almohad period, and Navarro and Jiménez for Murcia (2011). Gurriarán and Márquez (2003) describe some cases in Extremadura; Cobos, Castro and Canal (2012) describe lime and pebble concrete walls in Castilla y Leon, as do the studies and the methodological proposal of Gil and Maldonado (2015). Finally, we must refer to the ResTapia project, which is a national approach closely linked to conservation and restoration issues (Mileto and Vegas, 2014), as

well as the international congresses of earth architecture, a true historiographical reference from an international point of view.

This contribution is the result of adding experience that the authors in this article have been developing separately for years. From this union, an interdisciplinary project was born at the University of Castilla-La Mancha in the framework of a collaboration between architects, geologists, building engineers, historians, conservators and archaeologists.

1.2 *Geographic context*

The selected area of study is the present autonomous community of Castilla-La Mancha, owing only to practical and operational criteria. Thus, we are aware of the need to address geohistorical frameworks for the medieval period above all.

To illustrate the methodology for characterizing earth walls, we have chosen three case studies (with varying degrees of development) representative of different and distant geographic areas of our community, where rammed earth walls are relevant. The first case study is of the central area of Campo de Montiel, the second study is of the west side in the middle zone known as Campo de Calatrava, and the third study is of the east, in the Levantine influential area.

2 METHODOLOGY FOR CHARACTERIZATION

2.1 *Historical and archaeological approach*

We divide the research methodology into two major sections, depending on the approach and phase of the works.

In this section, we refer to research works that are mainly, but not exclusively, linked to the archaeology of architecture. First, there are the studies conducted from the analysis of the preserved historical documentation, the bibliographies generated, and the administrative records of intervention in buildings. Second, there are direct archaeological studies from both a preliminary point of view, in the case of superficial archaeological and geophysical prospecting, and those of greater depth, such as the stratigraphic reading of walls and drafts of plans and elevations. Finally, there is archaeological prospecting.

The analysis of archived historical documentation is fundamental for the knowledge of any building; however, this can be extremely varied and, in many cases, precarious. Fortresses linked to the dominions of military orders that occupy a large part of the regional territory have visitor records that offer valuable information for the 15th-18th centuries, but these are scarce for the previous centuries in which their primitive construction is presumed. For the most part, these accounts are deposited in the Archivo Histórico Nacional en Madrid, highlighting the recent cataloguing of the so-called Archivo Judicial de Toledo, with numerous contracts and judgements related to works of the 17th and 18th centuries. There is also need to consult the reserves in the Nobleza Section of the previously mentioned Archivo Histórico, deposited in the Hospital de Tavera in Toledo, municipal historical archives (Toledo, Cuenca, Ciudad Real, etc.) and to a lesser extent, ecclesiastical archives.

The application of the method of the stratigraphic reading of walls is fundamental to the analysis of historical buildings (Caballero 2002). This can be divided into two scales of action. The first is to identify the different construction techniques in each building, and record their stratigraphic position with respect to the whole. The second is the analysis of each technique by means of reading surface elements. To achieve both levels of detail, we must have the necessary floor plans and elevations, which in our case are obtained using a drone for the capture of images and the creation of photogrammetric models using Agisoft PhotoScan (Sabina et al. 2015).

Finally, the application of the most traditional archaeological tools such as excavation and prospecting are fundamental, as we have been able to develop in depth in the Campo de Montiel (Gallego, 2016). The practice of guided archaeological excavations, associated many times with isolated and specific actions, allows us to document the elevations of the walls preserved under the subsoil. This information is highly valuable for correctly registering all the elements of the wall due to its better state of conservation. Also of value is the ability to locate the archaeological materials linked to the foundations of these walls, thus dating them. The intensive archaeological survey allows us to obtain a sample of the ceramic referent conserved on the surface from which data on the chronological occupation of the site can be extracted.

2.2 *Constructive approach*

Archaeometry, or direct observation and analysis of the remains of preserved factories, and *experimental* archaeology are the basic activities in this phase of the study.

From our own experience, we state that the exhaustive data collection of the mixture's composition in the case of earth and/or limestone walls is fundamental to establish comparisons beyond the pure geometry of the wall. In this sense, in order to be able to associate a "type" of these classifications to each of the studied walls, we consider it necessary to establish a simple and objective way of collecting the necessary data. In the texts mentioned it is common to find charts and cataloguing tables elaborated "a posteriori" from the annotations or photographic and photogrammetric information. What is proposed is a model for systematic data

collection in the field that allows for personnel without special qualifications with a minimum of explanation to document all the relevant parameters to later characterize the walls and make the corresponding constructive hypotheses. It is also necessary to use terminology that allows us to refer to rammed earth variations in an effective way, just as we would with a contemporary concrete mix according to current regulations and thus speeds up their description and possible contrasting results in different case studies. The proposal made by Gil-Crespo and Maldonado (2015) is a great advance in this sense and can be a good starting point for its later concretion.

Thus, for the complete study of a wall, in addition to the usual measures corresponding to the dimensions of the rammed earth formwork (thickness, height and length, if this last one exists) and putlog hole distribution on the surface, it is of interest to determine the following parameters:

- Height of the layers, since their existence is often mistakenly associated with a ramming process.
- The thickness of the crust, if made with a different material than the infill, although a crust is not always present.
- In the case of the putlog holes, which do not pass through in most cases, their coincidence should be contrasted on both sides of the wall, as this may prove crucial in contrasting the constructive hypotheses often suggested with strings or crossing rods for the formwork stability.

Although this can also be done once the photogrammetric survey has been obtained, it is necessary to take some reference measurement in situ to contrast the images.

- The type, average and maximum size and the uniformity of the soil grains (gravels, pebbles). If the size is small this can be determined by laboratory analysis.
- The existence (or not) or evidence of embedded reinforcing elements, such as rods/logs parallel to the surfaces or crossing at the corners, and their possible distribution in the walls.

2.3 *Laboratory characterization*

Once all this information has been gathered it is very useful to perform sample tests in the laboratory and incorporate the results into a database so that one can cross-search and perform combinatorial analyses to define chrono-typological and constructive models.

The detailed characterization of the types of materials used, even with reference to specific quarries or digging areas, and their systematic registration, also allows for preventive conservation and restoration works in a much more efficient way that is also more respectful of the existing structures.

In this paper, some cases are studied, and rammed earth walls that have served as the basis for the methodological proposal constitute the basis of our project.

In every example, we give a brief historical and geographical approach to the building and a detailed characterization of the rammed earth variations that we could document in their study.

3 RAMMED EARTH CONSTRUCTION IN MIDDLE-AGE FORTIFICATIONS: CASE STUDIES

3.1 *La estrella castle*

The fortress is located next to the urban centre of Montiel, a population placed in the southeast zone of the province of Ciudad Real. This is the site where the research works are more developed due to the excavation and preventive conservation campaigns that we have been developing on site since 2012.

The walled enclosure is located in the upper area of the hill occupied by the archaeological site with a rough extension of one hectare. After the first analysis of the construction techniques (Gallego and Lillo 2012), we could observe that large samples of rammed earth walls were preserved, corresponding to several phases, all of which belonging to the Islamic period and differentiating up to three types.

The oldest one, documented both in excavation and by stratigraphic analysis, "Tapial 1.Es", covers a previous wall dated in the Omeya period. We have been able to date it to the 11th-12th century. It is a lime concrete wall with a significant proportion of clay-soil and stones, which rests on masonry foundations or, in some cases, directly on the rock over a previous base course of lime mortar. The earth-lime-concrete boxes reach 0.70 m height, with parallelism to similar walls of the nearby fortress ruins of Eznavexor (Villamanrique) and rectangular putlog holes with dimensions between 5 and 7 cm wide and 4 cm high. Putlogs are placed in the upper side of each row.

The second type, "Tapial 2.Es", located only in Tower 1 (Fig. 1), is attached to the previous wall

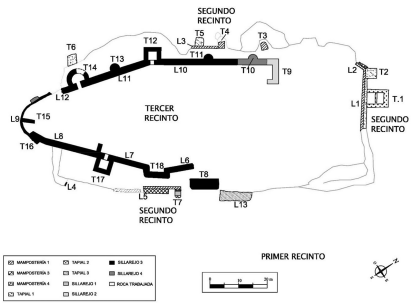


Figure 1. Montiel fortification plane.

and could already be included in the Almohad period considering the excavations in the surroundings (Late 12th century-early 13th century). In this case, the presence of lime and stones is very significant in the concrete mix (as the chemical analysis demonstrates), especially in the lower rows where it practically resembles a lime mortar. In the inner part of the wall, two peculiarities are highlighted. First, a tough Savin Juniper wood (*Juniperus Sabina*) is used parallel to the surface to reinforce the structure. Second a greater proportion of earth exists in the core of the wall (though it is difficult to distinguish a limit between infill and crust). The metric has a short modulation (Graciani 2009) that does not exceed 0.80 m high. The putlogs are rectangular with a 10 cm average width and are 3 to 5 cm high and placed in a groove made in the row beneath the one to be built.

"Tapial 3.Es" has yet to be defined accurately by archaeological excavation, however we can assume it is a rammed earth wall. It appears in the surroundings of surface 13, where a fragment of wall was covered by a crust of stone and lime mortar, already in the Christian period. They are not the only cases documented in Montiel, but the rest are still under study and we cannot provide definitive data on them.

3.2 *Miraflores castle*

The property is located in the municipality of Piedrabuena (Ciudad Real), in the so-called Campo de Calatrava, in the area of historical influence of Alarcos and Calatrava La Vieja and controlled one of the ways that Toledo communicated with Cordoba throughout Los Montes. It is a small building with a 1,250 m² polygonal footprint formed by walls that adapt themselves to the uneven topography of the rocky crest. In this enclosure, we were able to carry out a complete stratigraphic study of the walls as a preliminary step to the intervention project for the consolidation and rehabilitation of the building, which was completed by a survey to confirm the chronology of the walls.

Thanks to this research (Gallego et al. 2015), it has been possible to confirm that most of the vestiges preserved correspond to a construction of the Almohad period (1196–1212). Its construction fits within the examples of the official architecture of this empire, where most of the fortified enclosures are built following the technique of a lime-earth concrete wall, in this case with a decorative finish based on the so-called false ashlar technique (Azuar & Fernandes 2014, Molero et al. 2014). Lime mortar is laid over the joints of each concrete block, protecting the construction, hiding the putlogs holes, and giving the sensation in the distance of an ashlar masonry wall.

The fortress was raised with concrete blocks adapted to the rocky crests. By this means, quartzite masonry bases were made where needed, on which the formwork was later started. The composition of the wall is quite regular throughout the whole building (Tapial 1.Mi), but we could see how it changes in the blocks as the rows gain height. In the lower rows, quartzite and volcanic rock pebble are used for the concrete mix. In the upper rows the mixture diminishes its proportion of stony elements while they are reduced in size, introducing a large quantity of fragments of volcanic rock in the lime mortar.

Attending to metric characterization, we find regular measurements with block heights between 0.81 and 0.85 m and lengths varying from 2 to 2.3 m. There are similar measurements documented in other elements of identical chronology that move between 0.80 and 0.90 m, thus adopting the Mamouni elbow (0.47 m.) which can vary slightly according to the local uses (Gurriarrán & Sáez 2002, Azuar & Fernandes 2014). Bearing in mind the holes (as almost every putlog has disappeared), we observe two types of construction systems. The first corresponds to passing through putlogs located in the lower courses with a rectangular section (13 to 15 cm × 10 cm) and with a stone slab protecting the upper face. The second corresponds to half putlogs inserted in the upper faces of the blocks with a rectangular section (10 cm × 4 cm).

3.3 *Jorquera castle*

The urban settlement of Jorquera (Albacete) is located on the slope of a hill next to the Júcar river.



Figure 2. Tapial 2. Es. with rods inside.

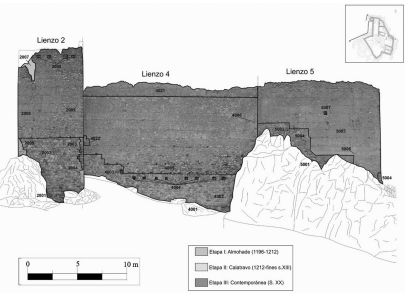


Figure 3. South elevation of Miraflores Castle.



Figure 4. Tapial 1.Mi. with covered joints.

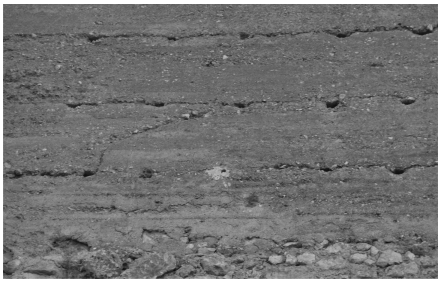


Figure 5. Tapial 1.Jo.

The fortification combines elements from various eras, expanding successively to encompass the growth of the town. The primitive settlement on top of this hill was surrounded by solid and powerful walls raised at the end of the twelfth century (Simon 2011). Its strategic purpose is justified by the advance of Christian King Alfonso 8th of Castile who conquered Cuenca in 1177. The next objective was the conquest of the Júcar valley such that the Almohads would prepare to defend themselves against these immediate incursions. The almond-shaped enclosure with a surface of approximately 14,000 m^2, now abandoned due to its uncomfortable accesses, is partially preserved and shows a different degree of deterioration due to the consolidation work carried out in the 1980s (Castilla 2012). The construction is made of a mix of lime, stones and brown earth from the area setting on a foundation of limestone, often excavated by erosion.

We have shorted two types of walls in this fortification. The first (Tapial 1.Jo), which predominates in almost the whole enclosure, is formed by a homogeneous mixture (0.90 m. thick). The metric of the courses is a 0.7 m average height and we can specify that it is a continuous formwork since we have not been able to document vertical joints but have documented a considerable number of pitched joints. The putlogs, although they are certainly irregular, are grooved at the top of each course and most of them are still in place. These have a rectangular section with approximate dimensions of 7×3 cm. The walls and towers have 10 to 12 course heights (depending on the rock foundation level), but on the inner side, just half of them rise up from the terrain.

The second variant, "Tapial 2.Jo", is located on the northeast wall section. Its thickness is 1.2 m, and it has a walkway in the upper part wider than the rest of the walls. The material in the concrete mix is similar to the aforementioned material, although it is possible to identify a crust of irregular thickness differentiating slightly from the inner filling. Putlogs are partially removed and holes demonstrate a non-passing through anchoring system.

4 CONCLUSIONS

The study of rammed earth walls both in medieval fortifications and other traditional construction requires the assistance of specialists from various branches of knowledge. Our proposal of collaborative work, adding individual experiences and forming a new methodological approach that tries to correct certain topics and a priori conclusions that have long been involved in the interpretation of this type of wall. Also to overcome the narrow frameworks of local studies to try to achieve wide-ranging links and conclusions, information obtained in similar research will be compared. This will allow us to continue to advance our regional research and to discuss it with specialists from other regions.

With regard specifically to rammed earth construction techniques, we propose a standard registration method in which key parameters are recorded, paying special attention to the metrics, materials and signs of formworks used in construction. In addition, according to our criteria, the stratigraphic reading of this constructive technique in relation to the rest of the construction stages becomes essential in order to chronologically and culturally frame this type of work. To do this, data collection and recording using drone photogrammetry is a substantial advancement, allowing us to obtain elevations and reading of walls in those areas that are often inaccessible.

Particularly interesting are the physical and chemical analyses of determinants to establish the types of binder used in the concrete or the enriched mixes used in crusted surfaces. Once the database is expanded with the results of this type of analysis, we hope to be able to propose a reference model for future comparative studies.

With all of this in place, we intend to advance in the intrinsic knowledge of military architecture in the region of La Mancha, not forgetting the study of the societies that built them. This should be kept in mind by future generations who must know, respect and value this type of construction as a legacy of cultural tradition and cultural heritage.

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The Islamic wall of Mula (Spain): 3D reconstruction, restoration and musealization

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ABSTRACT: In Mula, there are still wall stretches of the three enclosures that protected this city until the Renaissance. The first enclosure, the Alcazaba (citadel), is currently occupied by the Castle of Los Vélez (16th century), the second enclosure is the Albacar and the third one is the wall of the Madina, both of them are Islamic structures built in the 12th century. This paper describes the results of the historical, material and constructive analysis and the state of preservation of the enclosure of the Islamic Albacar, as well as the 3D volumetric reconstruction process of this walled ensemble. Based on the conclusions of this study, the full restoration, and most importantly, the musealization of the still standing Islamic wall stretches has been proposed, including the use of the cistern as an exhibition space, which ensures the conservation and enhancement of this heritage and cultural referent of Mula.

1 INTRODUCTION

Mula (Region of Murcia, Spain) is one of the seven Visigothic cities that in the year 713 A.D. became Muslim cities under the Treaty of Tudmir (also known as the Treaty of Theodemir). Two years after the Islamic invasion of the Iberian Peninsula, this Treaty was signed by Theodemir –the governor of the south-eastern part of the Peninsula– and the Muslim invaders, under which the Visigoths delivered their seven most important cities in return of the maintenance of peace and the respect for their customs and religion. There are certain doubts about the location of some of the cities specified in the Treaty; however, all the historical studies include Mula among them.

Nevertheless, the city of Mula delivered to the Muslims was not situated at its current location, but on the nearby Hill of La Almagra, approximately 4 km east. For unknown reasons, the original city was destroyed around the year 825 A.D. and its inhabitants were scattered over several settlements, including the current town of Mula, which at that time would probably be a small farmstead under the protection of a *hisn* (Andalusi castle). Its privileged location, which dominated the passage from Mursiya (currently known as Murcia) to the North-West, and its fertile meadows made the relevance of Mula greater and greater until it was considered as a *Madina* and became the capital of a great *iqlim* (district), which extended over a large part of the Region of Murcia, up to Caravaca de la Cruz.



Figure 1. View of the Castle of Mula (lower part) and the cistern known as "La Cueva de los Moros" (The cave of the Moorish) in the Albacar enclosure (lower part) (J. Fernández).

The internal conflicts in the Andalusi territory and the pressure exerted by the Christian kingdoms of the North conditioned the development of Mula. The constant threats obliged its inhabitants to develop their lives within strongly protected walled enclosures.

2 WALLED ENCLOSURES OF MULA DURING THE MEDIEVAL PERIOD

The lack of archaeological excavations carried out within the medieval enclosure of Mula makes it difficult to study the urban layout corresponding to that period. Nevertheless, the wall remains that are still standing allow us to delimit the perimeter

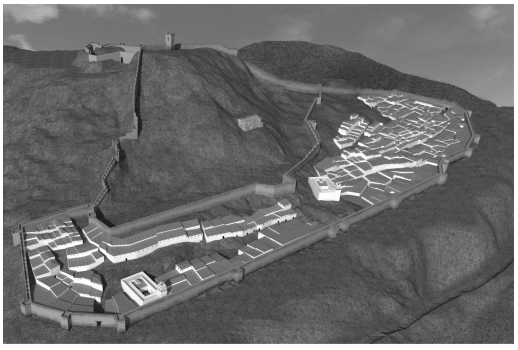


Figure 2. Virtual reconstruction of Mula during the Islamic period, with the three walled enclosures, according to the study conducted (J. Fernández).



Figure 3. Islamic wall stretch located on the east side of the Albacar enclosure (J. Fernández).

of the city, which had been already carried out by the historian Juan González in the late 20th century. However, the medieval urban layout may be intuited, since the historical centre develops by means of narrow, sinuous and almost labyrinthine streets and sometimes dead ends, which characterize the Hispanic-Muslim urban development.

The medieval city was divided into three walled enclosures, according to a pattern that was quite common to the settlements of that period: Alcazaba, Albacar and Madina.

The first enclosure, the Alcazaba, was located in the upper part of the hill, where the city was initially located. This was the smallest enclosure and had, at least, seven towers, among which the Torre del Homenaje (Tower of Homage) stands out, which was probably the only tower whose internal space was passable, whilst the rest of them were made of solid stonework; consequently, this would be the best defended enclosure in the city and the residence of the governor of the *Iqlim,* and it would have a military garrison. In the first quarter of the 16th century, this part of the city was the object of a significant reorganization with the construction of the Renaissance Castle, which is still standing.

The second enclosure, the Albacar, is located in the middle of the hillside and occupies 1.82 hectares. On its northern side, it was enclosed by the Alcazaba and on its southern side, by the Madina, whilst its eastern and western sides were walled, from which significant remains are still standing. The wall layout of this enclosure was approximately 600 metres long and, apart from its eventual use for farming purposes, which was typical to albacars, it seems that this Albacar of Mula linked the Madina with the Alcazaba. The internal part of the Albacar is notable for its rough terrain, with a steep slope and rocky elements, and that is why the Madina could not be developed next to the Alcazaba and required an enclosure that linked both of them and that also served as a second line of defence for the population. The only medieval building still existing in the Albacar (at least, the only building whose remains can be seen) is the cistern, commonly known as the «Cueva de los Moros».

Finally, there was the Madina, with an area of 3.55 hectares, which had the dwellings and other buildings typical to the Islamic architecture, such as the mosques that –according to tradition– occupied the space where the Santo Domingo de Guzmán Parish Church and the Nuestra Señora del Carmen Chapel are currently located. Nowadays, remains of the Madina walls can hardly be seen, given that lots of them were demolished during the urban sprawl of the 16th and 17th centuries.

Obviously, the Madina wall had entrance doors to the city. If a drawing of the city dating from the first half of the 16th century is deemed authentic, there would be six doors -on in the Alcazaba enclosure and five doors in the Madina- that have been located in a 3D reconstruction of the Mula walls.

3 CONSTRUCTIVE ANALYSIS OF MULA WALLS

The Islamic wall stretches that are still standing allow us to state that they were built according to the lime-crusted rammed earth technique; i.e., walls built with a wooden formwork, rammed earth layers and a lime mortar layer between them. Compaction makes lime mortar layers join on the external faces of the wall and form a continuous and resistant lime coating that protects the wall.

The foundations were made of limestone masonry and lime mortar. For some wall stretches, their foundations stood over the ground in order to protect the stonework from the soil moisture; and in the areas with rocky outcrops, the wall is directly

based on the rock or on small layered masonry stonework that were used to level the rammed earth sections making up the wall.

Lime mortar coating remains are visible on some of the wall stretches; therefore, at least in some areas, walls were reinforced and protected with another layer of lime coating, in addition to the external lime crust of the lime-crusted rammed earth. The existence of stones on the upper part of the wall gaps is worth mentioning. These stones isolated the wooden planks from the lime spilled over them, which made it easier to subsequently remove these wooden planks when uninstalling the wooden formwork.

According to the chronological and typological study conducted by A. Graciani and M. A. Tabales, the said stones were firstly used upon the arrival of the Almohads in the Iberian Peninsula in the 12th century. If this is true, Mula medieval walls –as they are known today– would be Almohad and were probably built in the 12th century, although it can be assumed that –previously, in the Almoravid period– there were also walls, given that they would be necessary due to the political instability of that period and the strategic importance of Mula.

A metrological study has also been conducted to determine the measurement unit used for rammed earth wall modules and to propose a reconstruction as close as possible to the original construction; this study has concluded that the said measurement unit was the *vara* of Castile (0.835 m), since it is the average height of the rammed earth wall modules, and sections range from 0.415 m to 2.08 m.

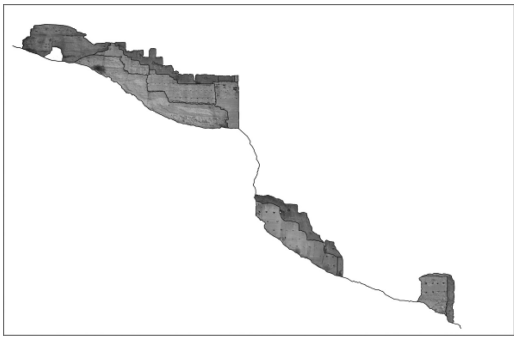


Figure 4. Albacar wall stretches obtained by means of the laser scanning and textured with orthophotos (J. Fernández).



Figure 5. Virtual reconstruction of Mula in the Islamic period (J. Fernández).

4 PLANIMETRIC SURVEY WITH LASER SCANNING AND 3D RECONSTRUCTION

One of the goals of our research has been the full planimetric survey of the Islamic wall stretches that are still standing in order to propose their 3D reconstruction. To that end, the corresponding sketches, measurements and photographs were initially taken in order to identify all the wall stretches and, subsequently, to use the laser scanning technique with a Leica Nova MS-50 multi-station. The use of this multi-station has allowed us to quickly capture, by scanning the walls, a great amount of detailed and accurate information.

The scanning process of each wall stretch started with the on-site determination of the various stations to be taken into account in order to cover all the faces of each wall stretch, by bearing in mind the rough terrain. Once that the scanning process has been carried out at the specified stations, the multi-station generates a point cloud that links the various scans of the same wall. And, from this point cloud, the various plans that graphically document each of the wall stretches still standing are obtained. Moreover, so that planimetry can generate more information and can be technically and visually more descriptive (identifying pathologies, deterioration, textures, tonalities...), orthophotos (images corrected to remove the perspective effect and to facilitate the scale measurement) of each stretch have been inserted.

After having drawn the plans of the various wall stretches and based on the maps of that area provided by the municipal technicians, the terrain contour lines were obtained and the wall remains were placed on the ground plan at their exact location, which had been found thanks to the satellite images obtained from Cartomur. Finally, Sketchup software facilitated the 3D reconstruction of the walls of the three enclosures that configured Mula in the Islamic period (Alcazaba, Albacar, and Madina) was obtained employing Sketchup software. This model identifies the still standing elements. This method facilitates the virtual reconstruction and both the historical and architectural interpretation of the city in the Islamic Period.



Figure 6. Remains of a tower and wall stretch in the southern part of the Albacar (J. Fernández).

5 STATE OF PRESERVATION OF THE ALBACAR WALL

The Albacar wall stretches that are still standing (16 wall stretches and 7 towers) are currently in a poor state of preservation. With the Christian reconquest of the city (in the middle of the 13th century) and the construction of the Castillo de Los Vélez (16th century), both the Albacar wall and the Madina wall gradually lost relevance. The lack of conservation and maintenance that these structures have suffered during the last decades puts the stability and survival of some wall stretches at risk.

Given that they are rammed earth walls, the main factor for their deterioration and degradation is the high exposure to weathering and the lack of maintenance, which has given rise to erosion, areas with important granular disaggregation and section losses, important cracking, collapses, coating cracks, presence of bio-deterioration and vegetation, black crust..., apart from dirt and abundant brushwood in the surrounding area. Furthermore, the cistern has lost an important part of its vault and in one of its enclosure walls there is a crack that puts its structural stability at risk.

Consequently, in order to preserve these Islamic walls, a full restoration must be planned to ensure their proper conservation and enhancement and, additionally, it is necessary to refurbish the natural and urban surrounding area in order to recover this space for the city with a use compatible with its heritage value, as shown below.

6 INTERVENTION PROPOSAL: RESTORATION AND MUSEALIZATION

Bearing in mind that the wall of the Albacar of Mula was declared as a monument and that it is in a poor state of preservation, the intervention proposal has been planned with two basic goals: the consolidation and restoration of the walls, and the enhancement of the architectural ensemble by means of the musealization and refurbishment of the natural and urban surrounding area.

Moreover, given that it was declared as a monument, the intervention criteria must be based on the knowledge of and utmost respect for all the historical, architectural, social and cultural values of these walls, by avoiding the reconstruction of the monument and by enhancing its consolidation and conservation, pursuant to the Law 4/2007 on Cultural Heritage of the Region of Murcia.

6.1 *Intervention on wall structures. Consolidation and restoration*

The first goal must be the consolidation, conservation and restoration of the Islamic wall stretches and towers, based on the premise of minimum intervention and by preventing the so-called "historical forgery". Therefore, the planned intervention includes the cleaning of wall faces and the consolidation and conservation of the existing structures by means of the reintegration of materials in areas with section losses (which shall prevent their eventual collapse), the reconstruction of the top of the existing wall (which shall facilitate the understanding of the monument and its conservation); however, the intervention does not include the reconstruction of the walls that had disappeared. This intervention must be conducted with the lime-crusted rammed earth building technique and with the *vara* of Castile as the measurement unit, according to the original technique used to build the monument. And all the foregoing must be carried out by differentiating the new parts from the original parts in a subtle manner in order not to distort the general image of the wall stretches.

Likewise, herbicides, biocides, consolidating elements and water repellents shall be applied to all the walls and towers to prevent, as far as possible, the deterioration and disintegration risk derived from the exposure to weathering of these structures.

The treatment proposed for the cistern ("Cueva de los Moros") in the Albacar enclosure is different from the treatment of the walls. Given that the intervention proposal includes the enhancement of the monumental ensemble by means of its musealization, the cistern would be the space refurbished to house the "*Centro de Interpretación de la Muralla de Mula*" (Mula Wall Interpretation Centre). Thus, apart from the comprehensive cleaning of the internal part and the surrounding area (under archaeological supervision) and the structural consolidation, this intervention proposes the full reconstruction of walls and vault, the access through the original entrance, and new metal stairs, as well as the installation of ornamental illumination and information boards (as exposed hereinafter). In order



Figure 7. Image of one of the information boards designed as a didactic and educational resource for the musealization of the Albacar enclosure (J. Fernández).



Figure 8. Current state of the Albacar path (J. Fernández).

to differentiate the original materials from the new ones, the volumetric reconstruction of the cistern vault has been planned with a light metal structure with timber cladding, both internally and externally. This way, the new materials added are perfectly differentiated from the original ones, which facilitates the interpretation of the intervention, as well as its eventual future disassembly, if necessary, given that the technical solution consists in some minimum supports on the rammed earth walls.

6.2 *Enhancement: Musealization and refurbishment of the surrounding area*

The intervention proposal as regards the wall stretches and towers of the Albacar enclosure takes into account the idea that only the monuments that have a purpose are properly conserved and maintained. Obviously, the future use of these heritage elements must be absolutely respectful to and compatible with all of their values.

Therefore, the enhancement of the Albacar enclosure was planned by giving it a cultural and touristic use through its musealization, which implies interventions on the paths and streets where the wall stretches are located and on their natural and landscape environment.

As already stated, the cistern would house the "Centro de Interpretación de la Muralla de Mula". The intention is to enhance this architectural element given that, if walls were important to protect the city, the cistern was essential to the life of its inhabitants. That is why the cistern assumes a leading role in the musealization of this environment. In its internal part (it has a surface area of 40 m^2), various information boards and didactic panels would be placed (with texts about the historical site and explanatory drawings), which have been designed as a didactic and educational resource for the planned musealization. These panels are aimed at informing, documenting and showing the eventual visitors how buildings were constructed during the Islamic period (the lime-crusted rammed earth technique) and the historical and formal conditions of the Albacar and its relation with its urban and landscape environment, which would help visitors to understand the heritage ensemble.

Moreover, in the internal part of the cistern, showcases would be installed in order to show the various items of historical interest that could appear as a result of the archaeological excavations performed during the conservation and maintenance process of the Albacar enclosure.

On its lower side, the Albacar enclosure is crossed by a path or road since the Medieval ages. Thus it has been proposed the creation of a cultural itinerary through this path, called "Senda del Albacar," which allows for exploring this historical, architectural and natural site and enjoying the landscape and views of the city. However, to that end, it is essential to adapt this path or road, to make it accessible and safe for any person, including rest areas and the proper furnishings (benches, litter bins, ornamental lighting markers...), in addition to the various information boards that shall show the visitor the history of this environment.

The adaptation and creation of this path implies the need to create a meeting point and rest area, so that a guide can bring together a group of visitors and offer them the corresponding explanations before initiating the tour. Consequently, a green and recreational area has been designed for the southwestern part of the Albacar, next to the entrance. Nowadays, this area (450 m^2 approximately) is occupied by dilapidated buildings that would be demolished in order to create a space easily accessible by vehicles and a new green area for the city.

Therefore, the musealization and urban and landscape adaptation planned for the Albacar enclosure would enhance the recovery and revitalization of



Figure 9. 3D recreation of the internal part of the cistern with the intervention and musealization proposal (J. Fernández).

this space for the city, which would have a cultural and touristic use compatible with its enormous monumental value. Following this intervention, the approval and development of the necessary *Master Plan for the Recovery of the Albacar of Mula* should guarantee the survival of this important historical and cultural heritage of the city of Mula and the Region of Murcia.

7 CONCLUSIONS

The historical investigation and the studies on construction techniques and pathologies conducted in connection with the walls of the Albacar of Mula have evidenced their poor state of preservation. This has prompted the suggestion of the full restoration to ensure their proper consolidation and conservation. Likewise, based on the idea that only the monuments that have a purpose (respectful to and compatible with its values) are properly conserved and maintained, the enhancement of the Albacar enclosure by means of its musealization has been planned, which implies the adaptation of its accessibility and the refurbishment of the natural and urban surrounding area, which would enhance the recovery and revitalization of this space for the city and would give it a cultural and touristic use compatible with its great heritage value.

The constructive analysis and the planimetric survey of the wall stretches and towers have allowed us to carry out the virtual (3D) reconstruction and recreation both of the walled enclosure and of the city in the Islamic period, which facilitates their understanding and historical and architectural interpretation on the part of visitors.

The installation of information and didactic panels, with texts and explanatory drawings in the internal part of the cistern and in several areas of the path "Senda del Albacar", allows to inform and to show the eventual visitors the historical, constructive and formal conditions of walled enclosures (Alcazaba, Albacar and Madina), and their relation with the current urban layout.

The refurbishment of the natural and urban surrounding area, the enhancement of the cultural tour "Senda del Albacar", and the adaptation of the cistern as the "Centro de Interpretación de la Muralla de Mula" –together with the installation of information boards that contribute to the proper interpretation of the three Islamic walled enclosures, as well as the urban and social evolution of the city– shall contribute to the revitalization of this area of the Historical Ensemble of Mula.

Finally, the implementation and development of the *Master Plan for the Recovery of the Albacar of Mula* would guarantee the proper conservation and survival of this important historical and cultural heritage of the Region of Murcia.

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The use of lime, an example of good practices in the conservation of cultural heritage built on earth

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ABSTRACT: The Andalusian Institute of Historical Heritage (IAPH) is a public agency of the Ministry of Culture of the Andalusian Regional Government, accredited as a member of the Andalusian Knowledge System since 2011. The IAPH launched a research project on the use of lime and its applications in conservation with the aim of establishing criteria for the use of materials compatible with traditional and historical masonry. The methodological document that it is proposed is structured in two parts: the first one focuses on the definition of heritage, identifying the scope and formulating procedures based on a tested methodology. The second part deals with the generation of requisites for the conservation of cultural assets which are amenable to standardization, in compliance with standards and recommendations.

1 INTRODUCTION

In the last decades, we have witnessed social demand, heightened by the economic crisis, for the responsible use of natural and cultural resources. In this context, there has been a change in the orientation of work in heritage, whose goal is to achieve sustainability, from the economic, social and environmental point of view, at the centre of the debate on cultural policies. This means a search for the improvement of the quality of interventions and a commitment to control, maintenance and preventive conservation as guarantees of the durability of the actions carried out.

The Charter of Krakow (2000) recognizes the critical nature of the intervention processes, asserting that any intervention on the well-being of a property "implies decisions, selections and responsibilities related to internal heritage, including those parts that do not have a specific meaning today, but may have in the future".

The concept of conservation and all those employed in the sector of cultural assets (restoration, rehabilitation, etc.) refer us to a broader concept that is related to the idea of "intervening heritage". In order to ensure quality in cultural heritage interventions and to meet the objectives of safeguarding, preserving their values and identity attributes, we will place our trust in the development of a methodology and of some intervention instruments, using the general objectives, principles and criteria set out in the international charters, texts and documents of reference and in the corresponding legislation on heritage as a starting point.

The tool established in the Charter of Krakow is the project, which Law 14/2007 of November 26th of the Historical Heritage of Andalusia specifies in the Conservation Project as the technical instrument that should govern interventions in movable and immovable assets which are inscribed in the General Catalogue of Andalusian Historical Heritage. Minimum contents that guarantee the quality of these processes are defined thus: the study of the asset and its cultural values, the diagnosis of its state, the description of the methodology to be used, the proposal of action from the theoretical, technical and economic point of view, and the impact on protected values. Finally, the law also establishes the obligation to develop a maintenance program.

The Conservation Project structure endorses the axiom of "knowing to intervene", a principle that underlies the methodology of the IAPH in the intervention of cultural heritage; a methodology of a critical-scientific nature that is based on a deep knowledge of the asset and its integral consideration through the formation of interdisciplinary teams.

In view of said situation, the IAPH, as an agent of the Andalusian knowledge system, assumes the challenge of setting guidelines and defining action protocols that cover all stages of the process of conservation of cultural assets. As a first action, it is proposed to standardize the use of traditional lime in heritage interventions, a project that is part of the Program for Standardization of Preliminary Studies and Quality Control applied to intervention in immovable assets, which the IAPH has been developing since 1996 (AAVV 1998, AAVV 2003,

AAVV2006) and currently constitutes one of its strategic lines. To this research activity is added its experience in intervention in cultural assets, in accordance with good practices for the preservation of heritage, working on the permanent search for a procedural model of value that translates into protocols capable of responding in the most effective way possible to the nature of the processes undertake and their associated problems.

2 STANDARDIZATION OF CONSERVATION OF ARCHITECTURE IN EARTH

The standardization project carried out by the IAPH proposes as the first action the definition of technical suitability documents for heritage conservation, defining three documents associated with the three phases that structure the development of conservation projects.

CONSERVATION PROJECT		
PRELIMINARY STUDIES	BASIC PROJECT AND EXECUTION	EXECUTION AND COMMISSIONING
STANDARDIZED SUITABILITY DOCUMENTS + TRANSFER		
Characterization	Proposal of treatment and products	Quality control

Each process should be defined based on methodologies already consolidated in different disciplinary fields, flexible and feasible from the point of view of project execution; which will allow us to adequately solve the problems of conservation, which are sometimes complex, that currently affect our Cultural Heritage and, specifically, that are built using earth. In addition, lime will be endorsed as a compatible and sustainable material.

The scope of this work is related to how the Andalusian Heritage Law defines the intervention criteria in Article 20 of Title II on Conservation and Restoration:

1. *The performance of interventions on assets registered in the CGPHA will seek by all means of science and technology their conservation, restoration and rehabilitation.*
2. *Restorations will respect the contributions of all existing epochs, as well as patinas. They should constitute a proper value of the asset. The elimination of some of them will only be authorized, if appropriate, and provided that it is justified that the element that is to be suppressed is degrading the asset and its elimination is necessary to allow the proper conservation of the asset and a better historical and cultural interpretation of said asset. The parts suppressed shall be duly documented.*
3. *The materials used in conservation, restoration and rehabilitation must be compatible with those of the asset. In their selection, criteria of reversibility will be followed, with the obligation of offering sufficiently contrasted behaviours and results. The construction methods and materials to be used must be compatible with the construction tradition of the asset.*
4. *In the case of immovable property, the actions referred to in paragraph 3 shall avoid attempts at reconstruction, unless in its repositioning some original parts of the asset are used or the necessary documentary information is available and its authenticity can be proved. If additional materials or parts are added, the additions should be recognisable and should avoid mimetic confusions.*

2.1 *Importance of preliminary studies in earth constructions*

The monitoring of all the processes to be developed in the Knowledge Phase, known as Preliminary Studies (see Fig. 1), is of interest because of the information about the building that can be obtained; Related to techniques-construction phases, use, restoration interventions, structural pathologies, materials analysis, etc. Results that should be useful in order to know the cultural values and authenticity of the Cultural Asset, the diagnosis of the state of conservation of the materials, the conservation needs of the building, conservation measures most suitable to apply and finally, the requirements of the asset maintenance plan.

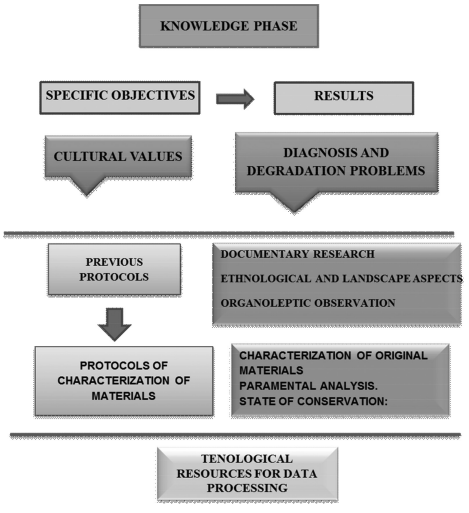


Figure 1. Process map of the knowledge phase or preliminary studies.

At the moment when we speak of actions of conservation traditional earth-based architecture it refers, unfortunately in the majority of cases, to the more initial levels of protection that are reduced to its cataloguing. When projects are carried out, it is worth noting that, considering the complexity of the conservation of the materiality of this construction masonry, the characterization of the original materials should not be systematically considered in the Knowledge Phase or Preliminary Studies. It is necessary to take into account that the valuation of the materialization of earth-based architecture is based on two groups of interest: the construction techniques used and the memory of the traditional activities that they use.

These aspects are already included in the various Letters of Restoration, for example CIAV-ICOMOS of 1992 (extension Charter of Venice 1964) and Charter of Krakow 2000 which establish as basic principles of conservation:

- Scientific research prior to the intervention and conservation of the original materials; In the case of degradation problems, more appropriate and compatible materials can be used.
- Interventions responding to contemporary use must be carried out by introducing techniques and materials that maintain a balance of expression, appearance, texture and shape with the original structure.
- And finally, being a typology of local or regional character integrated in the resources of the territory, its conservation must be approached respecting the landscape, enabling the conservation of traditional wisdom in the design and construction, strengthening and protecting their craft and traditional construction techniques. Their conservation should be supported by continuity of use and maintenance.

The challenge for the forthcoming years is to address integral interventions that contemplate the development of the different phases that make up a conservation project of excellence, using standardized protocols that in some way contribute to its protection.

Due to the cultural complexity of this type of architecture which involves patrimonial dimensions, both tangible and intangible, research in order to assess, diagnose and propose adequate solutions for its conservation and protection must be supported by multidisciplinarity.

The greatest difficulty arises in how to preserve the materiality of this type of architecture and work on this matter is very scarce, example (Elert et al. 2015).

Construction typologies, their forms of arrangement, union or assembly, among others, follow a logic in which they have been able to optimize available resources, establishing precise limits of action that are known and inherited. It is necessary to take into account that much of the knowledge of these activities has been lost at present and/or is found in few territories at world level, hence the importance of the Knowledge Phase and specifically the characterization of materials in conservation of this type of architecture (Guerrero et al. 2012).

2.2 *Fundamentals of study methodology*

The peculiarities of this masonry are due to the typology of the material used for its construction; earth and additives, which are generally used for stabilization and improvement. The investigation of earth as a construction material has been widely developed in the 20th century, related to the stabilization of land for its application in public works (for example roads). The earth is a mixture of clay, silt and sand, and occasionally, it may also contain small amounts of gravel and stones blocks. Its requirements as a construction material are mainly related to its granulometry and clay content, as these parameters define the optimal characteristics of earth for use in walls or adobes. Controlling the contents in clay fraction is due to the susceptibility to water presented by these mineralogical components, which can cause important disturbances in their structure by swelling and/or retraction. These aspects will condition the compaction and density (optimal values 1.7 and 2.3 g/cm^3); parameters that define the stability of this architectural masonry (Houben & Guillaud 1989).

The regulation applied to this type of materials is scarce, the first norm at national level was applied to this type of buildings in 2008: Blocks of compressed earth for walls and partitions. Definitions, specifications and testing methods. UNE 41410, Madrid, 2008. Issued by the sub-committee AEN/CTN 41 SC 10 "Building with raw earth" by AENOR. Most of the existing standards, even at the international level, do not cover the properties of earth as a building material as a whole. It is therefore necessary to standardize the tests applied to earth constructions, both for pieces and for monolithic walls, in order to be able to carry out an adequate comparative analysis between the different existing construction techniques (Cid et al. 2011).

The research on this subject is scarce if it compare it with other typologies of materials, as far as the characterization of original materials is concerned, as well as research in the line of conservation (Maldonado & Vela-Cossío 2011), with some standing out (Ontiveros 1995, Ontiveros et al. 1996, Aguilar Fletes et al. 1998, Ontiveros et al. 1999, Barbeta 2002, Conçalves da Silva Braga 2011). Based on this background, we propose the methodology on the characterization of materials indicated in Figures 2 and 3.

Methodology that is based on the following aspects:

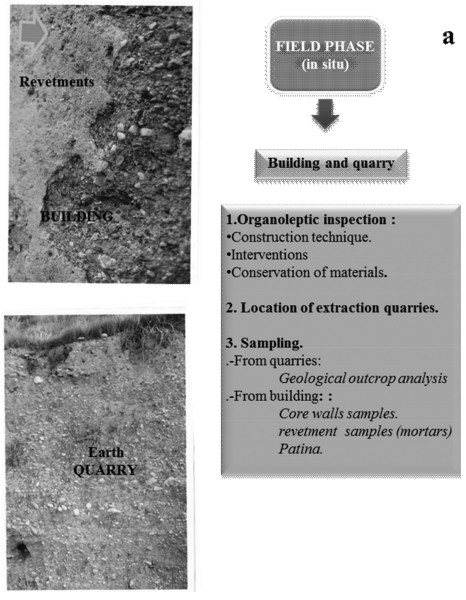


Figure 2. Methodology of field phase.

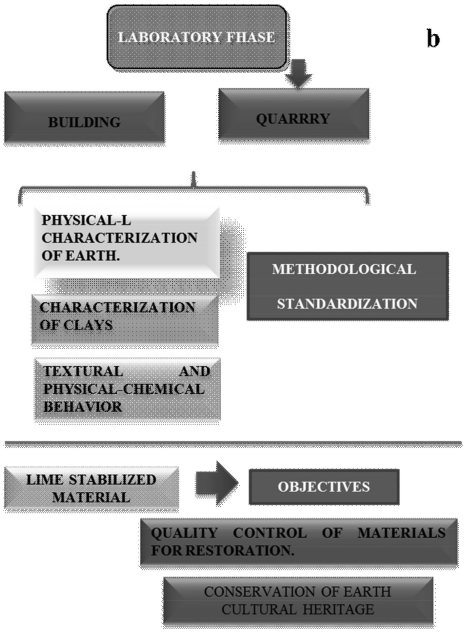


Figure 3. Methodology of laboratory phase.

– Direct observation of the behaviour of the soils and/or earth masonry by means of instrumentation and field tests, determining the most significant parameters from a construction point of view.
– Conducting laboratory tests, reproducing natural phenomena and analysing the influence of certain parameters on their behaviour as a construction material.
– Elaboration of general models of behaviour that allow us to predict the response of the soil to the stresses to which they are subjected.

In summary, there is a lack of experimentation concerning the scientific-technical methods of the parameters that identify earth from a construction point of view. This affects the set-up of tests to improve the stabilization of this material for its application in construction and restoration (proctor test, particle size test and its contradiction with plasticity curves), the lack of correspondence between laboratory and in situ studies on site, the absence of an integral and consensual method to obtain the parameters that define the chemical components of the earth, its durability and stabilization consistent with the chemistry of clays, as well as correspondence between the technological analysis of the implementation process and the architectonic parameters of the project (Barbeta 2002).

The panorama described demonstrates the lack of regulations to be applied in restoration works currently in terms of quality control, which ratifies the need to carry out Preliminary Studies to any intervention carried out in this type of buildings since the criteria used so far are very variable (Mileto et al. 2011).

2.3 *Lime and earth*

As discussed above; the conservation projects of architecture on earth are based on the conservation of the original materials, respect for the identity and the search for sustainable local development. These issues have to do with an adequate conservation with respect to the materiality of this construction masonry using the traditional activities as a strength to take into account in these patrimonial construction types (see Fig. 4).

Earth and lime are materials that have gone hand in hand since the earliest times in the history of construction, as evidenced by the countless examples of lime-stabilized earth masonry that we find in our cultural resources today.

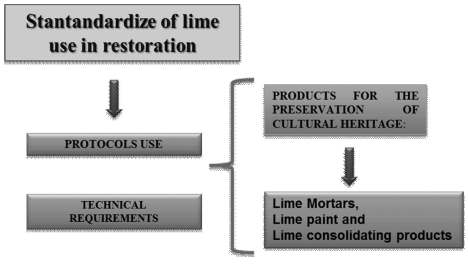


Figure 4. Objectives of the research on lime in conservation of cultural heritage.

Traditional architecture is sustainable since its inception, given that it uses the available resources of the natural environment and the territory in which it is located: construction materials, tools, utensils, preferably located in the vicinity of the construction to reduce costs. It also facilitates the conservation and regeneration of the territory, because it uses the materials it needs, allows the environment and vegetation to be cleaned (obtaining wood, river rocks, stone, etc.). These principles of traditional architecture are in line with what is now known as sustainable architecture and the recovery of Good Practices in construction, to be applied in the Conservation of Cultural Heritage.

On the other hand, in the most scientific area, the improvements that lime contributes to earth as a building material are already known (Houben & Guillaud 1989), which are:

- the drying effect of lime on the earth during the transformation process from quicklime to hydrated lime
- the change of cations, Ca for Na, K as a chemical process of interest since it causes the soil particles to flocculate and agglomerate;
- On the other hand, silica and free alumina in the earth react with lime and form calcium silicates and aluminates (pozzolanic reactions) that increase their hardness and in general the mechanical resistance of the masonry, together with the carbonation process that takes place when lime reacts with the CO_2 in the air.

In Spain there is a wide tradition of the use of aerial limes or plasters for stabilization and improvement of soils. Andalusia has a rich cultural heritage, where the use of aerial lime has played an important role, given that it is an area with important geological resources. This traditional activity of lime processing lasted until the middle of the 20th century, preserving itself in exceptional cases until today. An example of this exceptionality is the Comarca de Morón de la Frontera, in Seville; which is located in the subbetic area of the Béticas mountain range, has abundant outcrops of carbonate rocks, including oolitic limestones, which have been mined since ancient times for different uses in construction. Its use for the production of lime is connected with the activities of an artisan and industrial nature and more directly with its traditional architecture, mostly built on earth.

The peculiarities of this activity which is currently being developed in the region of Morón de la Frontera (Seville) justify its inclusion in the Inventory of Popular Architecture of Andalusia that is currently included in the Database of Immovable Assets of the Ministry of Culture. In 2008 it was registered in the General Catalogue of Historical Heritage of Andalusia as an Asset of Cultural Interest (BIC): "The Caleras de Sierra de Morón de la Frontera (Seville)" a place of Ethnological interest, protection of immovable assets associated with intangible activity: settlements, houses, lime kilns, areas linked to the activity and old extraction area (historic quarry). Finally in 2010, this activity was included in the second phase of the Intangible Atlas of Andalusia (Carrera & Olivi 2014). Its peculiarities earned it recognition in November 2011, on behalf of UNESCO; being included in the List of programs, projects and activities for the Safeguarding of Heritage and declared to be Intangible Heritage of Humanity in the Good Practices section. In 2013 it was included in the Spanish Network of Industrial Tourism.

The advance in knowledge about traditional production lime, elaborated in the region of Morón de la Frontera, Seville, will contribute to the technological advance through the design of products that will favour good practices in the matter of the Conservation of Cultural Assets and will have a significant effect on economic recovery at territorial level. At present, innovation and technological diffusion must be understood as processes whose management and development require the existence of suitable environments, or sets of interrelated elements, that generate a system with a certain spatial projection at national or regional level. (Gómez Uranga and Borja Álvarez, 1996). For this reason a structured and convergent network has been created, made up of scientific, technological and productive environments; environments which will contribute to a range of topics, from cooperation to knowledge development, technology and know-how, together with the creation of goods and services, which will have a direct impact on society, enhancing economic development and well-being.

It is of interest to determine the properties of lime for use as mortars, painting and consolidation of traditional construction masonry, with a view to its application in restoration works, which at present are not sufficiently promoted at market level. At present, research on lime, its application in the preservation of traditional masonry, is more oriented towards case studies, understanding that its application must be determined by forms of local production, linked to a territory and justified by its necessity and quality.

The implementation of lime and its viability as a material for conservation demands that the advance of the research experienced in the last decades serves to create products that show an appropriate behaviour on the building. The level of research currently allows us to adequately position ourselves before this problem and to form the aspects in which it is necessary to influence and develop. It is important to define the requirements of these products for use in restoration.

However, the problem of the use of lime in construction not only arises with the materials, their nomenclature or their design (Rosell 2012). The use

of lime requires a traditional way of working that is associated with the craft, at a pace of execution that respected the construction processes and maturation of materials and with a work schedule drawn up with much foresight. Traditionally the construction processes were slow which allowed the work to settle slowly, while the walls were being erected. The loss of water and the incorporation of CO2 were produced as the work aged and increased the rigidity of the materials through carbonation, all at a pace compatible with the construction process.

For this reason the conservation of traditional materials must be approached from the perspective of knowledge, quality control, minimal intervention, direct action on agents of deterioration, together with adequate preventive conservation measures.

3 CONCLUSIONS

The IAPH's objectives for the coming years are the drafting of technical documents associated with the different phases of intervention in heritage. The first document will be a technical document on the suitability of lime for use in the conservation of cultural property.

The ultimate goal of this task is to improve the quality of cultural heritage interventions. The sustainable use of the heritage resources of Andalusia must be based on the efficiency and sustainability of traditional activities, as a tool that contributes to social and economic development; revitalizing activities currently in danger of disappearing and that make the territory unique. These strategies must be supported by research, development and innovation. For this reason, and because of its compatibility with historic masonry, artisanal lime has been selected.

Lime products are in line with the fundamentals that define the conservation of cultural assets: protecting traditional techniques, documenting their uses and respecting the characteristics of the historical materials they are intended to restore or protect.

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Earth in historical fortifications. Pedro de Lucuze's method

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ABSTRACT: After the emergence of gunpowder in 1379 and later invention of cannons, the ancient fortifications were easy to be conquered, so a new system of defence was needed. It started by building lower walls with an impact-absorbing material, where visual rays were studied to avoid blind spots. Then, traces and geometry were used to trace the new fortification models, creating and improving numerous shapes for different defensive batteries, as ravelins or hornworks… with cheap, weatherproof and easy-built materials. This new philosophy was studied in the mathematics academies of the 17th and 18th centuries, in which each author and teacher developed different solutions. Pedro de Lucuze was the manager of the *Real Academia de Matemáticas y Fortificación* and developed a teaching method applying earth-rammed technics.

1 INTRODUCTION

Talking about earthen construction we would, for sure, have to talk about earth rammed and adobe construction. Less are the chances to talk about other techniques. In the case of defensive constructions, other less known techniques are used, such as earth bags and baskets, which were stacked to build trenches. Nevertheless, military engineers used to write treatises in which they teach other techniques to build "real forts".

Modern fortification, often miscalled trace Italian, is the new way of thinking fortification after the appearance of the gunpowder and cannons on the 15th century. The new ways of besieging made the old castles easy to be conquered: a few cannonballs and the wall fell, filling the moat with its ruins, creating a way to the offensive troops. Also, blind spots on towers were detected, which should be avoided for a proper defence.

Trying to fulfil these shortcomings, the way the fortification was thought changed to a new concept that was developed during the years to get the peak between the late 17th and early 18th centuries. Walls were built shorter and in a way they could absorb impacts, moats were wider and visuals were studied to avoid blind spots (or dead zones), which made the new forts look like stars (Fig. 1).

Modern fortification is not Italian trace, we may insist on that. It was thought on the Italian renaissance that geometry was the key to build a successful fort. And, of course, if the pentagon was the perfect polygon, that should be the shape all the forts should have. Due to this, the Italian forts are regular and have this pentagonal star shape. That is why modern fortification is known as Italian trace or star fort. But, beside the Italian school of thought, there were

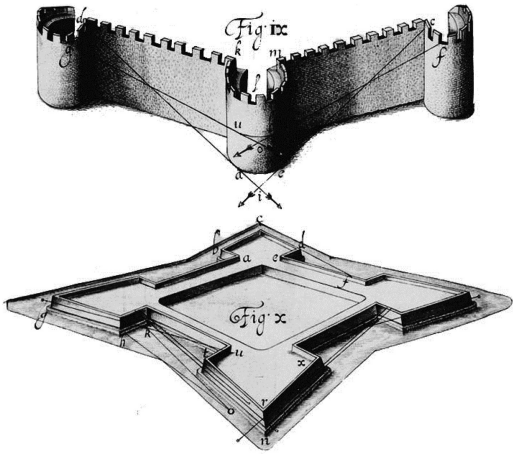


Figure 1. Evolution from the old tower bastion to the so called modern star shape forts (Dögen 1647).

others, like the French, Spanish and the Dutch one. Concerning the Spanish school of fortification, the first thought was that every fort should be designed for its own place and circumstances. That is why most of Spanish forts are irregular.

1.1 *On treatises*

It is worth starting by talking about treatises, before beginning to talk about the techniques themselves. First of all, we have to know that the best treatises on modern fortification we can read, have been written, most of them, between the 16th and 17th centuries. This works have three main topics, which are fort design, construction techniques and recommendations, and attack and defence strategies

according to J. Galindo Díaz's (1996) research. The ones we should be concerned about are the ones which talk about the second topic, construction, which are not as many as we could think. Only 38% of them talk about this topic and most of them in less than 10 pages (Op. cit.). Perhaps its formative nature leads us to think that those texts are simple but each word that they contain is highly loaded of subtleties and we should dive into the details.

Also worth to mention that almost all the authors wrote their works based on previous texts. So, the different texts we can read are few. The ones we are going to talk about are the works of Pedro de Lucuze, Vicente Mut, Cristóbal de Rojas, Vicente Tosca and Samuel Marolois, focusing on Pedro de Lucuze's definitions and recommendations.

1.1.1 *Pedro de Lucuze as a teacher*

Pedro de Lucuze y Ponce (Ávila, November 21st, 1692 - Barcelona, November 20th, 1779) started as a teacher of the *Real Academia de Matemáticas y Fortificación de* Barcelona on 1736. Along those years he wrote the project of a new regulation of academies, where he planned the new teaching method. On 1739 he started with the direction of the Academy and wrote the *Curso Matemático*. This work was a collection of eight treatises on different topics, dictated during the lessons and the pupils had to copy the text on their own copy of the treatises.

1.2 *Wall materiality*

Pedro de Lucuze mentions on his teaching program, the "*Curso inédito en matemáticas y fortificación*" (unpubl.), six different techniques in which a wall can be built: stone, brick, fascines, sods, rammed earth and adobe. This work, was an unpublished collection of 8 treatises on different topics such as math, geometry, mechanisms, static, hydraulics, optics, topography, artillery and, of course, architecture. All these contents were dictated to the students in the academy during the classes. Students should copy the texts and make their own copies of this collection. Thanks to them, we can now read the texts of Pedro de Lucuze. Unfortunately, many of those manuscripts have no source or author reference, or even title, and it is difficult to find any manuscript if you do not know what to look for (Gimeno 2016).

The techniques that Pedro de Lucuze (unpubl.) talks about are the first four from the list before mentioned: stone, brick, fascines and sods. The last two, rammed earth and adobe, are only mentioned and defined in his work, but there is not any kind of recommendation about. We can infer by reading Lucuze's work that, in one hand, the heavier materials, such as stone and brick, are the worst at absorbing impacts. And on the other hand we have the earthen techniques, which are poorly weather resistant but, are more plastic than the others and work fantastic on absorbing the cannonball impacts.

Also it is good to keep in mind that, to select the proper materials, the military engineer had to think on the availability and the quality of the materials in the country they are going to build the fort in. In this path of thinking, Vicente Mut (1664) wrote that the best materials to be chosen are the best the country can give us. What did he mean? In his treatise, Mut recommends to know which of all the techniques has the better resources in quantity and quality. For example, Cristóbal de Rojas (1598) said that brick walls are way much better than stone walls because of its higher plasticity. But, Mut (op. cit.) said that there are places, like Mallorca, where the local stone is a type of sandstone with a great durability but a great softness that allows the cannonballs to be put inside.

But not only materials, also the shape of walls is an important point to care about. Normally, the treatises talk about four main shapes (Fig. 2). The first one is the vertical wall, the second one with buttresses, the third one with buttresses and an embankment (a soil filling on its inner face) and, the last, when the full wall is made of soil. This kind of walls is each one worse than the next. The first wall, the vertical one, has no place in modern fortification. Due to its weakness to cannonball impacts, this wall is absurd to be built in modern fortifications. This is why we can see this kind of wall with buttresses or, with vaults in perpendicular direction like the ones we can see in Peñíscola's fortress (Fig. 3).

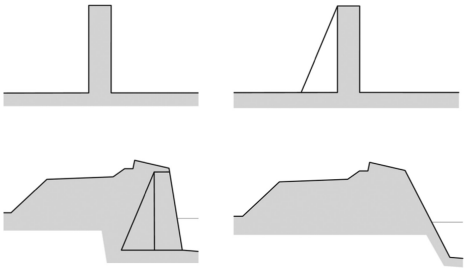


Figure 2. The 4 types of wall shapes in fortification.

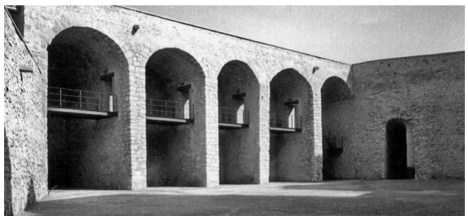


Figure 3. Inner part of Saint Mary's bastion at Peñíscola, Castellón (Balaguer 2012).

In the case of the third one, which has the embankment, the wall can be free of the buttresses, but it is very common that the treatises added buttresses to this kind of wall. In the last case, when the wall is fully made of soil, there are some strategies that the military engineer should follow to achieve the construction of a weather resistant wall. Normally, when there is soil behind the wall or the full wall is made of it, this filling is made of the remains of digging the moat, as a way of leveraging resources.

2 TECHNIQUES

Regarding the selection of the techniques, the military engineer should, as said before, know which are the pros and cons of the techniques available and then, choose the one that better fits the build according to the quality of the local resources. Among them, stone walls, which according to most of the writers, should be built with small stones. The reason for this is that the wall will have more joints as smaller the pieces are and, therefore, a higher wall plasticity to allow the absorption of cannonball impacts.

Then, we also have the brick walls, which all the authors also agree that the bricks should be placed undercooked so that, as in the case of stones, the wall has a greater capacity to absorb the impacts of the cannonballs.

But then we can read in some of the treatises that we can also build walls with raw soil. This kind of walls have to be built any way to interlock the earth, or preserve it from the weather. We can achieve this by alternating layers of soil with fascines and mixing some seeds on it (Mut 1664) and/or protecting it with an outer layer made with stone, bricks, lime mortar or sods (Lucuze unpubl.). This kind of wall can also be built from zero, without any kind of preparation of the ground. We have not found any author that speaks about building any kind of preparation or foundations except for Vicente Tosca (1712), who speaks about digging a little to engage the lower part on the fascine constructions.

2.1 *Sod constructions*

Sods are bricks made of turf, which have been long time used to build houses on steppe or peatlands, and also as a great heat source. We can see in the north of the United States, Canada, and Eastern Europe a huge variety of the so called turf or peat houses.

Sods are commonly defined in treatises as rectangle or triangular prism shaped rooted soil with grass on the top part (Fig. 4). Meanwhile the earth wall is growing in high, sods are being placed on the outer surface. Sods also are watered and sowed with grass seeds. They are placed rigged, like if they were bricks and, to enhance its function, they are also being nailed with wood stakes. The way Marolois explained to make use of sods is very similar to the masonry techniques.



Figure 4. Stake on a sod wall (Gimeno 2016).

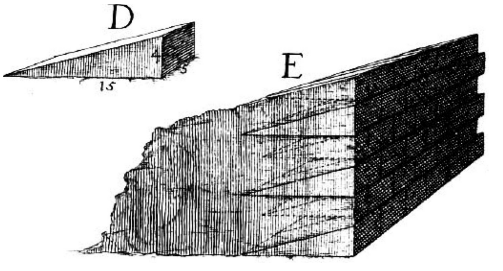


Figure 5. Shape of a sod and how to place it on the surface of a wall (Marolois 1614).

One of the pros of these constructions is the high capacity that the outer surface has to absorb cannonball impacts. We can see a section of a wall of this kind on Figure 5. Sods are commonly seen on the Dutch school of fortification, where fortress must be adapted to floodable terrains.

Vicente Mut (1664) says that sods are not easy to obtain in every place. The consistency of the soils and the kind of vegetation can make variable the quality of sods, so… if we want to build a seemingly wall, we should use adobe bricks to enhance the outer face. Regarding its construction, Lucuze (unpubl.) also says that joints have to be alternated on each row of sods and, as Mut (1664), also recommends to nail stakes and to distribute seeds. In addition, he also recommends to apply lime mortar to make it weatherproof.

2.2 *Fascine constructions*

The fascines (Fig. 6) are bundles made out of wooden branches and straw compact and tightly

tied. Those bundles are used to build trenches by alternating layers of fascines and soil. While the author, Pedro de Lucuze (unpubl.), states that bundles are made of thin branches. Cristóbal de Rojas (1598) said, one and a half century before, that these branches should have at least a 4 finger diameter (approximately 7 cm).

The construction of this type of wall is described by Lucuze as follows: A first layer has to be built using bundles from 7 to 8 palms long and 1 palm wide (2 m long and 30 cm wide approximately) placed perpendicular to the wall. Then, this is covered with soil and then compacted. Then a second layer of bundles has to be laid over the first layer, with the bundles placed in a longitudinal orientation (these are called sausages when placed this way). Then, soil has to be added and compacted as before, and so on. Each new layer after the first one has to be nailed with stakes to the previous level until reaching the wall's slope or scarp. After changing inclination, we start building, also with fascines inside of the soil volume, the parapets to the cannon batteries. We can see sections of this kind of earthwork in Figure 7.

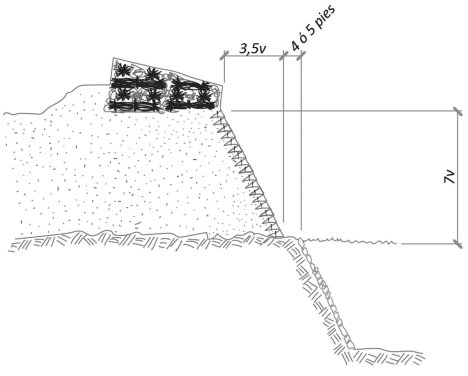


Figure 6. Section of a earthwork coated with sods (Gimeno 2016). Measures in Castilian units.

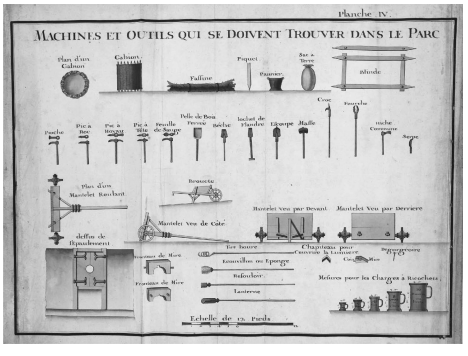


Figure 7. Drawing of Vauban (1714) with tools, machines, and some materials for earthworks. We can see a fascine third from top.

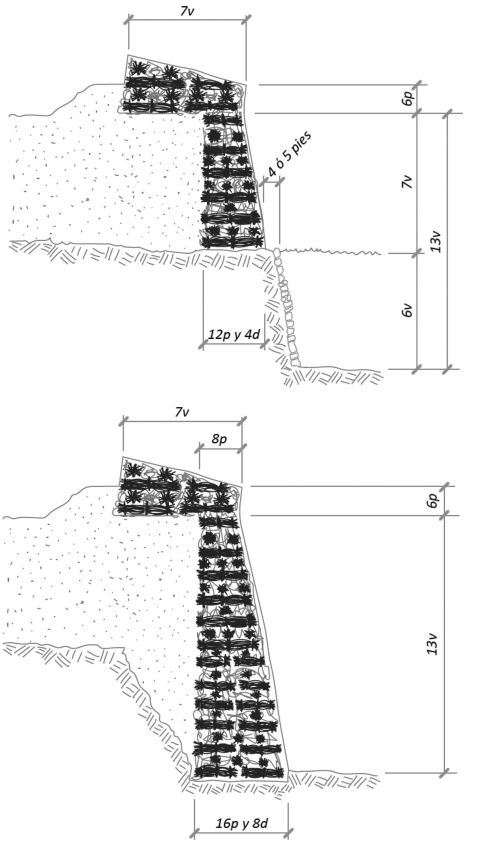


Figure 8. Different sections of a earthwork filled with fascines (Gimeno 2014). Measures in Castilian units.

All the authors agree that the fascines should be covered with soil but they disagree on the reason. Cristóbal de Rojas (1598) because the branches could be used by the enemy as a stair to climb the wall. Pedro de Lucuze (unpubl.) to avoid the wood to be burned by the enemy to ruin the wall.

One of the reasons why this construction technique was so useful is that the enemy's sappers can't dig the gallery to place the bomb because they will start finding branches inside the wall during the siege operations. Regarding its behaviour, Cristóbal de Rojas (1598) says that the cannonballs fed inside the soil if the wall has fascines inside. On the other side, Mut (1664) says the opposite: without fascines, the cannonball feeds about 1.50 m and with fascines it feeds almost 3 m inside the soil.

Talking about the scarp inclination of each one of the construction techniques, each author says a different thing, but they agree that wall and brick walls can have more slope, be more vertical, than earth walls. As we can see at Table 1, Cristóbal de Rojas suggests a low inclination for both

techniques, maybe because he distrusts the slope of the embankment. We can see can see also that Vicente Mut and Pedro de Lucuze are more permissive and have more vertical suggestions to earth solutions. It is clear that both of them rely much more on fascines than on sods because of the structure that staked fascines provide to the wall.

Table 1. Base/high ratio of the scarp inclination for different wall construction techniques, according to each author's criteria (Gimeno 2015).

Author	Stone and brick	Fascines	Sods
C. de Rojas	–	1/2	
V. Mut	1/5	2/5	2/5 to 1/2
P. de Lucuze*	1/6	1/5	1/2

*The same as the ones Vicente Tosca mentions in his treatise.

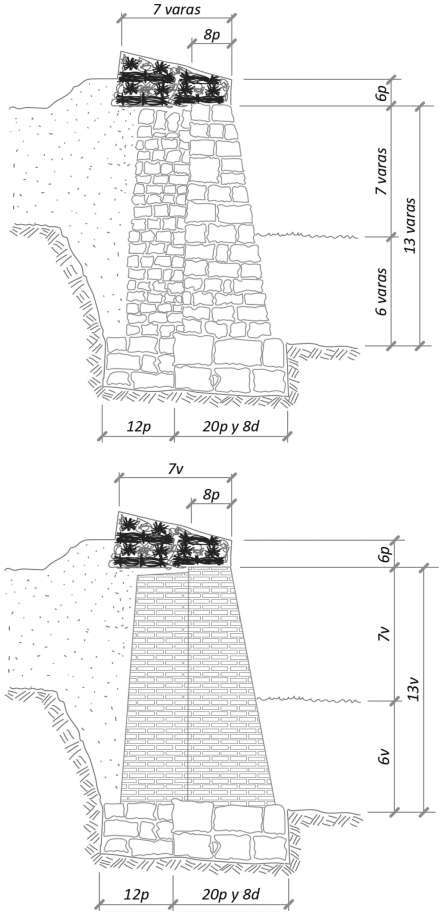


Figure 9. Different sections of a earthwork filled with fascines (Gimeno 2016). Measures in Castilian units.

3 USES ON MODERN FORTIFICATION

The main and most advisable use of fascines is to build small campaign fortress. Those, which are faster to be built near the enemy by night, can be built with pre-made fascines to fill faster the wall volume and then have an out layer made of sods to avoid crumbling (de Rojas 1598). This faster filling factor that fascines provide can be used also to raise trenches during offensive actions, with the use of gabions and bags of earth (Vauban 1714). Cristobal de Rojas also says that the walls made out of fascines can be covered with stone to protect it from the weather, after 3 or 4 years, when the soil is settled.

Pedro de Lucuze suggest to stop building to the end of the scarp of the wall and change the building technique to make the parapets out of fascines despite the technique used to build the wall (Fig. 7). Also, like other authors (Álvarez 2009), Lucuze suggests to building the double bastion (a second parapet built on top of the main bastion). Earthworks can also be used in this kind of fortification to repair temporally the mined walls due to its fast execution.

4 CONCLUSIONS

The wide range of different solutions to build the walls of a fortress is mind-blowing to the military engineer. All the different possibilities, its pros and cons, the way they react to cannonball impacts, the weather resistance and even the quality and availability of materials and local resources make the election a complex decision. Furthermore, walls are not made out of only one technique. Walls can be built combining stone, embankment, buttresses, sods, fascines… and each one of this give to our wall a new property.

When a military engineer had to build a fortress, he had to study the land, its geography, its resources… and then, combining all his knowledge, he had to make a choice to be right on firmness, speed of construction and economy (Fallois 1768).

As Cristóbal de Rojas (1598) said, "*on war things, where there are so many inventions and cautions, it is necessary to leave the way of common solutions and go to the particular solutions which are the base of good fortification*".

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PREFORTI project: The preventive conservation of historic rammed-earth

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ABSTRACT: The main purposes of the PREFORTI project "Sustainable Methodology for the Conservation and Maintenance of Medieval Earthen Fortifications in the South-East of the Iberian Peninsula: Diagnosis and Prevention of Natural and Human Risks", which was selected in 2015 for 'Projects of Excellence and Challenge', an invitation to tender by the Spanish Ministry of Economy and Competitiveness, are to recognise and highlight these Medieval earthen defensive structures, along with their different technical solutions; to systematise a model of analysis that allows us to assess their degree of vulnerability and susceptibility to natural and human risks and forces; and to establish mechanisms and strategies aimed at the effective preventative conservation of these structures in the provinces of Granada, Almeria and Murcia. This report aims to inform the scientific community about the background of the project and the needs that justify its existence, as well as its proposed objectives, the methodology suggested for its development, and the foreseeable results.

1 INTRODUCTION

The geographical area corresponding to the south-east of Spain, made up of the provinces of Granada, Almeria and Murcia, has a considerable array of historic Medieval defensive structures built of rammed earth, such that this group of provinces may be considered a single entity. Apart from their relationships in terms of territory, culture, architecture and landscape, they also share several problems and causes of deterioration, as well as a dearth of sustainable conservation strategies, which together pose the common problem of their vulnerability against natural and human risks and forces (Fig. 1).

This situation is now one of the direct causes of substantial investment in post-disaster repairs, as illustrated by the results of the recent earthquake in Lorca. This and other reasons justify the creation of an analytical methodology to evaluate the degree of vulnerability and susceptibility of the earthen defensive structures to risk factors, along with a proposal for preventative action policies, in order to achieve an effective, consistent preventative programme for these structures.

This operational methodology tries to broaden existing efforts towards conserving these defensive heritage structures, whose protection is clearly essential; the safeguarding of history and the collective memory and recognition of their legacy are ample justifications of this effort.

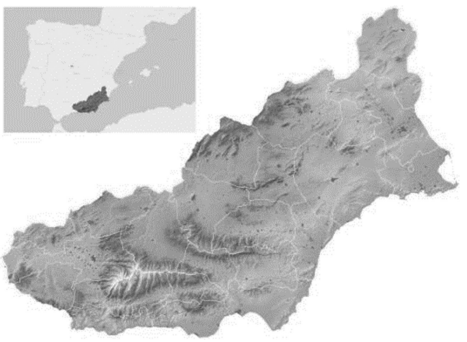


Figure 1. Digital Elevation Model, hydrographic network and provincial delimitation of the geographic scope of the study (Molero Melgarejo).

2 BACKGROUND

2.1 *Risks affecting the earthen defensive heritage defences*

Traditionally, the choice of specific, strategic sites with good visibility and limited access was related

to maintaining control over a particular area; such locations enabled the structures to fulfill the defensive function required of them (Malpica 1996). However, typologies of a defensive nature are also found on plains, designed to serve as refuges for the local population. Their construction on mountains, hills or elsewhere has meant that the sites they were placed on offer greater protection from certain natural risks, but they do not exempt them from the danger of other natural disasters. In fact, a remarkable number of structures are situated on promontories where they are highly exposed to landslides and rockfalls, climatological phenomena (rain, snow, lightning, etc.), and extreme weather conditions (coastlines directly eroded by the sea, etc.). On the other hand, the risks most widespread for structures located in lowland areas arise from river floods and their effect on inundation and liquefaction processes. In addition, the danger posed by the high degree of seismic activity throughout the south-east of the Iberian Peninsula contributes to the increased effects of this type of natural hazard on this unique heritage. Despite advances in historical and predictive research, we still suffer from a lack of studies focussed on the effective planning of preventative measures that would extend the protection and conservation of cultural heritage.

In addition, these structures have received widely varying social, political and administrative appreciation throughout their history; the interest they have attracted has therefore varied from their recognition as symbols of a particular time to their fall into oblivion. We would argue that their very origins present problems for their conservation; the defensive function they were built for has not been maintained over the course of time, and their lack of social value has therefore led to their abandonment (Molina 2004). On the other hand, human action has also taken the form of undue restorations, for example through the use of inappropriate materials and products that have caused serious modifications to the functional conditions of the wall structures, increasing the degree to which they have deteriorated. These inadequate operations, coupled with strong urban planning pressures, have led to an excessive alteration of the formal and functional reading of their defensive origins.

2.2 *Risks: Doctrine and legislation*

Over time, international and national efforts aimed at influencing their protection have increased; while at first these approaches revolved around recognising the importance of their protection, at present they are more committed to the will to prevent and minimise the risks of destruction, by means of criteria compatible with safeguarding Cultural Heritage (see Toledo Charter, ICOMOS 1986).

The protection plans have been instrumental in making it possible to strengthen the capacity to prevent risk and to promote environmental management and the principles of sustainable development. In recent years, the heritage doctrine in relation to natural risks has been taking steps that show greater interest in prevention, although we would still point out that it is insufficient.

From this point of view, without forgetting the international charters that focus on aspects related to risk-preventing conservation, such as the Noto Charter (Noto Consultancy 1986), the Washington Charter (ICOMOS 1987), the Xi'an Declaration (ICOMOS 2005), the Lima Declaration (ICOMOS 2010) or the The Valletta Principles (ICOMOS 2011), our project has also been supported by specific autonomous regional and national legislation, and by the state's experience in implementing National Plans promoted by the Instituto del Patrimonio Cultural de España (Spanish Cultural Heritage Institute). More specifically, the Plan Nacional de Conservación Preventiva (National Plan for Preventative Conservation 2011), the Plan Nacional de Arquitectura Defensiva (National Plan for Defensive Architecture (2011), the Plan Nacional de Emergencias y Gestión de Riesgos de Patrimonio Cultural (National Plan for Disaster Risk Management of Cultural Heritage 2015), and, at the level of autonomous regions, the PADA or Plan de Arquitectura Defensiva de Andalucía (Andalusian Plan for Defensive Architecture 2004) are particularly noteworthy. These plans determine the tools that we intend to put into practice experimentally in a selection of case studies among the earthen fortifications that the project covers.



Figure 2. Situation in the Vega de Granada of the Torre de Roma. Chauchina, Granada (Bestué Cardiel).

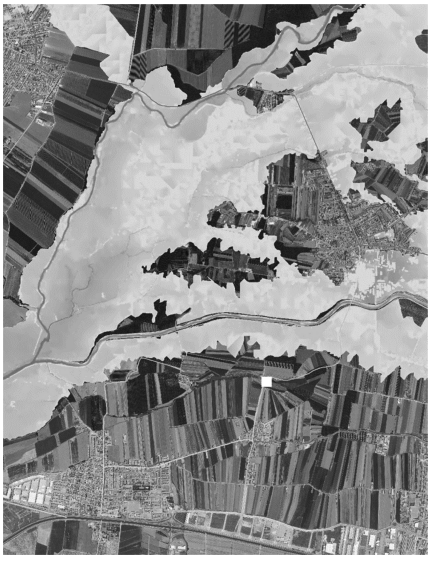


Figure 3. Mapping of risk of flood the area of the Torre de Roma. Chauchina, Granada (Molero Melgarejo).

3 THE STATE OF KNOWLEDGE: STARTING HYPOTHESIS

The traditional studies regarding causes of deterioration have not adequately valued harmful forces, whether natural or human, as far as their degree of incidence is concerned, even though they are very significant to the deterioration of earthen defensive structures. This vulnerability has become one of the serious, ongoing problems currently affecting these buildings, which are located in the geographical arc of the peninsular south-east, where geological and climatological conditions have a notably negative impact on masonry.

Research related to exposure to natural hazards has primarily been linked to the adoption of local corrective measures once the damage has already been done. It should be borne in mind that, in this context, neither urban planning nor the adoption of non-structural measures, such as the planning of ground use, can be applied to reduce the exposure of this cultural heritage; however, the risks and vulnerability involved can nevertheless be reduced. In addition, preventative structural measures that anticipate natural aggression are more appropriate than subsequent corrective measures, because, among other reasons, they are both cheaper and safer.

The principal historical studies on natural hazards affecting cultural heritage have been related to floods and/or destructive earthquakes (Rodriguez Pascua 2012). The impact of such natural hazards has been proven in the territory covered by our project, with examples such as the 1999 earthquake and its effects on the castle of Puebla de Mula (López Martínez 2002) or the most recent earthquake in Lorca on 11 May 2011, where some of the property damaged by the earthquake had already been affected during the seismic crisis of 1674 (Feriche 2012); or those related to the floods in the same municipality as a result of the breaking of the Puentes de Lorca dam in 1791; or the flooding of the Molina de Segura wall in the last floods of 2012. The past few centuries have affected Andalusia's cultural heritage, part of it being destroyed, such as the events that occurred in the historic centre of Malaga during the earthquake of 1680 (Goded 2012a, Goded 2012b), or after the 1907 "*riá*" (colloquialism for 'flood') of the river Guadalmedina (García Codron 2004) along its course through the city. The Alhambra of Granada is a paradigmatic case of historic structures being affected by natural and human risks. The high seismic activity of the area in which it is located is reflected in the continuous activity of the Tajo de San Pedro and the associated faults located in the lower area (Morales 2009, Justo 2008) over the last five centuries, where structures were partially destroyed by different earthquakes.

Other multidisciplinary studies are related to prevention, focussing on the problems derived from natural hazards mainly caused by earthquakes. Following the analysis of the effects and the consequences of disasters, efforts have been made to plan and set up protocols for natural risk management, especially those aimed at the improvement of future prevention and protection, taking shape in the field of education, training and the development of post-earthquake management plans.

On the other hand, the most recent land surveys at the national level have been aimed at defining the technical, constructive and material characteristics of the rammed-earth structures. These include more general studies and classifications (Pavón Maldonado, no date) to the more specific ones for the Granada area (Gallego 1992), (Ontiveros et al. 2008), or those that analyse traditional earthen architecture (Grupo Tierra, funded by F.J. Sandoval and J.L. Sainz of the Escuela Técnica Superior de Arquitectura in Valladolid), to the research projects related to the archaeology of architecture (Graciani & Tabales 2008), which centred on the possibility of generating a chronological classification based on the constructive and material characteristics of these rammed-earth structures.

Restoration work of structures built of earth, monumental or otherwise, has achieved a notable position in the last decade, providing an extensive reference that allows us to make a critical evaluation of the conservation criteria, the techniques used, and their results. This includes published studies that illustrate specific operations throughout the peninsular region, with the projects by J. Gallego, A. Orihuela Uzal (Orihuela Uzal, 2012), I. Bestué (Bestué Cardiel & López Martínez 2012), J.M. López Osorio (López Osorio

2012), F.J. López Martínez (López 1999, López 2002) and C. Mileto and F. Vegas of particular interest to the scope of this study, as they represent important contemporary experiences in the practise of restoring rammed-earth structures. The latter research project, "The Restoration of Rammed-Earth Architecture on the Iberian Peninsula (1980–2010): Criteria, Techniques, and Perspectives", is noteworthy for its unifying and integrative character. The results of this study are cutting-edge in this field, generating a large body of knowledge which we consider to be a model of good conservation practices (Mileto et al. 2012) (Mileto & Vegas 2014).

Moreover, the creation of the International Scientific Committee on Earthen Architectural Heritage (ISCEAH) by ICOMOS, along with the long history of the CRAterre Research Centre in France, illustrate the interest in the subject on an international level.

4 PROJECT OBJECTIVES

Having provided evidence for the deficiencies of this heritage in the area of preventative conservation, this project puts forward a number of objectives which we categorise into two groups: general and specific.

In relation to the former, and connected to aspects of methodology, models of analysis are suggested that allow for the assessment of the degree of vulnerability and susceptibility to human and natural agents on each particular structure, as well as the creation of preventative action maps, related to risk maps, in order to establish degrees of priority for action and responses to be carried out for specific purposes. These measures seek to create a sustainable model of heritage maintenance that would contribute to the reduction of conservation management costs.

Said objectives will be put into effect based on the systematisation of other specific objectives. During the first phase, it is essential to create a catalogue of the earthen defensive heritage structures in the region that encompasses the project by creating fact sheets describing material, constructive, and structural characteristics with geographical location support (GIS); different risks than those to which these structures are subjected will be detected and examined, the degree of vulnerability of each structure assessed, and pathology maps for each natural and human agent generated. During the second phase, the types of restorations undertaken on these buildings will be classified in order to repair the damage caused by natural and human factors, together with an analysis of the diachronic behaviour thereof, evaluating the way in which they have responded to the damage produced and the agents of repeated risk over time. During the third stage, a database of preventative actions that respond to the requirements of the risk maps analysed in relation to the physical reality of each building will be established. Models of good management in preventative conservation will be applied to heritage sites, comparing them to the project results, in order to establish transfer and applicability systems for other environments. Finally, the economic impact of preventative actions on the conservation of monuments will be studied, along with the establishment of pathways for the exchange of knowledge about the preventative conservation of earthen structures in other scenarios, in order to help recover traditional rammed earth techniques and skills.

5 METHODOLOGY

Based on the above mentioned objectives, a working methodology was developed that complies with the guidelines established by international theory, with heritage and town planning legislation at various levels, as well as the suggestions given by management software tools. Among the responses that need to be developed, the following stand out in particular:

Action 1. – Formalising and preparing a catalogue of the medieval rammed-earth defensive structures of the Spanish south-east.

The purpose of this database will be make a compilation of all the fortified elements built entirely or partly of earth during the Medieval period in the territory covered by the project (Granada-Almeria-Murcia). This tool should compile all the architectural elements that are part of the subject matter of this study in addition to establishing recognition and cataloguing criteria. This database will be kept open in order to continue adding new case studies beyond the present research project. In an effort to strengthen the exchange of information, this tool will be compatible with the Bienes de Interés Cultural (Assets of Cultural Interest) database developed by the Instituto de Patrimonio Cultural de España (Spanish Cultural Heritage Institute) and the Instituto Geológico y Minero de España (Spanish Institute of Geology and Mining).

Action 2. – Creating a geographic information web service.

This will involve the study a representative and homogeneously distributed selection in the area of Medieval earthen fortifications, using Geographic Information Systems as a tool.

The elements included in this group will be georeferenced using GIS methodology, making it possible to register them in a database associated with the territory they are located in. This will facilitate the selection of significant examples in terms of territorial characteristics and their impact on natural hazards in order to develop a detailed study.

Action 3. – Detecting and examining the natural and human risks that affect each architectural landmark in particular.

Four case studies will be selected in each province based on their unique and generic architectural (Fig. 4), constructional and territorial characteristics, and by the incidence of pathologies and restorations over time, in contrast to existing risk maps.
Action 4. – Generating pathology maps derived from the natural and human risks analysed in each case study.

For each case selected, the pathologies that are directly related to the risks being studied will be analysed. This will involve a precise field study with information gathered through various techniques and media.
Action 5. – Implementing a database incorporating information that refers to historical restorations related to human and natural hazards.

This would involve entering information into the initial database so that the user can see how the results are interconnected, thus creating a searchable documentation tool related to the restoration processes in historic earthen structures. Extending the database in this way will maintain the inclusion parameters in GIS in order to generate conclusions later regarding the region.
Action 6. – Carrying out practical laboratory tests using preventative treatments.

In this phase, once the interventions of other eras have been studied, evaluations of preventative treatments would be tested, as well as their evolution over time, their interaction with the original rammed-earth structures, and the pathologies that they could experience, taking into account the characterisation studies of existing rammed-earth structures, as well as others that could be carried out as part of the project.
Action 7. – Systematising the results and conclusions generated, and creating a database of preventative efforts.

The previously obtained results will be analysed critically. The suitability of the models generated, and their applicability to other cases, will be assessed according to the particular characteristics of each case. Subsequently, a database will be generated that integrates the results and establishes the preventative efforts to be considered in each case and for each type of risk, with systematised parameters.
Action 8. – Creating a maintenance manual for historic rammed-earth structures, as well as for rehabilitation and new earthen buildings, in relation to their risks.



Figure 4. Conservation status of the Torre de Bordonar, Granada (Bestué Cardiel).

The study of the models proposed in the test phase will enhance understanding of the process of ageing and deterioration of the rammed-earth structures over a considerable period of time. In this sense, we foresee the possibility of having sufficient information to create a database compiling all the pathological processes in relation to natural and human risks that can occur during different periods of time, and the possible preventative and maintenance responses to be considered in the interests of adequately conserving historic structures. We foresee these maintenance responses being put into practise for original structures as well as for restored structures.
Action 9. – Undertaking a study of the management and intervention models for preeminent assets in relation to natural and human risks.

The management model proposed by the Board of the Alhambra and Generalife, and especially its Master Plan, will be taken as a basis of this study, in which its implementation and the results obtained will be evaluated. At the same time, data from this model will be extrapolated to other scenarios. The document this study generates will serve as a management tool to be used by other public and private administrations in order to improve their systems of conserving and managing their historic buildings at a reduced cost.
Action 10. – Developing a training and dissemination programme of the results obtained.

This project aims to promote and create networks with other research teams and national and international technical and scientific platforms at different levels, together with promoting relationships with institutions and organisations linked to the conservation of cultural heritage. It also recommends the creation of a specialised training plan, as well as a body of knowledge whose dissemination will be organised and systematised in technical-scientific publications. For wider dissemination, the project will rely on the use of new technologies through the project's website and profiles on social networks.

6 FORESEABLE RESULTS

In general, once the methodology described above has been implemented, the research presented here aims to improve significantly the sustainable maintenance of a historical heritage that is broad yet difficult to conserve. The creation of an efficient preventative programme of mechanisms and strategies of action is suggested as an adequate

solution against the considerable danger posed by the effects of natural and human risks on these earthen structures. The ultimate goal of the project is to implement measures that will provide economical solutions to the processes of the conservation and management of defensive architecture, which is so difficult to preserve in the majority of cases.

NOTE

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3D modelling for the interpretation of watchtowers between capes of San Antonio and La Nao (Alicante, Spain)

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ABSTRACT: This paper presents the results of the TOVIVA project (Surveillance and Defense Towers of the Valencian Coast, Metadata generation and 3D models for interpretation and effective enhancement, HAR2013-41859-P) concerning the ancient defense towers of a particular area of the Valencian Coast: those between the San Antonio and La Nao capes, in the province of Alicante. The aim is to generate three-dimensional models for interpretation and effective enhancement, based on historical, geometric and constructive studies. For this study we have used the most advanced technical resources in the area of graphical representation and we have obtained photo-realistic and interactive 3D models, designed to improve the visibility and self-knowledge of this cultural heritage, typical of the western Mediterranean coastline.

1 TOVIVA PROJECT

1.1 *Introduction*

The phenomenon of pirate attacks was present on the Mediterranean coasts almost from the very origin of maritime navigation. In the area of the Ancient Kingdom of Valencia (Spain), and especially in the rocky coasts of La Marina (coastal region north of the province of Alicante), the attacks were considerably intensified in the first half of the 16th century, being especially ferocious in 1550, as a result of the alliance between Turkish and Berber pirates.

The network of defense towers erected on the Valencian coasts during the second half of the 16th century is a result of the geo-socio-political context of the time, of the humanistic spirit of the period and of factors related to progress in defense systems and technical military matters. They are part of a project intended to establish a coastal defense and watchtower system, and whose main objective was to warn, discourage and repel the frequent pirate attacks on villages near the coast. Emperor Charles V (1500-1558) impelled it and his successor to the crown, Philip II (1527-1598), ordered and executed it.

Coastal fortifications have long constituted a fundamental control and security system for the Mediterranean population. On the one hand, their location and defensive structure required functional and architectural competence regarding the possibility of sighting, resisting, attacking and protecting the territory, and communicating with the different fortified points of their surroundings. On the other hand, they transmitted the image of a safeguarded land ready to fight pirate vessels, at the same time symbolizing the power of the State whose frontier they defended. In addition, over time, the tower system has assumed a strong cultural identity component on the Mediterranean coastline, characterizing the coastal landscape and presenting features full of meaning, which today stand as fascinating historical testimonies.

At present, the towers ensemble constitutes an important architectural heritage that has lost its main characteristic: unity. Its current reality is diverse. Many are still preserved, in better or worse state, but some have been lost with no possibility of being recuperated; a good number of them are on privately owned land and are inaccessible.

1.2 *Project objectives*

The technological advancement achieved by hyper-realistic graphic surveys, based on the use of 3D laser scanning and the latest photogrammetric applications with photo-modeling systems (SfM: Structure from Motion), open new horizons for rigorous scientific documentation and virtual reconstruction of the cultural heritage.

The opportunity of this study goes beyond the scientific field, knowledge generation and the application of developing technological methodologies; it also offers the possibility of increasing the visibility of these cultural assets by providing high quality data and models that can also reach the general public through applications, cultural management agents or the administrations themselves.

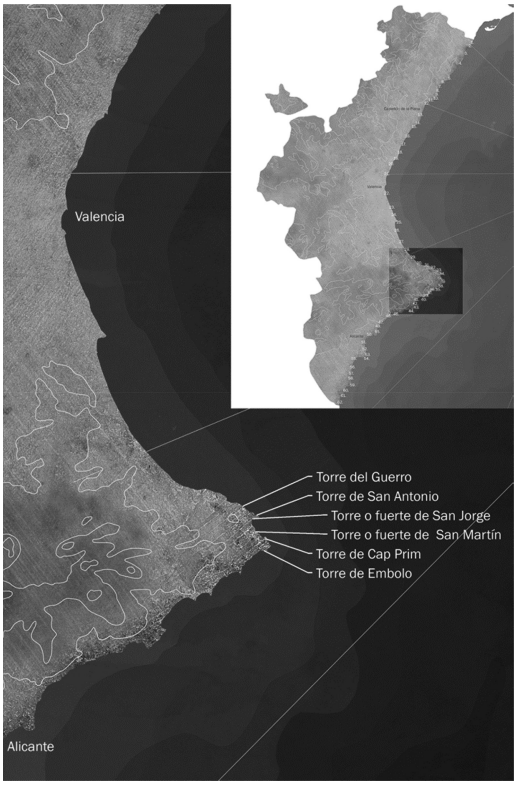


Figure 1. Situation of the Towers between the San Antonio and La Nao capes (Rodríguez-Navarro).

Through a single system of user-friendly computer applications, the "museum" can be everywhere, and heritage will be able to be interpreted by providing a reading that turns the visitors into an active subject, ubiquitously assisted in such a way that they are always able to reach an adequate level of knowledge and cultural enjoyment. These applications will provide appropriate and complete assistance to appreciate and interpret the asset, through a narration of high technological quality, wherever it is needed (Jaén & Canos, 2003).

The benefit of the project transcends the patrimonial scope, being able to influence the current economic juncture of the area thanks to the potentiality of culture as a driving force of local development. The Valencian coast, and in particular the region of La Marina, along with an intense touristic exploitation, possess a historical heritage linked, on a large extent, to the existence of this towers ensemble. An adequate management of these as a tourist-recreational resource could emerge as a favorable strategy for the sustainability of future development.

2 WATCHTOWERS BETWEEN THE SAN ANTONIO AND LA NAO CAPES

2.1 *Case study*

The present communication refers to a specific area of this "cultural unit" comprising a small portion of the network: the towers sub-system that defended the stretch of coast between the San Antonio and La Nao capes (Marina Alta area, Alicante).

To the south of the city of Denia, the coastline becomes abrupt: there are plenty of orographical accidents, with cliffs, islets and crannies that facilitated the refuge of the Berber vessels and made it difficult to defend the coast. Under these conditions, it was more difficult to deal with sighting and communication functions at the same time with the intention of defending strategic sites and fighting corsair vessels. For this reason, the main network of towers interconnected to form a system which subordinated local subsystems in specific places where the defense required protecting a way of access to a village, a fresh water supply or a place where the enemy could find shelter.

2.2 *The Guerro Tower*

The first tower of the system to the South-East of Denia (about 3 km away) is known as the Guerro Tower (due to its appearance similar to a jar). It is located in the zone of transition between the rocky beaches of Les Rotes and the strong cliffs conforming the San Antonio cape. The tower lies about 125 meters above sea level, over the Arenetes beach and the Aigua Dolça cove, or sheltered bay (which owes its name to the spring that flows up from the sea), with perfect visual monitoring of the islet located in front of the Cova Tallá quarry. It is in relatively good condition, thanks to the restoration done aproximately 20 years ago by the City council of Denia.

In addition to communicating with the castle of Denia, it linked visually with the consecutive towers of the network: to the Northwest with the tower of the Palmar (at the Girona river's mouth, next to the old tuna fishery of the Marquis of Denia), and to the South-East with the San Antonio Tower. It lacked *atalladors* (guards walking or horseback riding who watched the stretch between towers) to assist the "campara" guards (other guard posts subordinated to these towers), since the defense of the beaches to the North was assumed by the Denia castle and those to the South were secured by their own physical inaccessibility (Banyls & Co, 1996).

The tower was built in 1553 by order of Bernardino de Cárdenas y Pacheco (Duke of Maqueda). Its slender circular shape, with a smooth

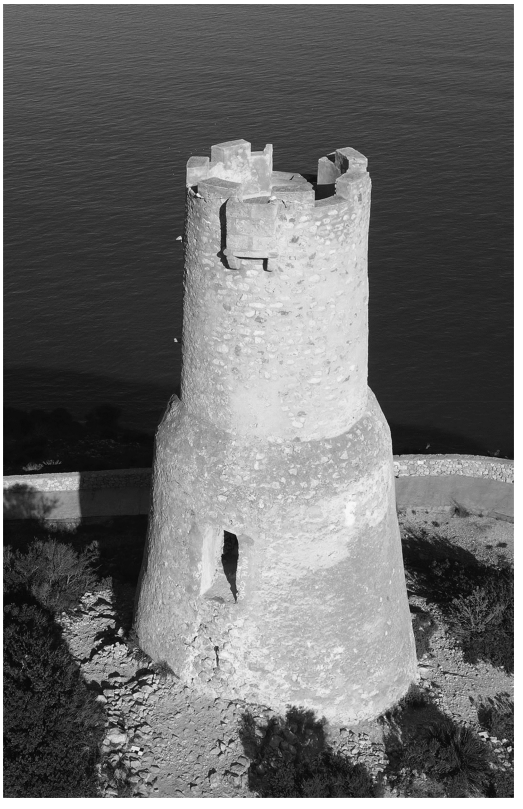


Figure 2. Guerro Tower, Denia (Rodríguez-Navarro).

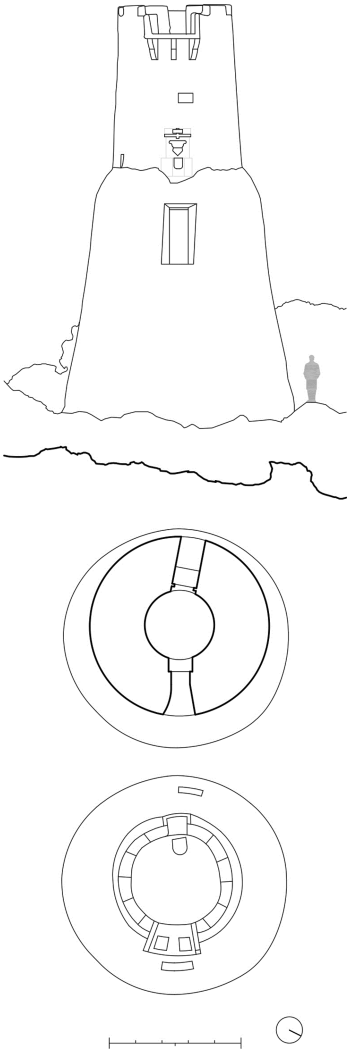


Figure 3. Guerro Tower, Denia (Rodríguez-Navarro & Juan Vidal).

slope, truncated cone-shaped and upper terrace, adheres itself to the type of towers promoted by him and built between 1553 and 1558. The sloped screed of the lower third is due to a later reinforcement, begun around 1585 (Acuña's report) and probably corresponds to the renovations proposed by Viceroy Vespasiano Gonzaga in 1575.

The most outstanding feature of this tower is the presence, over the access door, of a coat of arms that symbolizes the protection of the State against the threat of the infidel: the crown and the four bars of the Ancient Kingdom of Valencia, carried by the Empire's two-headed eagle, over the armorial bearing of the Duke of Maqueda, all under the cross of the Catholic religion that presides over the composition. At the footer an inscription reads SUB UMBRA TUARUM ALARUM PROTEGEM ("in the shadow of your wings I protect myself").

2.3 *San Antonio Tower*

About 3.5 km South-East, at the top of the massif of the San Antonio cape, at aproximately 165 meters high and attached to the hermitage dedicated to the saint, a few meters from where the lighthouse is situated today, a tower with the same name was raised, of which today there are scarcely any vestiges. Like the previous one, it was built by order of the Duke of Maqueda in 1553.

It connected visually with the Guerro Tower and with the following of the system towards the South: the Cap Prim Tower, in addition to communicating with the San Bartolomé church-fortress, in the municipality of Javea. Due to its elevated position with respect to the sea, this tower's function was mainly of vigilance, visually dominating



Figure 4. Cap Prim Tower, Javea (Rodríguez-Navarro).

the whole area of Javea's bay as well as the South-North maritime cabotage traffic.

It was a prism-shaped tower of rectangular plant and upper terrace, with sentry or machicolation protecting the access door (according to Juan de Acuña's report, 1585), similar to other towers like the Sal Tower in Cabanes (Castellón), except that the San Antonio Tower was not of cavalry and the door was elevated with respect to the ground.

2.4 *Cap Prim Tower*

Some 5 km further South, between the San Martí (Cap Prim) and Negro capes, located about 130 meters above the Portitxol cove and opposite to the islet of the same name, we find the tower known as Cap Prim. Currently located on a privately owned plot, it is in good conservation state. It presents improper elements, such as carpentry in hollows or a masonry staircase attached to its base (to reach high access), characteristic of its current destination for private use.

It connected visually with the previous one (San Antonio) and with the following one of the system to the South: the Ambolo Tower, besides communicating with the church-fortress of the town of Javea.

Built in 1553, its original, slender, circular-truncated cone-shaped form, like that of the Guerro Tower, responds to the model introduced by its promoter, the Duke of Maqueda. It presents differences in the location of the machicolations, which are accessed from the last level stay and not from the upper terrace.

Its function was coastline surveillance and the defence of shelters and possible landings (coves and islets). It had a guard post at the Negro cape (about 1,500 meters South-East) that was attended during the day by one of his soldiers (Banyuls & co, 1996).

2.5 *Ambolo Tower*

The next tower of the system is located about 3 km South of the previous one (1500 meters West

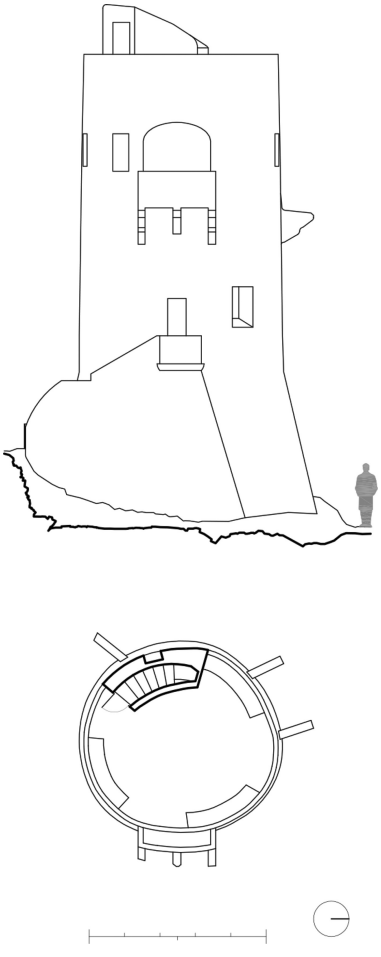


Figure 5. Cap Prim Tower. Javea, Ambolo Tower (d'Amblo) (Juan Vidal & Rodríguez-Navarro).

of La Nao cape), over the Ambolo cove, at about 100 meters of height in front of the Descubridor islet, in the mouth giving access to the Granadella inlet. It is currently on a private plot of land, its entire perimeter fenced in with no possibility to access it. It was in a state of ruin until about 20 years ago, when the City council of Javea undertook action to safeguard it that concluded with its restoration.

The tower connects visually with the previous one (Cap Prim) and with the following one of the system, towards the West: the Cap d'Or Tower or Punta de Moraira. It also responds to the type of towers ordered by the Duke of Maqueda in 1553 (circular truncated cone-shaped), in this case less slender, due to its location in a preeminent place on a cliff's edge, where it did not require greater height to fulfill its function with solvency.

It presents a solid reinforcement at the bottom, in the shape of a square-base pyramid embracing its shaft, attributable to the renovations that engineer Giovanni Battista Antonelli (1527–1588) recommended for this tower in the report he issued in 1563 to Philip II (Banyls & Co., 1996). Its strategic function was also to monitor and defend places of shelter and possible landings (coves, islets, inlet). One of his soldiers would attend the guard post on the top of La Nao cape.

2.6 *San Martín Tower or fort*

In the area of Javea's bay, dominated by the San Antonio and Cap Prim watchtowers, a defense subsystem was established with two other towers of an offensive nature, located at lower areas very close to the sea.

One of them took advantage of an old medieval tower, built in 1424 by order of King Alfonso V of Aragon (1396–1458) at the tip of the Arenal (small elevation south of the cove of the same name), a place also known as the Fontana cape. Their mission was to repel possible landings on the beach and protect the fresh water spring.

In the mid 16th century it underwent an extensive renovation in order to adapt it to the demands of modern fortification. The works began in 1558 and, according to Juan de Acuña's report (1585), the tower named del Rey at Oropesa, a very prestigious model at the time (Banyuls & Co, 1996), was taken as a reference.

Of square plan and ashlar masonry, it had two sentries at diagonal corners in the terrace, and two semi-spherical casemates in the corners of the opposite diagonal at the base. Given its large dimensions in plan and robust proportions, it was also known as fort, fortress or castle of San Martin.

Destroyed by the English during the Napoleonic Wars, the construction remained in ruins until the mid 20th century, when a block of tourist flats removed its vestiges, occupied its place and almost erased its memory (today, the apartments building is called Torre del Castillo or castle's tower).

2.7 *San Jorge Tower or fort*

The second tower of the subsystem in the bay was built in 1559 by order of the Marquis of Denia, Francisco Gómez de Sandoval y Rojas (1553–1625) (who in 1599 would receive the title of Duke of Lerma), in the place known as Racó de Sant Antoni, old pier and current location of the marina and fishing port of Javea. In the surroundings there must have been a primitive Muslim mosque, which gave it the name of Tower of the Mesquida, as it is also known.

Its mission was to dissuade and repel the landings, protecting the population from incursions and corsair attacks.

This is one of the towers that Giovanni Battista Antonelli proposed to erect in his 1563 inform, to complete the coastal defense system of the Ancient Kingdom of Valencia. Antonelli himself raised the plans to the Jurors for its construction during his visit to La Marina in 1562 (Banyuls & co, 1996). Its execution was not undertaken until 1578 due



Figure 6. Guerro Tower. Denia. 3D model on Skechfab (Rodríguez-Navarro).



Figure 7. Cap Prim Tower. Javea. 3D model on Skechfab (Rodríguez-Navarro).

to economic problems. Juan Acuña (1543–1615) describes it in his report (1585), which allows estimating its completion before that date.

It was one of the few towers projected by the illustrious engineer for the Valencian coastline that finally arrived to be constructed. It was conceived as an especially strong and robust tower (also called Sant Jordi fort or castle), designed according to the artillery that was supposed to house. Its shape was that of a regular prism of hexagonal plant with a scarped base, garlant ornament and upper terrace.

The only graphic document that testifies to its existence is a painting by Mariano Sánchez (1740-1822) that represents the San Antonio cape from the "racó", where the Sant Jordi tower appears in the background, presiding over the composition.

The tower disappeared in the 19th century, with the growth of the Javea port, but we can have an idea of its proportions and its typology contemplating the hexagonal towers that Antonelli himself designed in 1578 for the coast of Murcia, such as the Santa Elena Tower (La Azohía, Cartagena).

3 3D MODELS

The project for the ubiquitous interpretation of this coastline guard and defense tower system begins with the generation of hyperrealistic 3D models of the three preserved specimens. However, this area presents a high percentage of privately owned towers, specifically two of the three, unable to be visualized without entering these properties. This, which is a difficulty for 3D modeling, will be a great contribution since they will be visualized through these hyperrealistic models.

The towers that have been accessible for data collection are the Guerro Tower, which is located on public land with free access, and the Cap Prim Tower, which although it is in private property, its owner provided us with access to it.

The models can be viewed in the TOVIVA project's modelled towers collection, available in the online Sketchfab repository, at https://skfb.ly/NyzU. The address of the Guerro Tower model is https://skfb.ly/Y6yz and that of the Cap Prim Tower is https://skfb.ly/OyDF from where we also have access to the visualization of an aerial spherical panoramic view.

4 CONCLUSIONS

The preserved remains of these towers along the Ancient Kingdom of Valencia coastline, together with the memory of others that existed and disappeared, are testimony to a relevant episode of their history and can today be a favorable resource for the development of cultural tourism in the area. The generation of hyperrealistic 3D virtual models and their use as an accessible and interactive mean for the interpretation of the defensive system of which they were part, besides being a way of knowing and documenting this valuable heritage, is shown as an advantageous strategy to ubiquitously orient and assist the visitor attracted by the history of the place.

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Earthen architecture, appreciation and landscape: The oasis of Ferkla (Morocco)

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ABSTRACT: This communication shows part of the results obtained in the research project "*Arquitectura y Hábitat: investigación para la mejora global de espacios habitacionales en la región del Tafilalt—Arqui-Hábitat*" (ADSIDEO 15/16-AD1409-UPV) developed over two years in the oasis of Ferkla, and which included the participation of the Berber population, resident in ksar El Khorbat (earthen city). The study focuses on the findings of the analysis of visual preference, carried out with participation of native population. It aims to diagnose the "health" of its landscape and assess the risks of their identity features, especially of its earthen architecture.

1 EL KHORBAT AND THE FERKLA OASIS

1.1 *Description*

The area of study is a pre-Saharan valley to the south of the High Atlas Mountains, between the towns of Goulmima and Tinerhir. In the past, these territories were pastures for cattle, mostly ovine (goats and sheep) and bovine cattle of nomadic populations. With sedentarization, the oases were created: arable lands by artificial irrigation, surrounded by arid or desert territory. Irrigation combines the system of dams and ditches (seasonal waters) with wells that supply irrigation channels with water when the river becomes dry on the surface. In some areas, a system of collection and transport of groundwater from points far from the rivers, through khettaras, is added to this mixed system. Traditional crops combine palm and olive trees with cereals (wheat and barley) and legumes (alfalfa) for pastures.

Nowadays, two ways of life continue to coexist in Southern Morocco: the nomadic and the sedentary. Historically, the nomadic population has been considered more powerful. Their control over the handling of weapons and the ease in which they adapt to the environment has allowed them to maintain control over sedentary populations, obtaining everything they needed through looting, trading or simply in exchange for protection against rival tribes (Rodríguez & Gil, 2015).

The characteristic habitat of the area is the *ksar* (plural = *ksour*): a closed and fortified settlement where the population seeks refuge from external attacks, usually coming from the nomadic population. It is built using traditional techniques and employing local materials: raw soil in walls or mud bricks, palm tree and tamarisk wood, reeds or oleander stems. The Khorbat is one of the main *ksour* in the Ferkla Oasis, formed by two differentiated nuclei: the old town (*igrem akedim*), already abandoned and in ruin, and the new town (*igrem jdid*).

1.2 *Trends*

In the area of El Khorbat, it is possible to distinguish the orchards of the "historical" oasis from the more recent ones (late 20th or early 21st century), with a larger area and a result of public investment, where drip irrigation and electrical supply by solar panels for the motors of the wells has been introduced.

Currently, conventional building materials and systems, typical of the modern city (concrete, cement, brick, blocks, prefabricated joists, etc.) are replacing traditional ones. At the same time, isolated and semi-detached properties and houses, dispersed or located on roads and polygons, are replacing the urban organization concentrated in communal units or ksour.

The main population center of the area, Tinejdad, has experienced an exceptional urban development in the last years, occupying a considerable extension of the territory. The comforts of civilization are arriving thanks to the urban and domestic facilities, which are progressively implemented over territory, cities, properties and homes. Urban services are implemented as well, among which, urbanization (street paving, sidewalks curbing, public lighting, supplies, etc.) and urban waste handling, which still lacks effective infrastructures for its management (treatment and spill), are prominent.

2 THE LANDSCAPE AND ITS APPRECIATION

2.1 *Concept*

The current concept of "landscape" has a dual character. Consideration regarding the landscape has never stopped oscillating between the objective (natural environment) and the subjective (existential gaze). There has always been an anthropological relationship between human communities and their environment, which is at the origin of what we now understand as landscape. From an environmental psychology point of view, this phenomenon is explained with the concept of space appropriation in its two-fold aspect: action-transformation, linked to the needs of adaptation to the environment; and symbolic identification, referring to the affective, cognitive and interactive processes of people with their environment (Sierra 2014).

According to the European Landscape Convention (Council of Europe 2000), landscape means "any part of the territory, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors and their interrelations".

This definition identifies the nature of the landscape in the act of perception (subjective) and not in the physical (objective) medium itself. Thus, the landscape does not exist in and of itself, but arises from the relationship between the territory and the "populations" that inhabit it or visit it. As such, this perception—along with physical, natural and geographical characteristics, cultural factors such as history, experiences, memories, customs, practices, ideas and thoughts or artistic images—will interact in the mind.

Additionally, landscapes are also figures that play a relevant role in the representation of the identities of peoples. They contain a multitude of features replete with meanings, references of the image and the feeling of place. The landscape is, in short, the physical reality of the territory and, at the same time, the representation that communities culturally make of it (Díez 2015).

2.2 *Value*

For the European Landscape Convention, it "has an important public interest role in the cultural, ecological, environmental and social fields, and constitutes a resource favorable to economic activity. For that reason it proceeds to protect it, in the sense of preventing it from what generates greater social unrest: its uncontrolled transformation. The aesthetics of a landscape represents the cultural values of its inhabitants, and the globalization of the post-industrial society, which is no longer able to understand its meanings, threatens them (Sierra 2014). Above all, it proceeds to plan and manage it, "integrating it into land-use planning policies" (Council of Europe 2000), paying special attention to implementing citizen participation processes in its planning.

The wide variety of attributes that society appreciates in the landscape (economic, environmental, aesthetic, historical-patrimonial, social, spiritual, etc.) gives us an idea of the intersecting and multidisciplinary nature of any analysis intending to evaluate the landscape in a comprehensive way. That is probably why various analysis models have been applied for the assessment of the landscape, and none of them has so far received unanimous recognition by the experts (Scazzosi 2006).

2.3 *Assessment*

Among the various methods for assessing the landscape, we find visual analysis. They belong to the field of visual perception and are intended to characterize the image that the "peoples" are formed of the landscape, revealing the relationships and intersubjective meanings that explain it. It inquires into the cognitions, preferences and expectations of the people and seeks a prediction of the "visual quality" from concrete variables, chosen in each case. They are carried out by experts but require the participation of the population, without whose contribution it cannot be accomplished.

These methods resort to the identification of landscape patterns and units, as a useful tool to approach their complex reality, and seek the prior identification of resources and landscape conflicts. They focus on qualifying visual properties (visual units, exhibition, etc.), documenting iconic images (literature, painting, engravings, photographs, etc.), identifying the usual points of observation, recognizing the scenic routes (paths, roads, etc.), in evaluating the visual qualities (high, low, in shade, etc.) and, above all, in diagnosing the relationship of the peoples (communities, visitors, etc.) with the landscape.

This type of analysis requires resorting to participatory workshops that allow recognizing the relationship of the people with the landscape. Among the various strategies and activities applicable in this type of workshops, these two stand out: visual preference tests and landscape interviews/surveys.

3 VISUAL ANALYSES

3.1 *Starting points*

During the January 2016 campaign of the Arqui-Hábitat project, we sought to assess the appreciation of earth architecture as a reference of the

Ferkla Valley landscape and a visual analysis was carried out, among other examinations and tasks. The aim was to categorize the "visuality" (Díez 2015) of the local landscape and to identify the relationships established by its inhabitants and visitors, extracting any information allowing explaining its character and identifying its evolution trends.

A first approximation was made to the field of study, trying to include the main visual basins surrounding El Khorbat (Fig. 1).

The essential part of the work was done "in situ", during the first days of the workshop. The site was surveyed, touring the territory in the company of a local guide, an expert of the area and its culture. An exhaustive photographic report was made, features were assessed and the patterns identified provided us with guidelines used to delimit landscape units.

Four fundamental landscape patterns were identified, characterized by their distinctive features: Arid (natural and original desert landscape), Oasis (anthropized landscape, intended for cultivation of palm trees, olive trees, alfalfa and some cereals), Urban (artificial landscape for concentrated human settlements) and Wadi (W, specific part of the natural landscape through which the seasonal waters flow, with its own landscape features). Each of the first three was subdivided into two sub-patterns according to its different visual properties: Arid Mountain (AM, reliefs and sharp features) and Arid Plain (AL, large extensions with smooth slopes and hardly any geographical accidents); Historical Oasis (HO, traditional irrigation with small plots and ancient specimens) and New Oasis (NO, modern irrigation system, usually by dripping, with larger plots and young specimens); Contemporary Urban (CU, architectures using current shapes, construction systems and materials, of fast and spontaneous growth in open extensions close to streets and roads) and Traditional Urban (earth architecture with predominance of grouping in ksar type closed structures).

Since our study deals with the historical urban landscape of the place and focuses on earth architecture, the latter was subdivided, in turn, into two other sub-patterns that presented distinctive landscape-visual features: Exterior Traditional Urban (ETU, external view of the ksar, as a unique architectural unit erected in the scenery) and Interior Traditional Urban (ITU, set of plazas, passageways and galleries, which network constitutes the characteristic urban setting of the inner ksar). Therefore, eight different landscape patterns were identified: W, AM, AL, HO, NO, UC, ETU, ITU (Fig. 2).

At the same time, conflictive situations, which could constitute threats to the integrity of the landscape, could be identified. To facilitate their subsequent evaluation, we classified these conflicts into 5 groups: Natural (N, desertification, floods, etc.); Cultural (C, abandonment and ruin of traditional earth architectures); Architectural (A, adoption of foreign aesthetics, new materials, new construction techniques and new grouping dynamics in construction); Technological (T, discretionary implementation of new improper installations, such as electric laying, antennas, deposits, etc.); and Waste Management (WM, uncontrolled landfills with accumulation and dispersion of plastics and other non-degradable materials to the surrounding areas).

3.2 *Visual preference test*

The next step was the completion of "landscape workshops", with the participation of two different

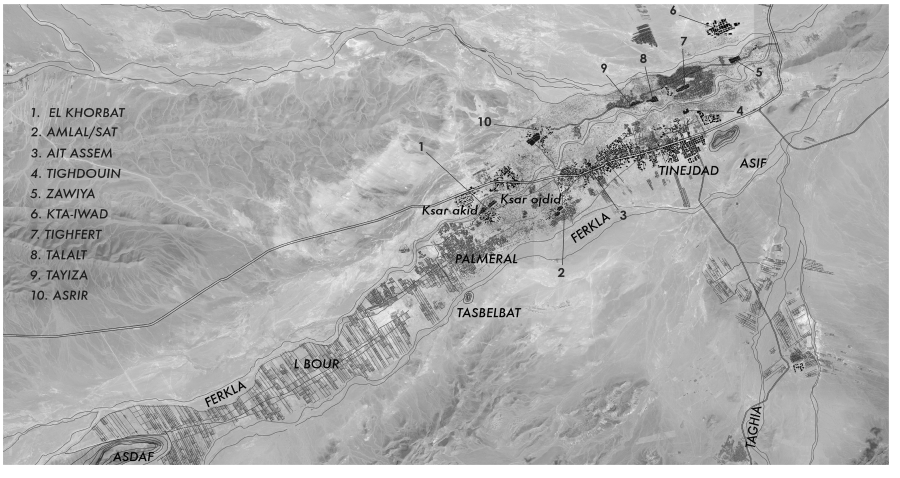


Figure 1. Field of study surrounding El Khorbat.

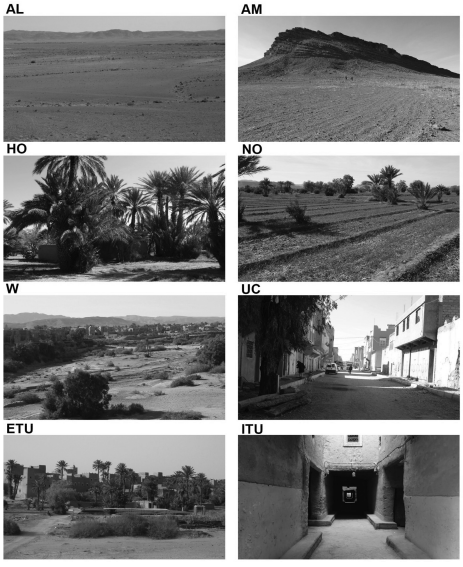


Figure 2. Landscape patterns.

types of populations: the local inhabitants on the one hand and the visitors, represented by the group of people who participated in the workshop, on the other.

The first activity of the workshop was the "visual preference test". Once the photographs were classified into one of the eight landscape patterns, the most representative of each pattern were selected (one per pattern) and six sets of eight images each were set up. In the workshop, the eight images were shown to the participants, set by set, and they were asked to choose five and rated them from 1 to 5, 5 being the maximum estimation and 1 the maximum rejection towards the landscape that the image represented, leaving 3 for an indistinct appreciation (Fig. 3).

This activity not only allowed us to detect the most valued and most rejected landscapes, but also to discover the so-called "forgotten landscapes", those that, being present in the territorial scene, go unnoticed or deserve the indifference of the population (shaded areas). This category is especially interesting for the diagnosis, since they tend to be the landscapes most vulnerable and susceptible to degradation.

The same was done with the photographs that represented conflictive situations, ordering them in four sets of five images (one per type of conflict). Participants were asked to rate them from 1 to 5, with 5 being the maximum and 1 being the least potential threat.

Among the noteworthy results, we could highlight that the landscape pattern most appreciated by the local population was the Historical Oasis,



Figure 3. Landscape workshop.

while to the visiting population it was the Traditional Urban or ksar in its two modalities: interior and exterior. These two patterns also occupied the second (ETU) and third (ITU) place of appreciation among the local population (Fig. 4). On the other hand, the pattern of landscape less valued by the local population was the Urban Contemporary coinciding this valuation with the one made by the visiting population, which only showed more rejection towards the Arid Mountain landscape.

The most "forgotten" pattern of landscape by the local population was the Arid, in its two modalities: Mountain and Plain. The latter was also the most "forgotten" by the visiting population. The Urban Contemporary pattern also reached a high degree of omission. These answers fall within the foreseeable results: the Arid pattern is the one that occupies the greatest extent and constitutes the natural local environment ("background" landscape), while the Urban Contemporary pattern is the commonplace (everyday) environment of the visiting population.

As for conflictive situations, both populations agreed to qualify as a greater potential threat those related to waste management (dispersion of plastics across the territory). Apart from this, both populations also agreed to notice a high threat potential coming from cultural conflicts (abandonment and ruin of earth architectures). Both groups differ in a third threat factor: the local population perceives danger in natural conflicts (desertification, floods, etc.) while visitors perceive it in architectural conflicts (new aesthetics, materials, dynamics, etc.). Although the profile of the population surveyed could influence this, these results are in agreement with the assessments made of the different patterns: the Historical Oasis, a landscape most valued by the local inhabitants, finds its greatest threat in natural conflicts (desertification, floods, etc.), while the ksar, more valued by visitors, is precisely the most threatened by architectural conflicts.

Note: as a remarkable result, that for the local inhabitants the conflicts that represent less threat are the technological related ones (facilities). The impact of these elements on the landscape, although evident, is assumed by the positive

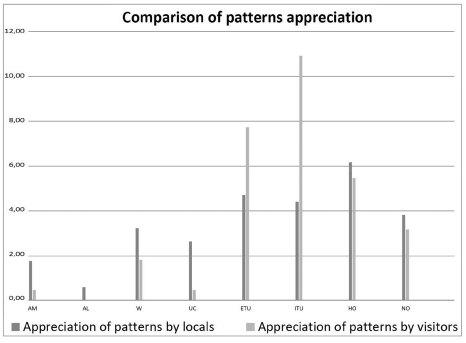


Figure 4. Appreciation of landscape patterns.

connotation of progress and advancement in the life conditions that they entail.

Due to the low number of people queried in both groups (17 inhabitants and 11 visitors), the results of these tests, despite their undeniable interest, cannot be considered definitive, but an approach, and need to be contrasted with further studies.

3.3 *Landscape survey*

The following activity developed in the workshops was the "interviews/landscape surveys", carried out only with the local population. Participants were not only asked about the most and least valued landscapes, but also the reasons for that assessment and the points from which they were better perceived. They were asked to indicate this and to write it down using stickers to place over a map of the territory, so it was thus possible to spontaneously map the results of these surveys. This activity provided data of a qualitative nature that allowed explaining much of the results of the previous tests and, above all, contributed to interpret the relationship of the local inhabitants with the landscape.

This experience helped to verify how the society identifies these generic units of landscape with concrete, socially meaningful and representative places of the territory. Thus, the Historical Oasis pattern was generally identified as the "Palm Grove" (*jmin slma*), giving preponderance to the perception of its iconic image. The traditional earth towns were identified with their town (El Khorbat) using their own terminology: *igrem akedim* (ancient town) and *igrem jdid* (new town). Within this latter, they referred mainly to the "public square" of the new ksar, as a place especially meaningful for the community.

To the question "What is the landscape you most appreciate?", they decided mainly on the new ksar and the old ksar, followed by the Palm Grove, while when they had to point out the landscape that they considered most appreciated by their community, the preference was mainly the Palm Grove, followed by the public square of the new ksar (Fig. 5). The reasons for choosing the ksar were representative-social ("I am from here", "my family lives here…") with a greater social component in the case of the public square ("meeting and relationships place …"). The choice of the Palm Grove was mostly for economic reasons ("we live from it", "provides us with food …"), but there were also environmental reasons ("natural environment, green, vegetation, etc.").

As for the preferred points of observation to appreciate these landscapes, in all cases they indicated mostly "from the inside", although it is worth mentioning that some preferred to observe the ksar from the rooftops of the houses. A point of observation indicated as suitable for appreciating both the ksar and the Palm Grove, was the mountain of Tinejdad.

The predominant answer to the question "What is the landscape you frequent the most?" continued to be the new ksar, followed by Tinejdad. The reasons were mostly social in the case of the ksar ("where I live, rest, I meet people …") and Tinejdad ("where I go shopping …"). At the time of pointing out the "landscape most frequented by the community", the preference was the majority opted for the Palm Grove. The reasons to select the Palm Grove were mainly economic ("where I work", "it is a source of goods …") but environmental ("vegetation, relaxation …"), aesthetic ("beautiful"), and even representative ("weddings") reasons were also present. The motivation for frequenting the Tinejdad market is related, on the other hand, to everyday purchases for the provision of goods and services (socio-economic).

The last survey questions referred to the landscapes perceived as most threatened. The old ksar was predominantly noted, followed by the Palm Grove as landscapes at risk. In the first case,

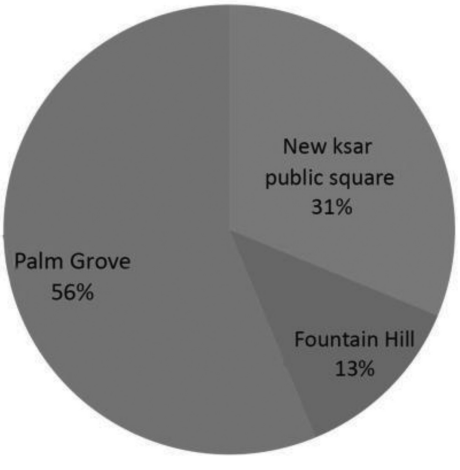


Figure 5. Landscape most appreciated by the community.

cultural causes ("abandonment", "lack of maintenance", "difficulty or inability to restore …") and natural ("weathering") were identified. In the second one, the threats are perceived as coming from natural causes ("drought", "floods, etc.") and architectural ("uncontrolled constructions, etc.").

Fifty percent of the local population surveyed was integrated by women between the ages of 30 and 50 (housewives), the remainder was completed by young men of school age (between 12 and 18 years) and there were only two adult males of working age. This imbalance in age and social group could be one of the causes that explain the notable differences between the subjective perception (landscape that you most appreciate and frequent) and collective (landscape most appreciated and most frequented by the community). In this sense, we must consider as most representative the results related to collective perception, considering the results of the subjective responses representative of the two social groups surveyed (housewives and young people in school age), among which there is no significant deviation in any of the questions asked.

With this proviso, the results obtained can be accepted as valid, since they are consistent with those thrown by the visual preference tests.

3.4 *Discussion*

The most relevant landscape pattern for the cultural image of the local population is the Historical Oasis, represented by the "Palm Grove" or palm orchard (*jmin slma*), for social, environmental, aesthetic, representative and fundamentally economic reasons. It is followed by the Traditional Urban pattern, identified in the new town of El Khorbat (*igrem jdid*), represented by its public square, for eminently social reasons, but also of a representative type. Paradoxically, among the rejected patterns, and therefore less identified with the cultural landscape of the place, is the Desert (Arid Plane), for environmental reasons and especially for symbolic reasons (representation of the inhospitable, barren and sterile environment that they have always had to overcome). Less appreciated is the Contemporary Urban landscape. Among the reasons for rejection are those of environmental kind.

Of special relevance is the Arid Mountain pattern, valued only as a point of observation, very preeminent in the territory and totally forgotten in the cultural image of the local landscape. This circumstance makes it especially vulnerable and probably explains the establishment of infrastructure facilities (antennas, reservoirs, etc), that are not perceived as threats, in the closest reliefs to the populations.

The landscapes perceived as more threatened coincide with the most appreciated ones, as expected, pointing out to natural or environmental causes (desertification, drought, floods, etc.). Again, there appears the destitute figure of the desert, as a threatening image. In the case of the earth town, the endangered landscape is identified, in this case, with the old ksar of El Khorbat (*igrem akedim*) and cultural causes, which lead to abandonment and result in ruin, are also argued.

4 CONCLUSIONS

It becomes clear that the Palm Grove and the earth towns are part of the cultural image of the place, unlike the contemporary town and recent architectures, which are conceived as improper elements of the landscape. Conflicts are observed related to those phenomena that threaten them (desertification, floods, abandonment, ruin, contemporary construction systems, etc.). The deserted plains and rocky hills inserted in the study area, despite their characteristic local image, deserve indifference and are in a situation of special vulnerability from the landscape point of view. Infrastructures and urban facilities are not perceived as threats, despite their obvious negative impact on the landscape.

This work is confined within the pre-examination phase and can be considered a step for the diagnosis of the Ferkla Oasis landscape, focused in the El Khorbat village. Its extension to other communities in the same territory and to other social profiles will allow completing and deepening the knowledge and the assessment of the landscape resources of the area, helping to characterize it and contributing to identify conflicts and the main landscape threats. Having a complete diagnosis of this kind will be the first step to identify the cultural image of this territory, to highlight its health degree and to detect its possible pathologies, many of them imperceptible or un-interpretable with the simple direct recognition of symptoms.

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New technology for analysis of the chapel of Santa María, Coahuila, Mexico

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ABSTRACT: The chapel of Santa María belongs to the hacienda with the same name. It is built in the 18th century. It is an example of earth architecture of Chihuhuense desert. It is built with adobe walls, closed by a flat ceiling in carved woodwork. The chapel present a single nave, ended topped in polygonal apse. The chapel was restored in 1984 with cement—sand covering, which interferes with the adobe's behavior, avoiding its transpiration. This treatment produces detachment of the coating, due to lack of adhesion and accumulation of moisture. These effects are causing major damages in the building. A preliminary photographic analysis is performed, for the description of the materials and damages. Later on, an architectural survey carried out through laser scanner, in order to get the point cloud and two-dimensional planes. Actually this information is nonexistent. All this information allows to evaluate the status of the temple.

1 INTRODUCTION

Earth architecture has been used since ancient times in various parts of world and now it is recognized that more than half of the world lives in houses made with earth (Jeffery 2015). The construction of earth causes a feeling of solid house, quiet, safe and silent. This kind of construction depends on resource availability (McHenry 2000). But earth as a building material is not used in housing construction only, but in other genres, such as temples, presidios and even bridges. Even though it is a material that is so used and makes up a large part of the heritage, there are few actions for its conservation and few technical knowledge for its maintenance and restoration.

The example that we present here is the chapel of Santa María del Rosario in the municipality of Ramos Arizpe, Coahuila, Mexico. It is constructed in a period that ranges from seventeen to eighteenth century, which is a wonderful example of Mexican Chihuahuan Desert architecture. Even so, there are no historical, iconographic or architectural information. Although is an important point for understanding the Camino Real de Tierra Afuera (Pérez-Gavilán 2016).

Despite the historical importance of this chapel, there is no architectural information that allows scientifically sustained interventions. The purpose of this work is to obtain preliminary information about the architectural party, the construction system and the characterization of the material used in the manufacture. As well as to understand the transformations that have suffered over time, in terms of style, religious dedication change and even nomination.

This work begins with the architectural survey in order to understand the spaces and structure of the temple. As well as to defined damages induced by intervention of 1984 and characterization of construction materials. All this will allow to make an *ad hoc* proposal considering identified problems and building characteristics.

2 HISTORICAL BACKGROUND

The occupation of the territory in America was marked by the immediacy of the exploitation of its resources. From the earliest times, the need to provide infrastructure necessary to extract those resources was present in the intentions of those who saw in them opportunities to get rich.

The northward expansion from the lands of the central valleys of Mexico, was marked by the presence of indigenous groups that they had to control,

in addition to an unknown geography that made more necessary the stability of the population, this would make possible to ensure its control and transit through it.

The arrival of the Spanish to the north of New Spain, meant the incorporation of drastic changes, in relation with earth, so that came to alter the traditional ways of seeing territory of indigenous populations. Subsistence needs are behind their implementation in agricultural exploitation, from waterwheels, ditches, dovecotes, rafts, etc. were inserted in the landscape, implementing a production that soon it will begin to supply urban centers that were appearing mottling an infinite territory for the European mind.

The units of exploitation that were brewing began their journey under the auspices of the Spanish Crown who wanted to avoid the aspirations of those to whom it was distributed as part of the process of territorial occupation. It was the time and the inability to control territories that were so extensive and far, what provoked an easier access to land ownership giving rise to the estates and latifundia as best exponents of those new owners.

In the case of Coahuila, it would not be until the last quarter of 16th century when the first properties appear, as a result of the land distribution to those who had participated in the foundation of Villa of Saltillo. The donations of Martin Lopez de Ibarra, handing over lands and water for livestock and the establishment of mills was the beginning of the exploitation of some lands that in less than forty years saw the first rural properties appear seed of future estates (Villarreal 2014: 19).

Properties throughout XVII century saw their initial extensions split as a result of the crisis of that time, the loss of labor or inheritance which was distributed among the descendants of the first families.

Located northeast to the city of Saltillo, Hacienda Santa María in the city of Ramos Arizpe, represents the peak of some constructions that during XVIII century prospered by the fertility of their lands and the strategic position in which they were within the course of Camino Real (Villarreal 2014:122). Its origin, is in the lands acquired by General Matías de Aguirre in 1707, and who converted this estate in one of the largest producers of wheat flour in the region (Villarreal 2014:122).

Obliged to preserve this inheritance, the intervention in the chapel of this estate, is the first of the steps for its recovery. Within a perfectly defined plan the chapel of this estate is the best exponent of the role of heritage as an element of social cohesion seeking recognition of the heritage that history has left us.

2.1 *Management of cultural heritage*

The evolution of the concept of heritage towards its current diversity and dematerialization is only the end point that began in the 19th century when the greatest monuments had the exclusivity of the protection. Nowadays, the dimension that its perception has acquire, has made its integration into the territory seen as the recognition of its complexity,

Possibly reflecting this situation is the figure of the cultural itinerary which recognizes the processes of displacement of the human being, and with that of objects and ideas, and of which its ability to intervene and modify the territory is not excluded, giving raise to cultural landscapes.

From the recognition of Camino de Santiago as a cultural itinerary in the 1990s, in the twentieth century, other routes have been integrated into that group, which have transited by disparate places on this planet in an attempt to identify and value other avenues, which through history, there have been interchanges with. In the American case, the declaration of Camino Real de Tierra Adentro in 2010 as a Heritage of Hummanity, set a guideline to which other proposals who seek the same recognition, as is the case of Camino del Inca in Southamerica, have been added.

In the case of Camino Real de Tierra Adentro, beyond being a single itinerary that communicated Mexico City and Santa Fe, New Mexico, a vast territory where there was room for other parallel territories linked to this, was articulated, which sought to vertebrate an extensive region to the north of the central Mexican valleys (López Morales 2001). The one that left from the city of San Luis Potosi was arranged in a territory that was drawn parallel to the curve of the Gulf of Mexico to the eastern land of Louisiana until reaching the territories of Florida. The effectiveness of this type of itineraries was based on the provision of infrastructures that would guarantee the circulation by them, besides its defense and as a basic pillar of the policy of the Spanish Crown in these territories, the evangelization of the indigenous populations.

In this line, we should focus on the understanding of Hacienda de Santa María inserted within the path of El Camino Real which went from Saltillo to the Texan City of San Antonio, an area of agricultural land exploitation that represents a series of past and present historical peculiarities. In the case of the first, taking into account that many of the missions that led the way were shot down to build on them some of the haciendas that have come to our time, offer a peculiar evolution different from the one we can find in other areas where it evolves from a religious space to a civil one; and on the other hand, the pressure to which this heritage is subjected, being that of Hacienda Santa María is located within an industrial area on

the outskirt of the city of Ramos Arizpe, which what is supposed of alteration in its environment and the danger to their facilities.

In the case of Hacienda Santa María, we are working with various groups from the City of Saltillo, headed by the Universidad Autónoma de Coahuila and the master in cultural management Ana Sofía Rodríguez Cepeda, with the intention of preserving the most outstanding milestones of what was the route of el Camino Real de Coahuila y los Texas.

The complex, integrated by the chapel, the sacristy, the attached sacristy, the big house, also the remains of the galleys, workmen´s house, cemetery, aqueduct and mill, is one of the best examples of this type of constructions, in spite of the dismembered state in which they are today, and where the analysis of the set of factors which are identify as necessary for its recovery only show the complexity of heritage.

The conflict of interests between the various social actors that concentrate in Hacienda Santa María, as is the case of the owners of plots in which the different buildings are distributed or the inhabitants of the community living within them and that have in the estate a social and landscape reference, in addition to local authorities, makes its presence a weakness that grips the proposals of intervention in the different properties that integrate the whole. A fact that can be significant is that to the present, the inhabitants of the community of Santa María have not been benefited by living in a site with historical and cultural value for the state of Coahuila. On the contrary and as a significant fact, can be, the isolation to which they are subjected with a very precarious access and functionality, even though it is located in a conurbation zone, in the community there is a shortage of water and not all primary services are available. Undoubtedly this results in the lack of implementation of programs for conservation and sustainable tourism development which is inserted into a context which is enhanced for the incipient character of the tourist sector in Coahuila, being its contribution to the state GDP (Gross Domestic Product) much smaller compared to other sectors such as industrial or manufacturing.

To the previous we must add a series of threats. As we pointed out earlier, the location of the estate within the facilities of an industrial polygon on the outskirts of the city of Ramos Arizpe is, because of its geographical situation, in imminent danger of disappearance since the area has been invaded by the construction of ships and industrial infrastructure that are increasingly approaching the monument. To this set of factors we must add the surplus value of the land where it is located which raises the risk of buying and selling and therefore the definitive privatization of the same and its possible disappearance.

Undoubtedly, the situation of abandonment and disuse in which it is, are accelerating in some cases its destruction, those aspects are reflected in the lack of continuity and follow up proposals for the rescue and conservation of the site.

Other risk factor is the ignorance, so that in general lines, there is around its historical and physical reality. A troubling negligence among some segments of the population which affects the historical and cultural value of this heritage, implying carelessness, disinterestedness and apathy to the potential of the site in terms of cultural tourism as an asset.

Nonetheless, it also has good points: the historical and cultural heritage of Santa María makes the site relevant within the regional context.

Despite the lack of knowledge, the disposition of diverse groups of interest for the conservation of the site and the diffusion of its value makes the internal articulation of the protagonists very necessary to stabilize the mechanisms of cultural heritage diffusion, especially when within its elements it is still possible to know, recognize and enjoy one of the most interesting representations of the regional vernacular architecture, and even more, when its strategic location is recognized by some economic sectors such as cultural and corporative sectors.

By last, the evolution of society is currently measured by the degree of sensitivity towards certain, such as cultural and environmental, what makes of interest the care and recognition of their culture, of their origins and environment, a determinant factor for some projects to continue.

2.2 *The impact of 1984 intervention*

The 1984 intervention carry out by Secretary of Urban Development and Ecology of Coahuila State. It was developed by Velarde and Associates Co; who left a writing mark on a girder, as it happened in 1721 (Figs. 1, 2). This work was done without protocols to consider the characteristics of materials, in order to prevent further damage. They used a cement coat onto adobes, both inside and outside of building, also on atrium wall, which has caused deep damage in material and building, described below.



Figure 1. 1983 reconstruction 1984 Velarde y Asociados SA Builders, Javier Velarde and Arq. Ernesto Guerra 10 January Antonio Flores Vera.



Figure 2. This chapel was finished in 1721 and the master Manuel de Peña carpenter finished it.

3 METHODOLOGY

3.1 *Laser scanner survey*

The architectural survey was carried out using the laser scanner technique, with a FARO® Focus3D device. Through a laser beam, allows the generation of three-dimensional models for objects and spaces. It contains measurable images which be transformed into two-dimensional planes (López de Juambelz et al. 2015).

The survey was performed in high resolution color, which refers to the number of points that form image on a standar quality. Since there are no elements that interfere and this parameter refers to the number of times the laser beam passes through the object. The building was surveyed on exterior and interior. Six reference spheres were used for each scene. The complete temple was surveyed with 40 scenes.

Once the survey is completed, post-production is the second step. From the scenes we proceed to manage the information, using the software SCENE own of this scanner. During this process, scenes are combined by reference objects. Subsequently, it is cleaned, edited and exported to create the 3D model in points cloud that is manipulated by POINT TOOLS software (Sainz & Rodríguez 2015), to make architectural plans. Finally, the transformation of the point cloud model into fully measurable two-dimensional plans is performed. Both the 3D model and the two-dimensional plans allow us to obtain reliable information about the structure, materials and damages, with which we can subsequently work to make a substained intervention proposal.

3.2 *Building materials analysis*

The analytical determination of the materials that compose adobes and earth roofs of the Chapel Santa María was carried out. The adobe sample was taken from a deteriorated section of the atrium wall. The roof sample was taken from the hacienda main house that is being removed, to replace it with concrete slab.

The analysis parameters were: Texture by sedimentation method, pH by potentiometer, humidity by air drying at constant weight, organic matter by ignition method.

4 RESULTS

4.1 *Image temple*

During the photographic survey the main characteristics of the elements that make up the chapel were determined, damages were identified.

4.2 *Architectural survey*

Spatial conformation of chapel consists of a rectangular nave topped by a polygonal apse. At foot of temple, on Gospel wall is located a baptistery of quadrangular form. Towards the presbytery on Epistola wall is the sacristy, also of quadrangular form but of greater dimension and it is connected with a small cellar rectangular. Between sacristy, nave and cellar there is a space that contains in the front, the cube that houses the staircase towards the belfry and a solid volume that is the buttress to support the weight of belfry.

Outside on headboard and Gospel wall we find a volume that follows geometry of building, it is



Figure 3. In the presbytery there is the main altar with a golden wooden altarpiece. This piece has a geommetry out of place which does not correspond to architectural form of the apse.



Figure 4. In gospel wall is access to the baptistery towards the foot of the temple. Also a side altarpiece of gold wood with heavy damages shows characteristics that do not correspond to the space, so it is presumed, it is a later addition.



Figure 5. First-order alfarje with simple jacenas on canes decorated with oblong petals flowers, supported on master beams.

a massive buttress that supports weight of both walls. The other buttress is located in the sacristy corner, corresponding to headboard side. The massive buttresses are not symmetrical, being smaller the one that sustains sacristy walls. The walls are made of adobe with a dimension of $54 \times 27 \times 12$.

4.3 *Material characterization*

We present obtained data from the laboratory analysis carried out on the material of the terrace and adobe that constitute the construction material of chapel and the Santa María Hacienda.

4.4 *Damage description*

In this preliminary damage determination, detachments of the plaster material are observed, both in the exterior and interior of the chapel and in the atrium wall.

The presence of moisture was induced by the plaster of cement that prevents the transpiration of the wall. This fact together with the waterproof treatment of the floor in the atrium, has caused that the water rises on adobe wall. Since adobe is the most hydrophilic material in the system. There is also growth of parasitic vegetation in the outer walls that show detachment of the plaster and deterioration of the adobe. This causes the formation of soil that can sustain vegetation. Among the species *Nicotiana glauca* is observed. There is an uneven mark in the ceiling above the gospel wall. The inclination causes dampness and disintegration of the resistant material that in this case is

Table 1. Analytical characterization of building materials.

Element	Humidity	Texture	pH	Organic mater
Earth roof	8.41%	Clay soil Clay 50.1% Silt 28.9% Sand 21.0%	8.27	8.58%
Adobe	6.23%	Clay soil Clay 56.0% Silt 26.6 Sand 17.4	8.23	17.33%



Figure 6. Plant. Obtained from points cloud, you can see: nave with polygonal apse, baptistery, sacristy, cellar, belfry and three volumes corresponding to buttresses.



Figure 7. Cross section. It shows altar that does not correspond in form, nor dimension to architectural space, reason why this altar is later than the sacristy is also shown.



Figure 8. Main facade. Obtained from point cloud, we observe a clean wall that corresponds to Plateresque style belongs to sixteenth century. The belfry tower is observed, with two botarel arches that contribute to support belfry weight.

adobe. In the atrium wall this effect has caused that only the concrete shell remains and the clay has been lost by the ruptures of the shell.

5 CONCLUSIONS

The Chapel of Santa María del Rosario in Ramos Arizpe, Coahuila presents last intervention in 1984, 20 years after the issuance of the Venice Charter (ICOMOS, 1964) which recommends the use of traditional techniques as a mechanism for restoration. This was not contemplated since cement was used, which was recommended by the Athens Charter issued in 1931 (International Office of Museums 2006). Intervention has not taken this into account today.

Currently the damage that affects the structure of the building and that can be observed in the section made from the cloud of points obtained from the survey with the laser scanner, is the settlement that has the roof to the gospel wall and that is causing humidity at top head of this wall. In the lower part and in some middle sections of the gospel wall you can see dampness that is casting cement and salts that denature the adobe causing damage to the resistant material. This damage is especially pronounced in the atrium wall. In this element we find sites with a total disintegration of the adobe, leaving hollow the shell of cement that breaks producing a deep damage.

It is important to make a new intervention based on the information about the spatial and material characteristics of the monument, taking into account all recommendations that mark the guidelines for intervention and restoration in heritage monuments that have a great historical importance for the identity of the nation.

NOTE

Knowledge to Fernando Rodríguez Manjarrez, pos- processing survey data. Daniel Guzmán Jaimes, laboratory analysis data. Jorge Segovia Balmes, Scanner laser Survey. This survey project was sponsored by the Support Program PAPIIT IG400714 and Posgraduate Programm in Architecture, UNAM.

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Implementing a GIS for cataloguing Medieval defensive earth architecture

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ABSTRACT: As part of the R+D+I project entitled "Sustainable methodology for the conservation and maintenance of the Medieval defensive earth architecture in the South-East Iberian Peninsula; diagnosis and prevention against natural and human risks (PREFORTI)", the task of creating a catalogue of defensive earth architecture located in the Spanish southeast, incorporating fact sheets on material, constructive and structural characteristics, was addressed. This geodatabase compiles all the architectural elements covered by this project and establishes recognition and cataloguing criteria that are integrated into an open source GIS. Cases that merit more detailed study are selected using the intersection of territorial information (natural and anthropogenic agents) and the precise location of the items listed. This selection will later be investigated more thoroughly in order to develop systematic databases that enable us to create charters of preventative measures, related to the risk charters recommended by the National Plan for Defensive Architecture and Preventative Conservation of Cultural Heritage. The present work deals with the choice of open source Database Management Systems (DBMS), as well as their attributes and normalisation, the data model used, and the web mapping application of the maps generated.

1 INTRODUCTION

In the framework of the research project entitled "Sustainable methodology for the conservation and maintenance of the Medieval defensive earth architecture in the South-East Iberian Peninsula; diagnosis and prevention against natural and human risks (PREFORTI)", the task of creating a catalogue of defensive earth architecture located in the Spanish southeast, incorporating fact sheets on material, constructive and structural characteristics, was addressed. This geodatabase compiles all the architectural elements covered by this project and establishes recognition and cataloguing criteria that are integrated into an open source GIS. Cases that merit more detailed study are selected using the intersection of territorial information (natural and anthropogenic agents) and the precise location of the items listed. This selection will later be investigated more thoroughly in order to develop systematic databases that enable us to create charters of preventative measures, related to the risk charters recommended by the National Plan for Defensive Architecture and Preventative Conservation of Cultural Heritage.

The present work deals with the choice of open source database management systems (DBMS), as well as their attributes and normalisation, the data model used, and the web mapping application of the maps generated.

2 BACKGROUND

In 1900, the Ministerio de Instrucción Pública y Bellas Artes was founded, which charged the Academias and the Comisión Monumental with the task of creating a Monument Catalogue.

The Conservation of Artistic Architectural Monuments Act of 1915 established cataloguing as the basis for the application of the law, thus adding to the groundswell of European policy on heritage preservation.

The 1933 law on the Defense, Conservation and Expansion of the National Historical-Artistic Patrimony stressed that an inventory of national historical-artistic heritage should be generated, based on the monument catalogues and the *Fichero de Arte Antiguo*. The decree on the protection of Spanish castles, issued on the 22nd April 1949, specifically commissioned an exhaustive inventory of these buildings, which was finally published in 1968.

Since 1998, the AEAC (The Spanish Association of Friends of Castles) has been working in conjunction with the Spanish Ministry of Culture on a scientific study to research and classify Spanish military heritage by compiling photographic and historical records for each monument. It is the most complete, systematic, and exhaustive inventory ever made in Spain of the country's historic fortifications. Consisting of over 14,500 items compiled by several interdisciplinary teams, it

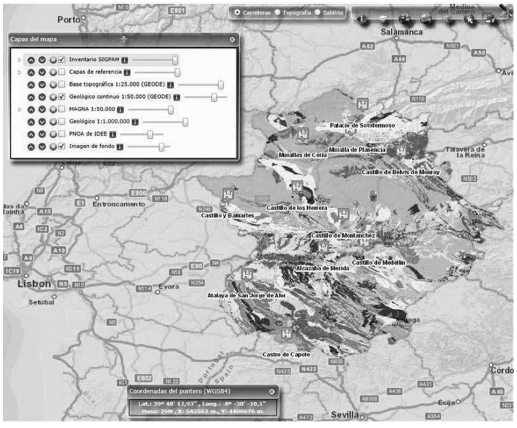


Figure 1. Geoscience Information System applied to Monumental Architectural Heritage (GIS/PAM).

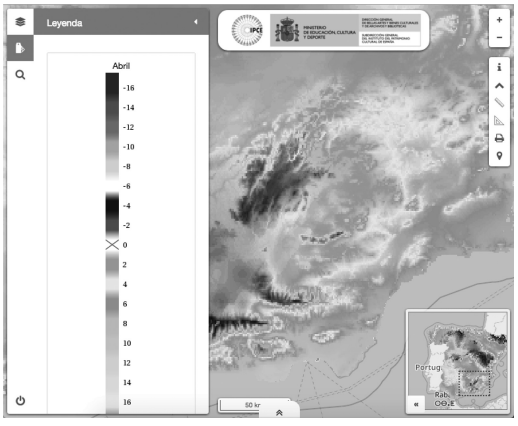


Figure 2. SDI of the Instituto del Patrimonio Cultural de España interface. (https://ipce.gvsigonline.com/gvsigonline/viewer_public/8/#!).

was awarded the Europa Nostra Research Special Prize in 2008. This inventory is now available in an interactive form on the internet. Users can suggest modifications to the files that will be implemented after being checked.

The Charter of Baños de la Encina (2006) recommended the development of a public, shared, and properly georeferenced inventory which would allow citizens to identify which and how many systems, groups, and constructions make up Spanish defensive architecture, thus facilitating the study of the subject matter and contributing to the good management of its conservation.

Regarding the use of Geographic Information Systems (GIS) for this purpose, the Geoscience Information System as applied to Monumental Architectural Heritage (GIS/PAM), led by the Instituto Geológico y Minero de España (IGME) and the Instituto del Patrimonio Cultural de España (IPCE), stands out as a computerised tool that integrates defensive architectural heritage and national geological knowledge. It uses the enormous possibilities of GIS to their full potential, combining national geological information, topography, location of historic quarries, and the contribution of each historic structure under evaluation, allowing the defensive structure in question to be studied from both global and relative perspectives. This facilitates not only our understanding of the control of territory over the course of history, but also the management of their conservation by their respective authorities. (Baltuille et al, 2014).

Also noteworthy, in the context of Spatial Data Infrastructures, is the development of the recent SDI by the Instituto del Patrimonio Cultural de España (IPCE), which is related to preventative conservation.

3 NATURAL AND HUMAN RISKS. RISK MAPS

Following the chronotypological classification established in the IPCE's National Plan for Defensive Architecture, the defensive architecture built in the southeastern Iberian Peninsula is mainly made up of medieval fortifications that have been continuously exposed to the effects of human and environmental agents since their construction.

Vulnerability to these agents is one of the serious problems affecting this type of rammed earth construction, particularly in the southeast of the peninsula. This is the direct cause of sizeable investments in latter-day repairs, as in the case of the recent earthquake in Lorca, near Granada.

Risk maps can be produced by cross-referencing the georeferenced items and the selected natural and human variables.

As reflected in the National Plan for Defensive Architecture: *To improve investment programming by the bodies responsible for conserving these historical assets, the inventory should be complemented with Risk Maps that, as an instrument for managing preventive conservation, should be the framework for evaluating the state of conservation of the defensive heritage and its requirements. They should provide all the necessary information to enable us to look ahead and take advance decisions as well as to establish the shortcomings and priorities of these assets as a whole through systems and procedures that allow us to schedule interventions that improve their protection. These maps will be available to the authorities responsible for the conservation of these historical cultural assets as an effective tool with which to undertake the most urgent works and to improve the*

distribution of funds that each one allocates to the conservation and restoration of these assets, as well as to observing and conducting research on them, thus facilitating the maintenance and dissemination of these investigations. They should contain, through an interactive, updatable map equipped with a Geographic Information System (GIS), all cultural assets grouped under 'defensive architecture', properly identified, georeferenced and differentiated by typology, so that each one of them may be interpreted in an interrelated way with the rest of the historical assets whose territory they share and which, together with contemporary elements, are needed in order to understand their existence. This makes it possible to conduct a better study of the local cultural, transversal and integral management of the territory on which they stand.

4 THE SPATIAL DATA INFRASTRUCTURE (SDI)

INSPIRE (Infrastructure for Spatial Information in Europe) is a European Commission initiative, from the Directorate General of the Environment, which aims to establish a Spatial Data Infrastructure (SDI) in Europe. It is a computer system composed of a set of resources (catalogues, servers, programmes, applications, web pages, etc.) that allows datasets and geographic services (described through their metadata) to be accessed and managed via the Internet; it complies with a number of norms, standards and specifications that regulate and guarantee the interoperability of geographic information.

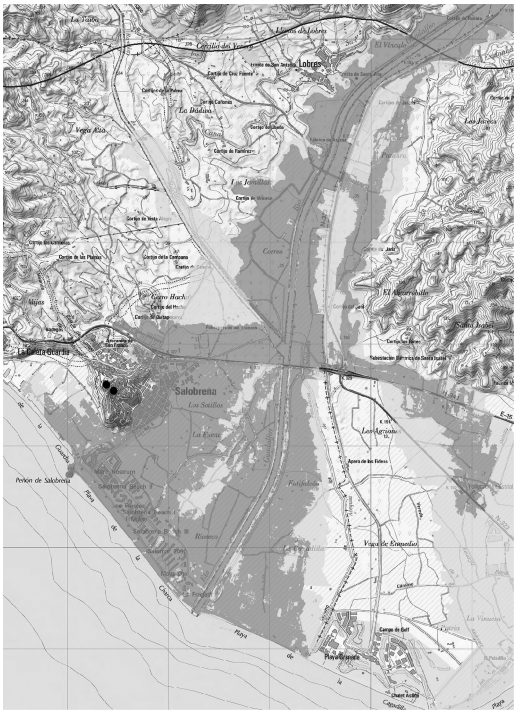


Figure 3. Risk of flooding at the mouth of the Guadalfeo River.



Figure 4. Inventory of geolocations of Medieval defensive structures in Granada (Spain).

This directive was incorporated into the Spanish legal system in Law 14/2010, of the 5th of July, on geographical information infrastructures and services in Spain (LISIGE). Its objectives include the standardisation of digital geographic information and the adaptation of data models and specifications for protected sites (Historical-Cultural Heritage), among many other datasets.

5 THE GEOGRAPHICAL INFORMATION WEB SERVICE

This project proposes the study of a representative selection of medieval fortifications built on land, evenly distributed over the territory in question. For this, Geographic Information Systems were used as a key tool.

5.1 *Methodology*

All the items in the inventory were georeferenced using GIS methodology, making it possible to record them in a database associated to territory. GIS methodology allowed us to select a few significant examples, based on their territorial characteristics and their incidence of natural risks, in order to develop a detailed study of them. This study

includes storing and managing the documentation previously collected for the selected cases (i.e. the catalogue) and subsequently analysing it and extracting useful data which can be extrapolated to the overall investigation. The task of data processing involves mapping or digitising the information on each case in order to incorporate it into the GIS. This methodology will make it possible to have each asset's objective data systematised and classified in the computer database, in addition to facilitating the tasks of information analysis, conclusions, and the graphic production of results.

5.2 *Open source GIS*

Two open source geographic information systems, gvSIG and Qgis, were used. These applications are open source, licensed as GPL (GNU Public License), which allows them to be freely used, distributed, studied, and improved upon. In addition, special emphasis has been placed on their extensibility, so that potential developers can easily extend application functionality, as well as develop entirely new applications from the libraries used in both.

The latest stable version of gvSIG, 2.3.1, includes the Sextante (Sistema Extremeño de Análisis Territorial), developed by the Universidad de Extremadura (UNEX), a set of tools or library of spatial analysis algorithms for working in raster format. In addition to all the algorithms developed by the team itself and its collaborators, it is possible to integrate GRASS into Sextante, which considerably increases the number of algorithms available through its graphic interface. This extension also has a command line, a batch processing manager, a model generator, and a history of commands made by the user in order to make it easy to repeat processes.

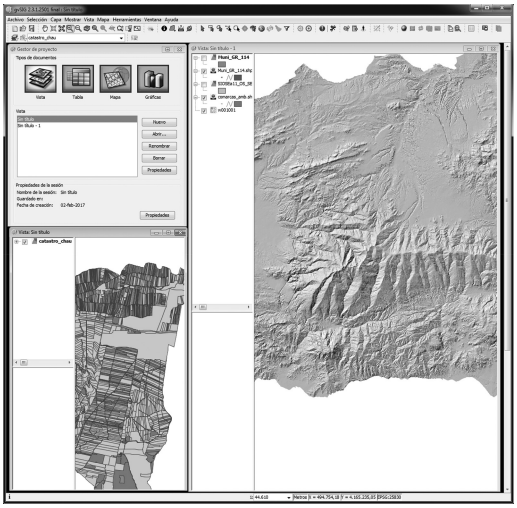


Figure 5. gvSIG interface.

5.3 *Geodatabase, data models and metadata*

For the geodatabase (database with a spatial component), PostGIS is used as a module for the PostgreSQL data engine, which adds support for geographic data types.

The data model defines the computer structure through which the geographic information will be stored. It reduces real-world variability by organising it into a simplified structure which is standardised and usable by a database manager.

The data model applicable to spatial data sets is in the process of standardisation, within the framework defined by the European Union's INSPIRE (Infrastructure for Spatial Information in Europe) initiative. INSPIRE does not yet have a thematic data model for cultural heritage. On the other hand, since the end of 2010 there has been a shared data model to describe the records of protected heritage sites. In particular, the data model for Protected Sites is laid out in point 9 of Annex I to the Regulation entitled "Commission Regulation (EU) No. 1089/2010 of the 23rd of November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council on the Interoperability of Spatial Data Sets and Services".

In summary, this data model presents a computerised structure stored in a relational database with a layer (called "ProtectedSites") formed by polygonal objects, to which the following voidable attributes must be associated:

Inspire ID: Unique external identifier of the spatial object (protected place) published by the authority responsible.

Geometry: Geometry that defines the geographical limits of the protected place. These are point, line or polygon geometries; it is recommended that areas larger than 1 ha are represented by polygons.

Legal Foundation Date: Date on which the protected site was legally created. This is the date on which the legal declaration of protection is made, not the date on which its representation was created in an information system.

Legal Foundation Document: URL or textual quote that refers to the legal act that created the protected place.

Site Designation: Composed of the type of designation of the protected place and the scheme from which it comes. Protected locations must use designations from an appropriate designation scheme and the designation code value must match the designation scheme.

Site Name: Name of the protected place, in the instrument that declares it. Can be expressed in different languages; it is recommended that the language be completed whenever possible, as the name is an important attribute to identify the protected place.

Site Protection Classification (archaeological): Classification of the protected place based on the purpose of the protection.

This model of data defined by the regulations deriving from the European INSPIRE Directive is to be understood as a minimum mandatory model for the exchange of geographical information on protected asset records. Together with this common core, those who manage the patrimonial information can define extensions to the model that complete that minimum according to their specific needs. The data model established by the European Union must be understood as an exchange model, while the extensions define a model for exploitation and analysis.

The geographical information managed by the Instituto Andaluz de Patrimonio Histórico (IAPH) has its own model of data that includes not only protected assets, but also other patrimonial entities known from various sources of information (inventories, diagnostic files, studies, bibliography, etc.). For this reason, specific attributes are added to the mandatory attributes at European level. The IAPH geographical database model includes the following attributes:

- Identifier (FID): Unique identifier of the spatial object.
- Geometry (shape): limits of the patrimonial entity.
- Area: area of the asset.
- Perimeter (perimeter): perimeter of the asset.
- Code (code): identifier of the patrimonial entity in the SIPHA/MOSAICO system.
- Province (province): province where the patrimonial entity is located.
- Municipality: (municipality): name of the municipality where the patrimonial entity is located.
- Municipal code (prmun): municipality code according to the National Institute of Statistics.
- Name (denominaci): denomination of the patrimonial entity.
- Generic period (per_hist_g): Generic historical period of creation of the patrimonial entity.
- Specific period (per_hist_e): specific historical period of creation of the patrimonial entity.
- Ethnicity (ethnicity): ethnicity to which the patrimonial entity is attributed.
- Generic typology (tipol_gen): generic typology of the patrimonial entity.
- Specific typology (typol_esp): specific typology of the patrimonial entity.
- Style (style): artistic style of the patrimonial entity.
- Activity (activity): original and current use of the patrimonial entity.
- Legal figure (figure): legal figure of legal protection.
- Legal type (tipol_jur): type of cultural property declared.
- Legal status (state): status of the cultural asset declaration file.
- Archaeological value (p_arqueo): existence of archaeological values in the patrimonial entity.
- Architectural value (p_arqui): existence of architectural values in the patrimonial entity.
- Ethnological value (p_etnol): existence of ethnological values of the patrimonial entity.

Each one of these attributes is normalised by controlled lists (Regulation 1089/2010), in order to protect the consistency of the data and to ensure that the user can only enter one out of a number of values shown in the list, reducing the risk of mistakes. The terminology is defined in the "Tesauro de Patrimonio Histórico Andaluz", published by the IAPH.

The official geodetic reference system in Spanish territory is the ETRS89 (European Terrestrial Reference System 1989), as established in Royal Decree 1071/2007 of the 27th of July. This geodetic system is equivalent, in practical terms, to the WGS84 (World Geodetic System 1984), which uses the GPS (Global Positioning System) network, since both use a same ellipsoid, denominated GRS80. This reference system has been officially adopted throughout Europe and is managed by EUREF as the European Subcommittee of the International Association of Geodesy (IAG). In Spanish territory, this system is managed by the IGN (Instituto Geográfico Nacional) and is materialised by way of geodetic vertices according to the framework defined by the Red Geodética Nacional por Técnicas Spaciales (REGENTE). The characteristics of the geodetic reference system to retrieve geographic information on patrimonial entities are as follows:

Horizontal Datum: ETRS89
Vertical Datum: NMMA (Middle Sea Level in the tide gauge of Alicante)
Ellipsoid: GRS80 (~ WGS84)
Projection system: UTM (Universal Transverse Mercator), spindle 30, zone North.

Once the project is finished, the information generated will be accessible through OGC (Open Geospatial Consortium) standards and the WMS (Web Map Service), which produces spatially referenced data maps, dynamically based on geographic information.

Users will be able to explore Mapserver 7.0.4 as an Internet Map Server that stands out for the quality of its implementation in the WMS space. It uses numerous open source libraries like GDAL, OGR or PROJ4. The geoportal will be designed to be interactive and upgradeable.

6 PLANNING INSTRUMENTS

Based on the data provided by the inventories and catalogues, and after creating the corresponding risk maps, a more precise knowledge of the state of defensive cultural heritage in Spain will be obtained.

As provided for by the National Plan of Defensive Architecture, local territorial planning instruments such as General Urban Planning Plans, Special Plans, Building Catalogues or others, can precisely delimit the environment of protection of defensive assets of cultural interest, in order to obtain appropriate protection for them and for their territorial relationship to the area to which they belong.

Strategic Management Plans are also very useful for providing comprehensive treatment for a group of assets with characteristics in the same range, such as defensive systems on boundary lines, as they provide the authorities responsible for implementing conservation work with action guidelines that ensure their integrity and social return. The powerful interconnectedness of cultural assets in the field of defensive patrimony also produces a considerable number of relationships with other assets, both similar and dissimilar, as they complement each other through historical and cultural ties. Such is this interrelationship that these historic structures and their environments can be said to form a complex, complete, recognisable heritage system, closely linked to natural heritage, whose problems go beyond strictly architectural systems. These plans are tools for coordinating the agents involved in conservation processes, providing a guarantee and plans for the scales of action described in the National Plan for Defensive Architecture. For this reason, the aims of a Strategic Management Plan should focus on optimising existing resources, establishing guidelines for interventions on cultural assets that define the necessary synergies between all the economic and social sectors that overlap in the sphere of influence affected by this plan.

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The defense of the technique of rammed earth made by Giovanni Battista Antonelli in 1560

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ABSTRACT: Military engineer Giovanni Battista Antonelli (1527–1588) served the Spanish crown at the time when King Philip II (1527–1598) needed to defend his vast empire. The controversial Italian engineer was one of the best representatives of the *alla moderna* design, clearly demonstrated by the use of the typical 16th century geometry. In addition, contrary to the prevailing trend of the period, he was a defender of earth building in defensive architecture, and more specifically of rammed earth construction. The aim of the present work is to deepen in the knowledge of: the arguments that led Antonelli to defend the use of rammed earth against the tendency to use the stone, supported in this case by Vespasiano Gonzaga, Viceroy of the Kingdom of Valencia; and Antonelli's influence on the design of the new towers that were built to defend the Spanish eastern coastline.

1 INTRODUCTION

1.1 *Prejudices*

Construction materials transcend on many occasions their mere constructive technique, granting certain characteristics or attributes to the work itself and to its dweller. This fact is not new, and in the early modern period, as at present, the stone constructions of the Iberian Peninsula have been incorporated to the Roman repertoire, whereas the rammed earth ones have been identified as Moorish. In addition, stone represents greatness, strength and immutability, while the use of land is assimilated to simplicity, poverty and the ephemeral.

Although this technique was already used on the peninsula before the arrival of the Moors, they were the ones who generalized its use in all areas. Thus, being ours the point of view of the conqueror, it is possible that we have failed to fully appreciate this technique.

1.2 *Advantages and disadvantages*

Rammed earth's greatest potential relies on the economy of the material since it is usually available in the surroundings, requiring very little processing and almost no transport. In addition, it is not a very complicated technique, requiring less effort and time for learning.

One of its great virtues is the execution speed, known and experienced by the Valentinian Muslims, who built their watchtowers and castles in a very short period of time.

However, its detractors, which it also has, emphasize its poor performance facing water, especially runoff water, erosion, its limited resistance to compression and its less noble aspect, adding to all this the continuous maintenance needed, as opposite to its virtual absence in the case of stone works (Arciniega 2006).

1.3 *The maritime border of the Kingdom of Valencia*

Since the early 16th century, the problem of piracy in the western Mediterranean was exacerbated to the point of making it unsustainable for the coastal population. The Valentinian Kingdom was not freed from this pressure, but quite the opposite, with a long maritime border it was the scene of a multitude of dramatic episodes. As a result, the cities were either moved away from the coast or fortified, but there were still many areas for the provisioning and landing of pirates and corsairs. History repeats itself: in Moorish Valencia, the incursions of King James I of Aragón (1213–1273), known as *cavalçades*, consisted of punctual and quick attacks of armed horseback riders. This situation forced the Moors to build their watchtowers on these lands (Rodríguez-Navarro 2008). Years later, under Christian rule, the incursions came from the sea, in galleys, but they were very similar, based on surprise and speed, obtaining spoils and slaves without much difficulty.

Thus, in the 16th century, the maritime border becomes a real problem for its inhabitants.

2 GIOVANNI BATTISTA ANTONELLI AT THE SERVICE OF KING PHILIP II

2.1 *The encounter with an engineer viceroy*

Before King Philip II (1527–1598) came to the throne, his father Charles V (1500–1558) had already begun strengthening the works of the coastal defenses, in response to the population's demand. Bernardino de Cárdenas y Pacheco (?–1560), Duke of Maqueda, carried out the first works in the mid 16th century, but it was not until a few years later, with the arrival of Philip II, when he faced the problem of the coastal defense of the Kingdom of Valencia as a whole.

For this work, the king brought together two personalities of his confidence who would influence the development of history: Vespaciano Gonzaga (1531–1591), Viceroy of Valencia, and Giovanni Battista Antonelli, a prestigious military engineer. Both were engineers, although they arrived from different fields. Gonzaga was a renowned military man with extensive field experience, while Antonelli (1527–1588) was more of an engineering theorist, contributing to the more advanced designs of the time, called *alla moderna* (trend-like), which led him to write his own treatise. They were two influential and well trained figures, with different ways of seeing and understanding military defense.

They travelled together along the eastern coast to assess the state of the towers and propose necessary renovations and new constructions. Antonelli issued a report in 1563 (AGS, Estado, I, f. 13) where he documented his opinion of the current state of defense of the kingdom and what changes should be faced, that is, that new constructions, not only towers but also castles, were necessary to ensure safety. His intention was to replace old obsolete towers with new constructions based on modern designs that would guarantee a solid, functional construction, incorporating artillery (Boira Maiques, 1994).

2.2 *The defense of the use of rammed earth in defensive architecture*

There were many differences between these two personalities in terms of the defense of the coast, being the objective of the present contribution to analyze one of them: the use of earth building techniques and, more specifically, the use of rammed earth in defensive architecture.

Gonzaga's vision, considering that he had been Captain General before becoming viceroy, was that stone work, whether based on ashlars or masonry, should be imposed. The stone reflects the strength of its constructions, and this was commonly assumed by most engineers at the time.

On the other hand, Antonelli, who was implementing a new vision of the fortifications design, also raised a technical and scientific reflection regarding the materials used, choosing to use different materials depending on their function. It is at this point when he introduced the use of rammed earth for the walls of towers and fortifications, citing Plinio as a guarantee, when he asserted that Hannibal's were made out of this material (Cámara 1990).

In his discourse on fortification, Antonelli begins to propose the use of rammed earth, finding it for the first time in reference to the defense of Santa Pola's island, where he succinctly proposes the construction of a rammed earth fortress, as he simply says that since it will be made out of rammed earth it will require little lime and it will be possible to use the island's sand. (AGS, Estado, I, f.13, f.10r). Later, in the same discourse on fortification, he proposes the construction of the San Julián Tower in the vicinity of Castellón, providing, among other details, the thickness that rammed earth walls should have. (AGS, Estado, I, f.13, f.15r).

Antonelli masterfully reconciles the new *alla moderna* ways of designing and building, without forgetting the advantages that traditional materials and constructive systems can provide (Bertacci 2012, p.17). In this sense, in his manuscript Epitomi delle fortificationi moderne, from 1560, he defended the greater capacity of rammed earth walls to absorb the impacts of artillery as opposed to masonry walls. In addition, he highlighted the substantial economic reduction of rammed earth works, subject of no small significance given the size of the defense project.

2.3 *Rammed earth for the walls of coastal towers*

A magnificent example of rammed earth use in the towers of the eastern peninsula is found in the graphical proposal of a hexagonal tower typology. These two documents, attributed to Antonelli, constitute the design and development of the execution of the tower, including the measurements for economic and temporal calculations.

The first one we show contains a schematic plan and annotations. As a statement of intent, the document is headed by a text that defines the dimensions of the rammed earth walls and their number: "the wall is 14 spans long, 5 high and 2 ½ thick with a total area of 175 spans". Then we find the scheme in plan of the tower with its thicknesses and dimensions; to its right, appear the operations to calculate the number of rammed earth units for the walls, which total the amount pointed out at the beginning. The rest of the document is dedicated just as clearly to the other elements of the tower: the slope, arches, garland and parapet.

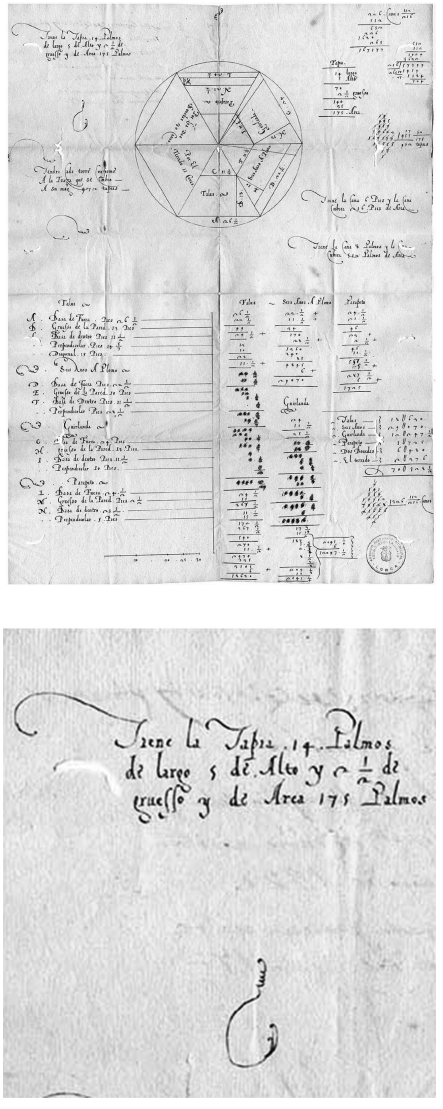


Figure 1. Measurement for the construction of a rammed earth hexagonal tower. It contains a schematic plan with indications for its implementation, the dimensional characteristics of each wall, and the total number of walls. (Below: extension of the dimensions of the rammed earth wall: 14 × 5 × 2 ½ spans). Attributed to Giovanni Battista Antonelli. Lorca's Municipal Archive. AML, La Marina towers monographic file, 1578. Possibly, the first graphic document that refers to rammed earth in coastal defense in early modern period.

The second document shows the outline of the tower's construction section and its upper floor, indicating several spaces and elements. These two documents perfectly defined the typology of this tower and made possible to build in series.

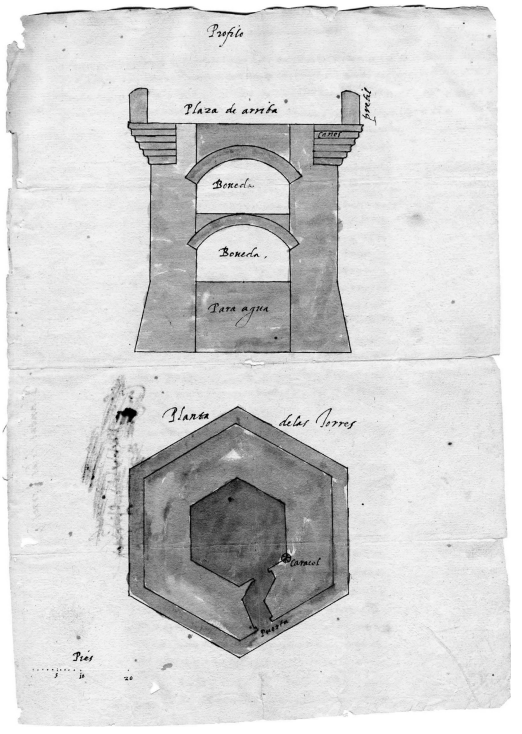


Figure 2. Construction and section of the hexagonal tower. Attributed to Giovanni Battista Antonelli. Lorca's Municipal Archive. AML, La Marina towers monographic file, 1578.

2.4 *Alicante's castle and the fort of Bernia*

Based on the same criteria of durability, absorption of artillery impacts, execution speed and economy, Antonelli followed his proposal to use the rammed earth technique, making it extensive to castles on this occasion.

Thus, when he approached Alicante's castle renovation project, which incorporated a walled enclosure for the city, this constructive technique was still present, affirming "all the work has to be executed using rammed earth to better resist the impacts as well as to be built faster and easier "(AMA, arm. 1, lib. 11, f. 14 v)".

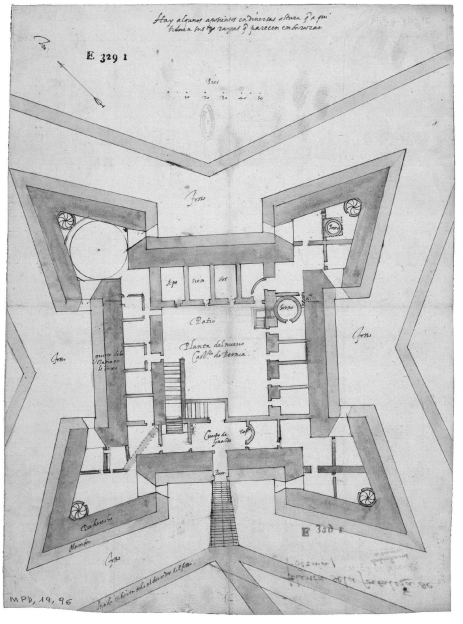
Alicante's enclosure wall project was not pursued and his proposal was abandoned, but Antonelli's great project, the fort of Bernia, was accomplished. Bernia must have been the long awaited opportunity for a theorist of the fortifications like Antonelli, who had been seeing how his interventions were conditioned, a priori, by different factors:

– The need to adapt to the existing constructions, not leaving the possibility of developing his *alla moderna* geometry in its entire splendor.

– The conditions of his superiors, at that moment Viceroy Gonzaga or King Philip II himself.

Thus, Antonelli built his "ideal" castle, fruit of the development of all his advances using, as well, the materials he deemed appropriate. The work was done in 1562, at a great speed, due mainly to the use of rammed earth to build the walls and embankments that were reinforced by ashlar masonry in the corners. In fact, in the project plan delineated by Antonelli himself, we can read "thickness of the rammed earth wall in the bottom", being the only reference to the type of constructive system used that appears in said graphic document.

However, due to other reasons, the fort was abandoned and, in 1612, King Philip III ordered its demolition, since a castle so well designed and executed, falling into enemy hands would become a serious problem.



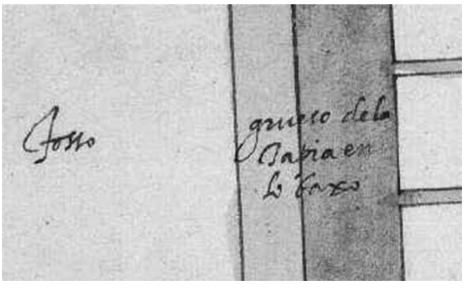


Figure 3. Bernia Fort Plant. Giovanni Battista Antonelli. AGS, MPD, 19, 096, 1562 (?). Below, detail of the floor plan with writing that indicates "thickness of the rammed earth wall…".

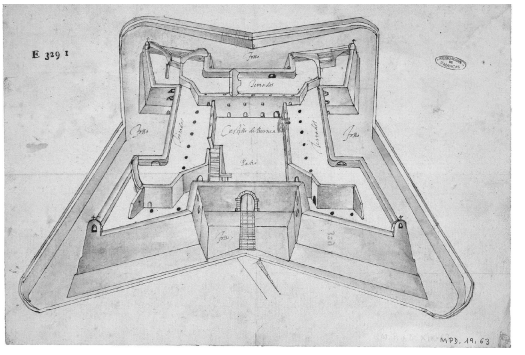


Figure 4. Perspective of the Bernia Fort. Giovanni Battista Antonelli. AGS, MPD, 19, 063,1562 (?).

3 THE OPOSITION OF VESPASIANO GONZAGA TO THE RAMMED EARTH WORK

As we discussed at the beginning of this study, Gonzaga and Antonelli had absolutely disparate visions on a multitude of occasions and subjects. Thus, in response to Antonelli's continued defense of the use of rammed earth in fortifications, Gonzaga always provided a list of reasons to try to refute this solution in favor of the use of masonry and ashlars.

The document dating from 1570 in which Gonzaga collected his opinion as regards the coastal towers, after completing the tour with Antonelli, clearly shows his rejection of Antonelli's proposal, both in terms of the number of towers and the construction technology proposition. (BHUV, Ms. 5, ff. 8 v- 12 v).

In this sense it is very clear and it is worthwhile to transcribe literally the paragraph in reference to the opposition found related to rammed earth use:

> "… I am not certain that the earth can cover it and sustain it although Juan Bautista Antonelli sees it easier than I think it can be and he is of the opinion of building the towers using rammed earth, with which I do not agree because the sea soil is sandy and if they have to bring it from afar with boats it will be even more expensive, and in some places they will have to raise it very high, and the southwest wind usually eats the lime walls, so even more it will do with the rammed earth. Besides having to build vaults, or at least the top one that has to support the artillery, I would not trust much the rammed earth walls, and in the end it would be of higher expense although it seems less, since it is not a perpetual work … (?) and they could be torn down, and those of masonry are more

resilient and it is more difficult to cut them, so for these reasons I understand, with reference to who knows more of this, that it is not convenient to make them of rammed earth, and if they still had to be made out of it, they should at least have fifteen feet of ashlar from the ground, of carved hewn stone or masonry" (BHUV, Ms. 5, ff. 8 v- 9 v)[2]

Gonzaga, although a viceroy, was forced to report his opinion to King Philip II himself, which also allows seeing the hierarchical difficulties between the two, stating that the choice of material should be the king's decision. Analyzing his writing, we see how he enumerated a series of chained arguments. He began by stating that his opinion was contrary to using earth, and in particular rammed earth, to build the coastal towers. From there, he argued his opinion based on the following reasons:

- The soil in the vicinity of the sea is sandy.
- If it has to be transported in boats and carried up to the place of construction, it will be very costly.
- In addition, it needs water and on the coast they use salty one, which does not work well with this constructive technique.
- The southwest wind erodes the lime walls and even more if they are rammed earth based.
- He distrusts the ability of earth vaults to support the artillery.
- He distrusts the ease of undoing these walls at their base.

For all this, he concluded that it would be better to execute them with masonry and stonework, stating that although they were more expensive "at least they are definitive" However, not sure of the king's response, he concluded by saying that if they were finally constructed of rammed earth, at least, the base of the towers should be made of masonry and stonework (up to 15 feet high).

Some of his statements seem forced by confrontation, since all the towers had fresh water supplies in their vicinity, and the sandy soil was only found in the low part of the coast, being normally suitable and previously used. However, it is true that Antonelli himself proposed on some occasions the use of beach sand:

"(…) being of rammed earth, it won't be necessary to use a lot of lime, having earth and sand in the island and using some from the sea for the work "(sic) (AGS, Estado, I, f. 9v)

4 CONCLUSIONS

Giovanni Battista Antonelli presented himself as an engineer under the orders of King Philip II, carrying his theoretical knowledge of the new way of designing military architecture, adapted to the new needs resulting from the development of artillery. But his concern was not outside the ambit of the local constructive tradition, which led him to reinterpret his own proposals enriching them, fundamentally, with the rammed earth use tradition in the fortifications. He quickly understood how this material's performance, less rigid, was suitable for absorbing the artillery impacts, at the time it required less qualified labor. In addition, there was earth available in the vicinity of the constructions themselves, so that more and better towers could be built, in less time and with lower costs.

The only thing he did not take into account was the prejudices (Arciniaga 2006) related to the rammed earth technique, associated to poor, weak and ephemeral works and, moreover, of Moorish origin, all these reasons defended by Gonzaga, as viceroy, and strongly brought to the attention of the King of Spain himself.

Finally, the king had to make a decision, and at Gonzaga's report itself, an annotation made by King Philip II himself allows us to know his resolution,



Figure 5. Cristóbal de Rojas, 1613. Proposal of a square based rammed earth tower for the Andalusian coast. It is possible to read "the tower has 240 rammed earth walls, which at 5 ducats each gives a cost of 1200 ducats" (AGS, MPD, 36, 017, 1613). Years later, the rammed earth construction proposals initiated by Antonelli followed.



Figure 6. Ruins of Bernia Fort. Giovanni Battista Antonelli (Google Earth 2004).

indicating that works should not be made of rammed earth but of masonry (Cámara 1991, p. 54).

NOTES

AGS. Archivo General de Simancas.
AMA. Archivo Municipal de Alicante
BHUV. Biblioteca Històrica Universitat de València

[1] This paper presents results of TOVIVA project (Surveillance and Defense Towers of the Valencian Coast, Metadata generation and 3D models for interpretation and effective enhancement, HAR2013–41859-P) funded by the National Program for Fostering Excellence in Scientific and Technical Research, National Sub-Program for Knowledge Generation, Ministry of Economy and Competitiveness MINECO (Government of Spain).

[2] (original text) "(…) no se si la tierra lo puede çufrir y sustentar aunque Juan Batta lo façilite mas de lo que yo alcanço que puede ser y en esto el se mueve porque tiene opinion de lebantar las d[ich] as torres de tapieria en lo qual yo no me afirmo porque la tierra ordinariamente de la mar es arenosa y si la de traer buena de lexos con bagajes o barcas todavia hara costa y en algunas partes havran de subir muy alto y esta tierra (?) y pedrisca sea de amaser con aguas salada y estas escupe mucho la tierra y an de estar situadas al mediodia y lebecho que suele comer los muros de cal y tanto mayormente hara los de tapias. Tambien haviendose de estorbar en ellas las bovedas a lo menos de arriva por haver desertales que puedan sustentar artilleria no fiaria mucho de las d[ich]as Tapias y al fin se gastaria mas en ellas aunque pareçe menos por no ser obra perpetua dexal aparte quel legandose enemigos a ellas con mantas para cubrirse de los barbacanes con quatro (?) son derribadas que todavia les de mamposteria hazen mas resistençia y difficultan el cortar, assi que por estas razones entiendo remitiendome a quien sabe mas desto que no es conveniente hazellas de tapieria y quando todavia se hubiessen de hazer a lo menos quinze pies del suelo arriba querria se labrasse de canteria, o manposteria." (sic).

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An approach to earthen fortifications in villages of La Serranía (Valencia, Spain)

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ABSTRACT: The region known as "La Serranía" which lies in the extreme north west of the Valencian province (Spain) crosses over those historical paths of Castile and Aragon, in which you can appreciate certain influences of both Castilian and Aragonese architecture. These classified fortifications form both part of the urban area of their villages and of their surrounding environments. Such elements respond to fortress defensive models or watchtowers. In both cases, the building systems employed the technique of rammed earth. Although, at the moment, we have stopped analysing the morphology, cultural heritage and typology of these fortified remains, as a result of the initial work carried out new lines of investigation about earthen architecture in relation to its use in ceremonial, popular and pre-industrial construction have emerged.

1 INTRODUCTION

The interest of this study is to encompass the following. Firstly, to show how its urban footprint has generated a focal point for its historic districts. Secondly, to demonstrate its monumental value as a landmark in both the urban and rural landscape. Thirdly, to highlight its construction importance as an exemplary model for historic earthen architecture whose mark has left its own stamp on religious, domestic and vernacular architecture. In all of its typological variants there are to be found churches, chapels houses, palaces or manor houses; ovens, mills and wine presses (which are traditionally known as "*cubos de vino*").

In short, it deals with listing work related to fortified architecture which highlights its territorial, cultural and material links.

In the case we are concerned with, we have focused on an area of 140,528 ha which currently includes the extension of nineteen municipalities. Defensive remains have been identified in twelve of these municipalities within two of these, two more different locations have been found along with their respective pieces. So finally, there are a total fourteen cases in the study. This choice of scope within the study affords us a broader spectrum of work offering us new research challenges.

2 AIM

The classification of this fortified earthen architecture which had been erected in this region was to extract specific examples as a guide.

In this way, professionals, researchers and society are afforded the possibility to re-assess with greater clarity their culture and their environment, thus enabling them to affirm their own identity as well as achieve a stronger social cohesion.

3 WORK METHODOLOGY

3.1 *Phase 1*

Our first investigatory task begins by compiling all the necessary bibliographic material related to its historical, archaeological and architectural backgrounds. Devising a contrastive theoretical framework will aid us to put into context each case and at the same time transform this reference information into public interest.

The fortifications are legally protected as Assets of Cultural Interest under the category of Monuments (*Bienes de Interés Cultural*). This was proposed in the generic Declaration of a Decree on the 22nd of April 1949 by The Ministry of Education in which Spanish castles are safeguarded. Later this was further enacted in the following legislation concerned with cutural heritage (The Central Government Law of 16/1985 and The Local Government Law of 4/1998). Yet it has to be said that some examples should be marked out as they do not fit into those categories as stipulated by the above-mentioned laws. Another shortcoming is that their descriptions lack sufficient detail and precision. In Andilla, the area of the castle ruins found at the top of a hill is officially declared a cultural heritage. Despite this recognition that the castle walls and the watchtower have subsequently

been absorbed by the surrounding houses and their enclosure and surrounding area remain undefined. The above-mentioned watchtower (Portal de la Muralla) has been listed as an ethnological asset on The Valencian Inventory of Cultural Heritage. In Gestalgar, castle ruins which lie at the top of a hill are treated as national heritage e,yet its gate (Arco del Porche) found in the middle of the village has not been given any form of protection. However, it is included in the new General Plan which is under way. Through the Catalogue of Protected Sites and Areas not only will this fortress gate be potentially considered as a cultural heritage but also its Torre Señorial (Roger 2015: 618–621).

3.2 *Phase 2*

A map of the region was elaborated to place these fortified elements allowing us to identify their exaction position (Fig. 1). This also facilitates the undertaking of any field work allowing easy recognition of their remains (Fig. 2). An evaluation of their state of conservation and an analysis of the quality of the building technique applied.

During this stage of work an ample typological diversity was observed and these findings have been grouped into various classifications (Fig. 3):

In Alpuente, Andilla, Chelva (La Posada), Gestalgar and Tuéjar, the fortifications are castles all of which are situated on a hilltop with a walled enclosure, but whose castle walls have been swallowed up by the surrounding houses. In the cases of Alpuente, Andilla and Gestalgar this also includes their gateways and towers. But within all these types, they can further be classified into two main groups; those with a square base (as those found in Alpuente, Andilla, Chelva and Tuéjar) and the remaining of circular or semicircular base (as those found in Gestalgar).

In Alpuente (El Poyo), Chulilla, Domeño and Titaguas, only those castles which have been built high up are recognised. In the case of Chulilla, documentation has suggested that the missing castle



Figure 1. A map of the region of La Serranía with photographic identification of its fortified remains (Roger) and sketch of Torre de Castro in Calles (Unknown author, 1840).

walls lie within the town (Estela 1990: 112). As to date this documentation has not been validated. The first three above-mentioned castles have towers with a circular base, yet Titaguas's castle is quite different. An analysis of its construction technique reveals its different characteristics.

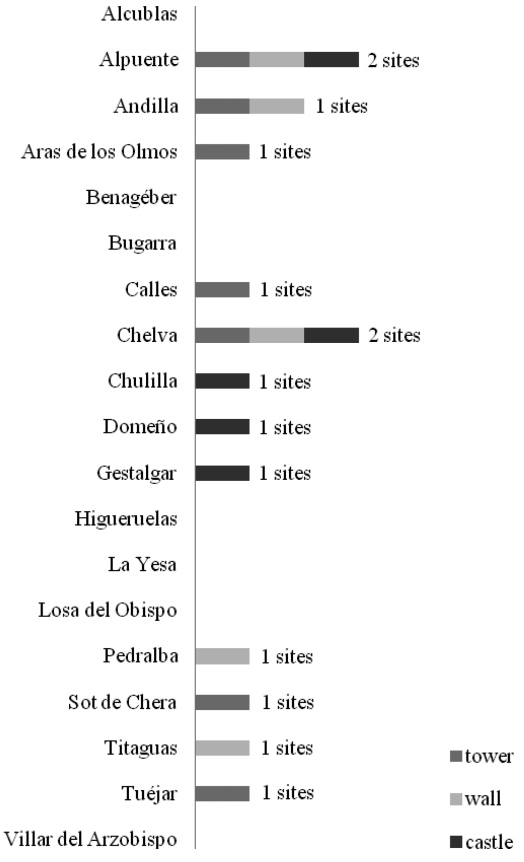


Figure 2. Table with identification of remains and sites (Roger).

In Aras de los Olmos, Calles (La Torre de Castro), Chelva (La Torrecilla) and Sot de Chera, only the square base of the towers or some of their remains are still to be found. In Aras de los Olmos some remains lay, giving testimony to where the enclosure was.

Chulilla (Valencia, Spain), A plan (Roger) and graphic done from a drawing by Sebastián (1991: 10) which was published in this book *Approach to the History of the Barony of Chulilla: Castle and Territory.*

Sot de Chera (Valencia, Spain), A plan (Roger) drawn up from the *Catalogue of Protected Sites and Areas* (2006).

3.3 *Phase 3*

The filling in of the documentation sheets supplied by the research project SOStierra, "Restoration and Refurbishment of Traditional Architecture within The Iberian Peninsula. Guidelines and Tools for Sustainable Interventions".

As key points of the cataloguing the following reference points were extracted:

1. General information about the fortifications, their location, use and ownership.
2. Building typology, conditions of its urban or natural environment and whether or not there have been substantial changes.
3. Identification of the construction technique used.
4. Detection of pathologies.
5. Interventions carried out and those techniques applied.
6. Bibliography an sources of documentation.

3.4 *Phase 4*

The results obtained from the catalogue cards brought together four concepts previously highlighted.

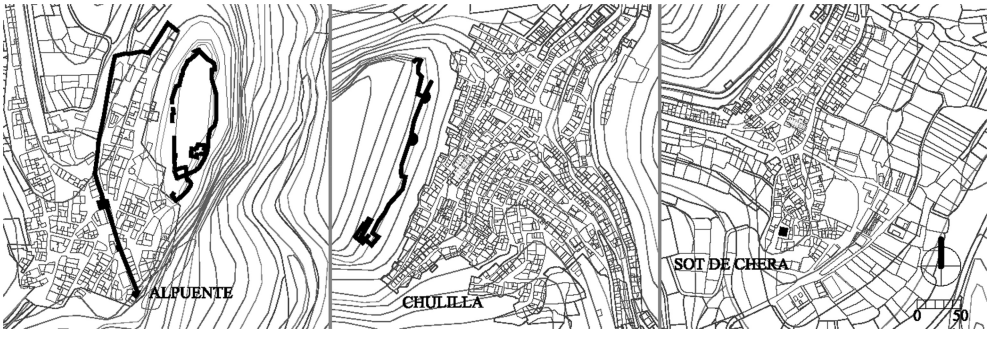


Figure 3. Alpuente (Valencia, Spain), A plan (Roger) was drawn up for a *project, to excavate, to consolidate and to recognise the value of both the entrance and palatine area of Alpuente Castle Area* (AAVV 2008: 10–40).

First.- In all cases, those discernible fortified remains such as castles and towers have been proven to be without any specific use and to be of public property. However, their walls and colonnade have gradually become a part of the surrounding public and private properties. Regarding the Alhama tower in Alpuente, after having been part of a fortress,it first went on to be a contractual marketplace, then the Muslim governor´s residence and long after it was turned into the townhall (Mateu 1944: 4). Currently, it is part of a museum tour of the muncipality. In Andilla, at present the Archaeological Museum is found at the highest point of the portal wall. In the case of Chelva (La Posada), the colonnade which links the Main Square and Palacio Street is where the townhall of today has also been built upon. Previously to this, the townhall was at 19 Arrabal Plaza this building was also erected on the colonnade but at the present time it is privately owned.

Second.- When castles or towers have been erected on a crag their natural topography separates them from the surrounding terrain below keeping them free from urban occupation. Infact,this terrain may be close by or indeed even shield them. However,this is not so with the remains of the castle in Chelva (La Posada) whose fragments are hidden by the buildings that are opposite the Main Square. Neither is it true for The tower "Torre del Cortijo" in Aras de los Olmos which is not discernible from a public thoroughfare. In order to be able to, it is necessary to go through the local Ecomuseo located at 2 Iglesia Street. Yet there are cases unlike the above mentioned. The remains of towers such as, La Torre de Castro in Calles and La Torrecilla in Chelva, along with the castle in Titaguas, are all located far away from the centre of their towns. The first two mentioned are typical examples of watchtowers which were built in strategic points to watch over the fortresses in Domeño and Chelva (Lloria et al. 2015: 178). Without a shadow of a doubt, whilst on the one hand such remains can either determine and condition the growth of their historic centres, their urban development can also destroy or hide their presence. Even so such monuments are useful to us as a visual reference within our surroundings, whether they be urban, rural, flat lands or mountainous.

Third.-As shown in Figure 4 in the cases of Alpuente (Alpuente castle and El Poyo castle), Andilla, Aras de los Olmos, as well as two examples in Chelva (La Posada and La Torrecilla), Chulilla, Domeño, Gestalgar, Pedralba, Sot de Chera and Tuéjar, the construction technique employed was that of rammed earth. Sadly with respect to the tower "Torre de Castro" only remnants have endured the passing of time. There is nothing left of the former tower. Yet it has to be said that in the case of Titaguas it is somewhat distinct. Even though having being considered as an Iberian construction after further analysis has shown that the building technique employed was not that of rammed earth.

Fourth.- Regarding those pathologies identified during the field work carried out, we were able to reach the following observations: First, The pathological process of these monuments began as a result of the destruction that they underwent during those wars in the 19th and 20th century along with subsequent plunders. Second, as a consequence of their abandonment after having lost their use they became derelict. Third, We can also blame a lack of funding for their preservation. Finally, added to all these circumstances that cause such deterioration are those physical elements (damp, rainfall, temperature changes and wind), chemical elements (salts and gases) and biological elements (microorganisms, plants, animals).

Fifth.- Through time it has been shown that whilst all those interventions carried out were done so in different locations under various authorities leading to different approaches and different types of treatment, all of them have been rigorously documented since the end of the 20th century. Under the new billing which advocated that all national heritage whether it be nationally or regionally should be provided for.

- In the castle in Alpuente, there was talk of restoration, excavation, foundation work and restoring it back to its cultural heritage (these projects were in 1978 and 2008) (Herrero 1978: 83, Ribera 1986: 249–279, Cotino 2015: 108–115, AVV 2015: 186–191, López 2002: 133–134 (I), 67, 85, 87, 91, 145, 212 (II)).
- In "La Posada" (Chelva), in a previous study, archaeological testing and archaeological reports had been done (these projects were in 1997, 2011) (Benavent 1998: 41–47). (López 2002).
- In "La Torrecilla" (Chelva), an archaeological campaign, reconstruction and a workshop for the unemployed had all been set up (these projects were from 1996 to 2014) (Lloria 2015: 178–185). (López 2002: 136 (I)).
- In the Chulilla castle, a survey, a historical study and restoration were carried out (these projects were from 1982 to 2001) (López 2002: 138 (I); 118–119, 197 (II)).
- In Sot de Chera, their tower had prospecting, documentation, restoration, foundation work and volume recovery done (this project was from 2000 to 2005) (López 2012: 375–380). (López 2002: 139 (I); 220–221 (II)).
- In Gestalgar, their castle was restored (2011) (Cháfer 2015: 170–177). (López 2002: 140 (I)).

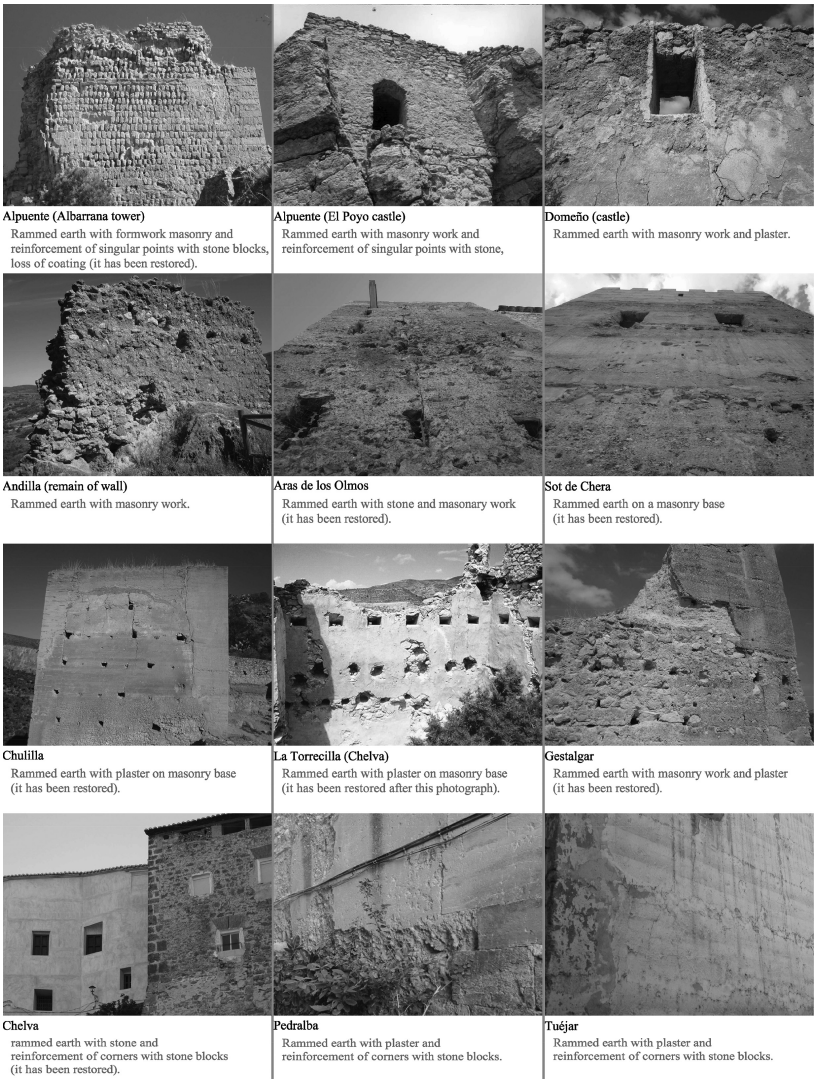


Figure 4. Sample of rammed earth fragments (Font & Hidalgo 2011: 21–34) (AAVV 2012: 232–241). This composition has been elaborated with own photographs, excepting the one of the castle of El Poyo in Alpuente and La Torrecilla in Chelva. Both of them have been recovered of the Fototeca del Patrimonio Cultural de la Generalitat Valenciana.

4 CONCLUSIONS

The geographical dispersion of these elements in this territory has led to a certain inequality when evaluating their protection, intervention and assessment (i.e. what treatment such monuments should be given according to their diverse cultural and material typology). This is due to their belonging to different administrative and governmental entities. Therefore, it is deemed necessary the creation of a Master Plan that on a regional level studies a strategy and a common plan of action. This document should integrate and include all cases yet at the same time respect their uniqueness and reinforcing their global connection to their cultural network.

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The first rammed earth wall in America. Earth in 16th-century Dominican architecture

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ABSTRACT: One of the most striking chapters of the analysis of the processes of cultural translation between Europe and America from the end of the fifteenth century is the identification of European aspects, subsequently integrated into the mechanisms of spatial definition and territorial occupation. The constructive program carried out on the island of Hispaniola (Dominican Republic) stands out from the others because it is the first instance of the introduction of cultural translation in a dissimilar context between the sending and the receiving territory. Focusing our analysis on architecture, and specifically on the use of earth as a material and rammed earth as a technique, is arguably one of the best examples of the process of cultural fusion to occur in America. This vast area is also an essential point of reference for the nuances that identify this building solution.

1 INTRODUCTION

One of the most striking chapters in the analysis of cultural translation processes between Europe and America from the late fifteenth century is that which identifies the European aspects incorporated into American mechanisms for spatial definition and territorial occupation.

The constructive program executed in Hispaniola (Dominican Republic) in the 16th century stands out as the first setting to introduce European techniques into a different context from that of the emitting territory. This marked the start of a process of assimilation and synthesis which became characteristic in those early years, both on the island and on continental territories.

This analysis focuses on architecture, specifically the use of earth as a material and rammed earth as a technique, as it is one of the examples of the cultural fusion which occurred in America, a specific geographical location which became an essential point of reference for understanding the nuances of this constructive solution.

The chronological context is important, given that a major part of the first American architecture to be influenced by medieval Iberian Peninsula construction was built in the 16th century in Santo Domingo. This started a journey of absorption which prompted the creation of a unique architecture developing characteristic solutions that initially spread to nearby Caribbean territories, including Puerto Rico. This is an example of the system which was taking shape and was used from that point on in other contexts relating to territorial and architectural occupation.

2 CONTEXT

The arrival of the Catholic Monarchs in Granada in 1492 marked the end of a clearly defined historical process, which had started with the early movements on the border between the medieval Christian kingdoms of the Iberian Peninsula and al-Andalus in the eleventh century, and ended with the War of Granada (1482–1492). This led to a gradual progressive process of territorial occupation which required an adaptation to the new locations under Christian control, after the Moorish population had moved south in search of urban nuclei beyond the Tajo River where they could take refuge.

The cycle of knowledge accumulated in the constructive, urban, and territorial structuring processes, was interrupted by the fall of Granada, which put an end to centuries of activity.

The discovery of America reactivated this cycle and gave it renewed continuity. These experiences could now be applied to newly discovered territories, and new elements added at different stages, as in the case of experiences in the Canaries or Caribbean islands, until it arrived in the American continent where contact was made with more developed pre-Hispanic cultures such as the Aztecs or Incas.

In this context it is assumed that the constructive program defined in Santo Domingo in the 16th century was the first to be applied in America, based on the "uncontaminated" experience of agents applying knowledge from their places of origin in new territories. The late fifteenth century was a time when traditions inherited in the Iberian Peninsula, from the Andalusi, Jewish, and

Christian cultures which had characterized their history in the Middle Ages, were reflected in the architectural designs and techniques of the time, one of the most enlightening examples of which was Mudejar.

This translation of experiences was the start of a process of integration in the Caribbean islands. This was particularly interesting as given the lack of major architecture it was possible to transfer the peninsular European models undiluted without having to adapt to the materials provided by the land. In the first quarter of the 16th century, the incorporation of pre-Hispanic techniques and the adaptation to new materials enriched architecture. On occasion, this brought about an improvement in solutions, and in turn the appearance of a strictly speaking American third way, which could be qualified as the result of a fusion and synthesis of European and pre-Hispanic elements.

In addition to the above, it should be noted that architects and builders traveled from the Iberian Peninsula to America in the 16th century when the construction of the main buildings in American cities required a level of expertise that could guarantee a speedy and efficient process, as shown below. These aspects had been vital to the concept of Mudejar from the eleventh century onwards and were also reflected on the other side of the Atlantic. In addition, some authors observe that Moorish architects and builders were among the first professionals to arrive (Buscaglia Salgado 2014).

Further analysis of the components found in the Caribbean context also serves as a reminder of other locations which between the late fifteenth and early 16th centuries saw the appearance of their first stable settlements. Both local and imported urbanizing processes were used in these. Initially constructive techniques allowed stable structures, tangible proof of the new order to be built following an aesthetic which transformed architecture into an eloquent ideological weapon.

2.1 *Background*

There is no doubt that since antiquity earthen construction has been present in the Iberian Peninsula. Iberians, Romans, Visigoths, and Moors used earth in constructive systems which became synonymous with the dominant culture of each period (Gurriarán Daza 2016).

Although use of this constructive technique was already recorded in antiquity, research on rammed earth building in the Middle Ages has led to historiographical debate on the role of archeology in studying its characteristics.

An examination of the medieval Iberian Peninsula shows how amongst the cultures which cohabited in it, the Moors made widespread use of rammed earth construction from the eleventh century on, when groups such as the Almoravids and Almohads arrived from North Africa, putting an end to the dominance of stone in construction which was a feature of the Caliphate.

The eloquence of architecture should also be kept in mind, as it is a visual representation of an ideology expressing the status of its owner and the ruling political order. This ideology explains governments' insistence on the construction of solid structures to reflect the established order, as their representatives found it necessary to give visible form to the new regime. In the case of architecture, since antiquity, materials have been used in different ways and simpler materials have been covered with other more ephemeral ones.

Following the entry into Granada of Castilian troops the metamorphosis of Andalusi techniques began, often leading to their disappearance as techniques due to the loss of skilled manual labor and of memory, accelerated by their lack of coding. Over time, rammed earth construction ceased to be seen as a solution and was relegated to the fringes as a traditional constructive technique.

3 THE FIRST BUILDINGS IN HISPANIOLA

The constructive program implemented in Hispaniola under the supervision of Nicolás de Ovando, aimed to provide the new city of Santo Domingo with the infrastructures needed to become a successful nerve center for the new territories. The dynamics of the Iberian Peninsula were copied in an attempt to execute political, economic, religious, and even medical care tasks in new buildings, including the governor's home, the foundry, the cathedral, and monasteries of religious orders in charge of the indoctrination and evangelization of indigenous population, as well as medical care.

It is in the earliest buildings that the survival of medieval techniques is found, clearly reflecting the immediate transfer of interpretations of construction, independent of resolutions found in other territories. That is why there is a predominance of late Gothic and Renaissance forms. In terms of constructive techniques, these make striking use of rammed earth in walls, combining it with masonry and ashlar solutions or brick piers and buttresses like those used in the Iberian Peninsula throughout the Middle Ages. Such techniques survived until the 16th century with slight modifications, particularly in the rammed earth walls, a striking feature of these buildings.

Gonzalo Fernández de Oviedo, author of *Sumario de la Natural Historia de Las Indias* (1526), shows that the cathedral, the monasteries of Santo Domingo, San Francisco, and Santa María de la Merced, as well as a hospital, were

already built at the time of publication (González de Oviedo 2002: 66). The resources of this first city planned in America attest to the importance of the church's role in these urban processes as well as to the implementation of an efficient constructive practice which meant they were in use within twenty-five years of the city's foundation.

Of the buildings mentioned, the three monasteries and hospital are of particular interest given that use of rammed earth formwork can be seen in the surviving structural remains. Thus, while the first recorded use of this technique in America is its appearance in a series of 16th-century buildings, it subsequently dwindled in a process similar to that which occurred in the Iberian Peninsula, where the term *tapia* was transformed and went from describing a technique to describing a measurement unit almost until the mid-twentieth century.

The phases observed in these buildings were defined from the very beginning: an initial construction using plants was normally replaced by an earthen one in an intermediate step prior to the definitive construction in stone. This, at least, is what is deduced from the data collected on the churches built in Hispaniola. In fact, even when Santo Domingo was transferred across the Ozama River from its original site in 1502 it was rebuilt using ephemeral materials as part of the building process (Palm 1955: 25). The appearance of these buildings has been reconstructed from surviving remains, but also thanks to known documentation from which the use of rammed earth in its structures can be deduced. Thus, the royal program of constructions probably devised by Ferdinand the Catholic in 1510, as it is recorded in the Royal Charter of 15 June 1510: '…that [the churches] should be good and very strong even if they are not high or very large […] only the foundations should be stone, the rest should be rammed earth …' (Palm 1955: 26).

At that point expeditions of artists, craftsmen, architects, and specialist workers were traveling to Hispaniola to work on the construction of these buildings. The construction of the church of Santiago and the original church of Santo Domingo can be dated to 1510 and 1511 respectively, and Palm states that the latter must have been one of the economical churches in rammed earth with a wooden roof ordered by the king (Palm 1955: 27). The king was subsequently satisfied with its completion in 1511 (Palm 1955: 27, note 42).

The construction of the second cathedral circa 1512–1513 is surprisingly described as built using: '…rammed earth (*lutus*), wooden boards, and a type of *tejamanil* or small wooden roof tiles (*rami arborum veluti topiaria arte intertexti)* and straw (*cespites*)' (Palm 1955: 29).

As for the convents, although these reflected the delays characteristic of 16th-century construction in America, San Francisco in particular offers an interesting evolution of the terminology. In 1544 *tapial* was not being used to refer to technique, but in this case to a unit of construction, a stone one. Palm notes how in the mid-16th century the church of San Francisco had an open foundation in a magnificent site overlooking the city, with these foundations consisting of: 'more than two *tapias* of stone masonry' (Palm 1955: 79). However, this does not mean that the combined use of stone and earth had disappeared. An example of this is the church of Santa Bárbara in the neighborhood of Canteros, still unbuilt in 1571, with the documentation highlighting the neighborhood's poverty, stating that: 'it is a very poor straw shack, because the parish and the city are so poor that they are not able to build it with stone or rammed earth' (Palm 1955: 85).

The last building in this initial analysis is the church of Regina Angelorum, whose chronology is unclear according to Palm (Palm, 1955: 89). The church belongs to the second foundation of a convent on the island, following that of San Francisco. The building follows the logical constructive process, using a provisional church to build a second. This second church is more relevant to this research as by 1569 it had: '…walls four *tapias* high in one part and five in another', as work at the time was halted due to lack of funds (Palm 1955: 90).

3.1 *Current remains*

While the available documentation provides information on the use of rammed earth in the construction of these early buildings, the surviving remains show that it was widely used.

Among these, two buildings stand out for the volume and size of the rammed earth construction, reflecting the extent to which this technique was used: the hospital of San Nicolás de Bari (Fig. 1) and the church and monastery of San Francisco.



Figure 1. Hospital of San Nicolás de Bari. Santo Domingo. Dominican Republic. 1503–1552.

In the case of the former, the passing of time has left an imposing structure with rammed earth walls reinforced by brick piers; in addition to the series of late Gothic pointed arches in the internal structure (Fig. 2).

Founded by Nicolás de Ovando in 1503, it was completed in 1552 with a series of extensions. This was the first example in America to repeat the Renaissance designs of this type of hospital building. It was built in three stages. The first, from 1503 to 1519, consisted in the construction of the main nucleus, while the other two stages, from 1519 to 1533 and from 1533 to 1552, focused on extensions (Angulo Íñiguez 1933: 47–56). The structure remained untouched until the eighteenth century, when the city grew with the new arrivals from the Canaries, the Bourbon reforms of Charles III, and increased trade with other territories such as Haiti (Guerrero Cano 78).

The other example is the convent of San Francisco (Fig. 3). Here, there are several different parts of the buildings that are worth noting, the two churches, the cloister, and the convent. On the one hand the late Gothic *ad lauda* structure of the church preserves an interesting combination of stone and earth in the structure, which combines ashlar buttresses with rammed earth and brick. Another element, this time characteristically Renaissance and designed by Rodrigo de Lindo in 1548, is that of a second church with ashlar buttresses between which there are sections of wall built with rammed earth formwork and an apse with brick and rammed earth walls between the buttresses (Fig. 4). A rammed earth structure also appears in the loadbearing walls of the cloister, again in combination with brick.

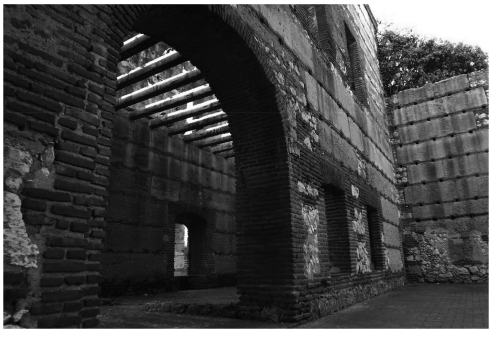


Figure 2. San Nicolás de Bari. Santo Domingo. Dominican Republic. 1508–1552. Constructive detail.



Figure 3. Convent of San Francisco. Santo Domingo. Dominican Republic. 1508–1556.



Figure 4. Convent of San Francisco. Apse of the Renaissance church. 1548.

4 THE CARIBBEAN CONTEXT. PUERTO RICO

The occupation of other nearby islands such as Puerto Rico provides an understanding of the modus operandi in the construction of homes for those who had just arrived, and how these replaced those of the indigenous population. While it is noted that there are still rehabilitated domestic structures belonging to some of the most important figures in the city in Santo Domingo, and some of these reflect how rammed earth was used in their construction, the information gleaned from Puerto Rico can be applied to Santo Domingo, from which the occupation models were copied.

As in the case of Hispaniola, it should be noted that the documentation consulted for Puerto Rico, including charters (Murga 1981), provides information on the constructive processes used on the island in the 16th century in different typologies and also mentions rammed earth. *Tapia* gradually became a measurement unit, a meaning which disappeared as the century went on.

Among the surviving 16th-century documents there is a description by Juan Ponce de León of his home, in a letter to the governor of the Indies, Nicolás de Ovando, which sheds much light on this: 'I ordered the construction of a medium-sized house, with a flat roof and parapet and battlements,

and a fence in front, it was limewashed inside and out, seven tapias high, including the parapet and battlements'. (Murga 1957: 223).

In 1532, ten years after the foundation of the island, Governor Lando told of how in total there were eighty-six structures in the settlement. Lando described the numbers of buildings according to their construction materials: '…six houses in rammed earth (five of which had two stories and one, that of the King, had one), thirty of wood and straw, twenty of straw, and between twenty-five and thirty wooden and tile houses …' (Ramírez de Arellano 1967: 224).

Juan López Melgarejo, interim governor of Puerto Rico in 1581–1582 wrote in his memoirs about what he observed in the city at that time: 'The forms of building of some of the houses in the city of Puerto Rico are in rammed earth and brick. The materials used are red clay, fine sand, and limestone; this mix is so strong that it is easier to break a masonry wall than a rammed earth one; the roofs are tile and a few of them have flat roofs; the rest of houses are made of shelving, very straight trees and palmwood boards, while the roofs are tiled' (Caro 1971: 224).

5 CONCLUSIONS

Cultural translation processes have been the cornerstone for explaining the dynamics of social change throughout history. In the case of America, two realities, European and pre-Hispanic, each with varied and solid personalities developed over centuries, came into contact with each other.

This meeting was unequal to a different degree in the various territories, but it highlighted how European proposals had to adapt to a new and completely unknown context.

In order to understand what happened, what is called for is an analysis of details rather than an overview of the process. In this respect, answers were provided by a more in-depth examination of the dynamics of incorporating rammed earth into the buildings being executed in America. The first reason for this was that this millenary technique only became widespread in the Iberian Peninsula with the Moorish presence from the ninth century on. The first recorded accounts were of constructions using rammed earth sections in communities far removed from the centralized control of the Caliphate in Cordoba. Secondly, it was predominant from the eleventh century on when Mudejar architecture became a point of reference in the synthesis of Moorish, Christian, and Jewish architectural practices which survived until the second half of the seventeenth century in the Iberian Peninsula and until the eighteenth in America.

Thirdly, its reliability prompted its widespread use in domestic, palatial, and military architecture, as a technique which spread to across the Atlantic from the early 16th century on.

Finally, its evolution reflects the dynamics of cultural exchanges given that it clearly shows how a process of progressive dissolution followed its adaptation to a new situation. It lost its original meaning of technique and went on to become merely a unit of measurement, while its essential meaning was forgotten, transformed, and moved on to be applied to any structure in any material which divides or surrounds a space.

NOTE

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The preservation of the Nubian earthen architecture

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ABSTRACT: In relation to the Qatar-Sudan Archaeological Project (QSAP), which promotes the valuation of the Sudanese archaeological sites, some mudbrick tombs superstructures of the Egyptian New Kingdom elite necropolis SA.C.5 on Sai Island (Sudan) were restored in 2015. In order to preserve the few remains from degradation agents (climatic and anthropic), a protective layer was added to the original structures. Our proposal also included other interventions, such as minimal replacement of missing parts or restoration of the landscape, in response to a request to restore value to these monuments. We used local materials and techniques in earthen building, which are probably similar as in ancient times, and we respected the current rules of the restoration international ethical code.

1 INTRODUCTION

Sai Island is located in the North province of Sudan and the Nubian Desert, near the modern town of Abri, at about 750 km to the north of the capital of the country, Khartoum. It is one of the largest islands across the Middle Nile extending about 12 km east-west and 5.5 km north-south. Almost totally arid, its banks are however cultivable due to the fertile sediments deposited by the river since 10,000 BC.

Sai Island is a remarkable witness of the history of the populating of the Sudanese Nubia since it has been inhabited from Prehistory to Modern times by several human groups. Sai Island, which has a strategic position on the Nile upstream to the 2nd Cataract, was indeed known by ancient Egyptians from the Middle Kingdom (beginning of the second thousand before our era), but it was only at the beginning of the New Kingdom (1500 BC) they began hostilities against the Upper Nubia. At that time, Sai Island was occupied by a Kerma community dependent on the powerful Kingdom of Kerma located upstream to the 3rd Cataract but, during some reigns, the Kingdom of Kerma collapsed and its culture disappeared. Sai became one of the pivots of the Egyptian expansion and the Pharaonic vestiges found on the island—a fortified town and its temple, as well as several necropolises –, all concentrated in the northeast, are linked to the history of the conquest and the colonization of the Nubia.

Archaeological investigations began on Sai Island in 1954 as a French concession supervised by the Egyptologist Jean Vercoutter to the University of Lille. During the season 1971–1972, the French team discovered an elite cemetery (called SA.C.5), located on a terrace, in which twenty-six tombs have been discovered until now. They have mudbrick superstructures, oriented east-west, including at least a chapel-enclosure in which a shaft opens. This may include a small pyramid to the west and a court to the east (except for the « Big Pyramid », the tomb 23). The shaft's entrance is sealed by a schist block and leads to a vault—none of which was discovered intact –, consisting of one to four rooms, dug into the soft part of the sandstone layer.

In relation to the Qatar-Sudan Archaeological Project (QSAP), which promotes the restoration of the value of the Sudanese archaeological sites, important conservation and restoration works were carried by our team in 2015 in order to preserve the few remains of three mudbrick superstructures tombs (T23, T8 and T9) from climatic and anthropic damage.

In the Figure 1, one can see the North part of the site with the superstructure remains of the tomb 23 in the foreground after our intervention, then the modern village of Adou, the East river of



Figure 1. Aerial view of T23 tomb after the intervention (Th. Nicq, QSAP—Saï, Halma—UMR 8164).

the Nile and in the background the mountain of Jebel Abri.

2 THE INTERVENTION

After doing a preliminary study to determine the areas in which it was necessary to intervene, by identifying the different deteriorations and their causes, we then set up the intervention program.

We were asked to intervene not only for conservation but also to restore value to the remains, so our proposal contained several objectives concerning 3 different fields:

2.1 *Conservation of the remains*

– Creation of a very simple drainage system to reduce the risk of dissolution of original bricks.

Rain is not common in this area, but the risk has increased with the construction of the dams due to the evaporation of the large surface of water created. To avoid the water accumulating too near the walls, earth was added to their bases making slopes that conduct the water far away from them.

Additionally, this gave good support to the occasional weakened bases of the walls. In the foreground of Figure 2, one can see the weakened bases of the North corridor of T23 before adding earth, and in the background, the earth had already been added.

– Protection of the remains with a new *layer of mud-bricks that will be eroded instead of the original ones*.

The new layer was applied adapting to the shape of the remains.

The new bricks were made in the same size as the original ones and with a very similar material, a mix of the black sediment left by the Nile, fine sand and straw mixed with excrement.



Figure 2. Weakened bases of the walls (G. Torra i Campos).

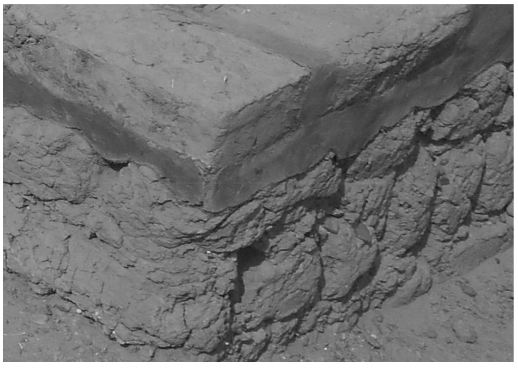


Figure 3. Alternating layers of bricks (G. Torra i Campos).

A plastic net, bought from the souk of Omdurman near Khartoum, was placed between the new material and the ancient to keep them separate. The net, visible from close up, allows the viewers to clearly distinguish the original parts, as the international restoration ethical code requires (Fig. 3). We didn't put mortar on the sides of the walls precisely for this reason. As covering the remains completely, would hide the difference between the new and the ancient.

2.2 *Restoration of the monument*

– Presentation of the original building technique placing the new adobes in the way that they were originally planned to be placed.

The original placement of bricks with the alternating layers can be observed in Figure 3.

– Part restoration of the missing parts to allow the construction to be more easily understood.

A layer of new bricks was placed in the areas where the whole width of the wall had disappeared. All these additions are recognizable due to the plastic net placed below.

The low walls that visitors will find now in these areas, instead of the open spaces that existed before, will not encourage them to enter any more.

In Figures 4 and 5, the T23 superstructure can be compared before and after the intervention. The completed parts of the ramp highlight the original shape of the monument.



Figure 4. Ramp remains before the intervention (G. Torra i Campos).



Figure 5. Ramp remains after the intervention (G. Torra i Campos).

The grounds that were at a lower level, mainly due to the archaeologists work, were filled to recover the original aspect of the site (Figs. 4 and 5).

2.3 *Restoration of the landscape*

All the artificial mounds of excavated material visible around the tombs were removed and used to refill the grounds.

3 CONCLUSION

The main purpose was achieved, namely that the conservation of the remains is ensured. The two most important causes of deterioration will now encounter obstacles. The original adobes are now protected against the climate: horizontal surfaces, which were most in danger, are now completely covered by the protection layer, and the exposure of vertical surfaces has been reduced thanks to the increased level of the grounds. Humans are the second most important cause of deterioration, and the increased height of the walls will encourage visitors to stay outside the monument. And even if they enter and they climb on the walls, there is no danger of them damaging the remains as previously because they will walk on the new adobes.

The second objective was also accomplished, that is restoring value to the site. The structure of the monuments became clearly visible, as can be appreciated by comparing the aspect of tombs T8 and T9, located in the South sector of the necropolis, before (Fig. 6) and after the intervention (Fig. 7).

All of that was done respecting the international ethical code of restoration that includes three fundamental principles: compatibility of the materials, reversibility, and easy distinction of the new and the old.



Figure 6. Superstructures of T8 and T9 tombs before the intervention (I. García).



Figure 7. Superstructures of T8 and T9 tombs after the intervention (I. García).

4 PERSONAL REFLECTIONS

People from this area have been building with mudbricks for thousands of years and all this precious knowledge could now be in danger by the building of a new dam, which would have serious consequences: the uprooting and the moving of the population and the destruction of the remains we restored. The Nubian mudbrick building technique could disappear, as well as other elements of the cultural heritage of the area.

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Constructive analysis of the rammed earth walls in the Petrés Castle (Valencia, Spain)

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ABSTRACT: The Castle of the Aguiló family is a fifteenth-century fortress located in the municipality of Petrés, Valencia. The castle, built with strong rammed earth walls, was well conserved until the mid-twentieth century, when it was abandoned and partly demolished by its owners. Although currently in very poor condition, the strong construction of its rammed earth walls and other valuable elements of constructive interest, including the earthen vaults in the galleries of the lower part of the building, are worthy of detailed case study. This article presents the constructive and architectural features of the castle, following the lines of earlier studies by a multidisciplinary group of researchers aiming to assess its condition and establish guidelines for possible restoration.

1 CASE STUDY

1.1 *Geographical and historical context*

Dating back to the late fourteenth and early fifteenth century, the Castle of the Aguiló family in Petrés was constructed with strong rammed earth walls and a layout characteristic of the late middle ages. The purely defensive function of Reconquest fortresses was lessened, and more residential elements were incorporated into the castle, evolving toward a typology similar to Gothic castle-palaces (López González 2015).

The castle, made up of two volumes with a rectangular floorplan, is located on a small promontory overlooking the town of Petrés (Fig. 1). This site approximately 30 km North of Valencia was probably originated as a Moorish rural settlement belonging to the city of Sagunto, and its designation as a municipality in the mid-fourteenth century is closely linked to the construction of Aguiló Castle (Corresa 2016).

Diverse graphic and documentary sources quoted in the literature (Iborra 2016, Corresa 2016) show that the castle was well conserved until the mid-twentieth century, when it was abandoned, partly demolished by its owners, and left in very poor condition. As a result, there is currently a broad range of degradation and structural damage issues urgently requiring consolidation work.

1.2 *Architectural approach*

The castle in Petrés is made up of two very different volumes, yet both were built mainly using earthen formwork elements (Fig. 1).



Figure 1. General view of the Castle of Aguiló in Petrés, Valencia (P. Rodríguez Navarro).

The upper part of the construction is a volume of almost square proportions (21 × 19 m) consisting of five rooms organized around an inner courtyard measuring 8 × 9 m (Fig. 2). Until the mid-twentieth century it had two floors, now missing, which were accessed by an ashlar staircase on rampant arches in this central space.

Below this there is a second more massive volume. Its roof forms a terrace which is accessed through an ashlar gate on the south façade of the upper volume, presumably the original main entrance to the castle. The accessible spaces in this volume are an *aljibe* (Moorish water cistern) and three vaulted galleries running parallel to the castle facades (Fig. 2). The area without perforations when superimposing the voids in the galleries on the built volume is almost certainly the result of the slope on which the upper volume was built.

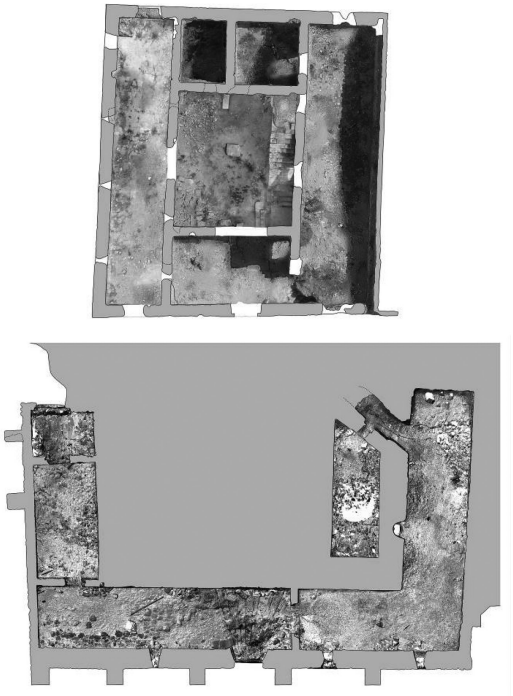


Figure 2. Graphic survey of the castle floorplans (P. Rodríguez Navarro & A. Pérez Vila).

2 METHODOLOGY

The results of the constructive analysis of Petrés Castle presented in this article were obtained through the preliminary studies carried out by a multidisciplinary group of researchers from the Universitat Politècnica de València. This team aims to establish the current conditions of the castle, as well as intervention criteria geared towards its eventual restoration.

Numerous analyses from many angles favored the development of a global view and better understanding of the castle's history and current condition:

- A complete 3D survey following a comprehensive methodology that included techniques ranging from the traditional direct survey to an indirect survey using active and passive systems (photogrammetry, topography and 3D laser scanner).
- Exhaustive data collection and historic and documentary study.
- Military study to identify possible design criteria associated with defensive functions.
- Complete study of constructive materials and techniques with cataloged fiches and plans.
- Study and diagnosis of material pathologies establishing the main lesions present and their possible causes using cataloged fiches and plans.
- Analysis of the structure and fissures of the building, identifying and recording cracks on the outer part of the building, studying their origin, and determining the main elements of the castle which appear unstable.
- Stratigraphic study, identifying the different units in the construction and the relationships between them to establish the construction periods for this study.

3 CONSTRUCTIVE ANALYSIS OF THE FORMWORK ELEMENTS OF THE CASTLE

3.1 *Study of materials and measurements*

Petrés Castle is a highly heterogeneous building given that different techniques were used in the execution of its different spaces, even when completing similar elements within a single body. However, the use of a poured mass of earth, lime, and stone as a basic material is a constant in the construction of most of the elements (Fig. 3).

The imprints left by the auxiliary devices on the castle walls during construction suggest something akin to rammed earth construction (See 3.2 *Constructive techniques*). However, the number of large pebbles on the walls must have hindered the manual tamping of the material poured in, and as can be seen from the marks on the walls, the layers applied were thicker than those usually seen in rammed earth construction: 18 cm instead of the 10 cm considered suitable for compacting (López Martínez 1999).



Figure 3. Detail of the north facade of the upper volume (Authors).

In this case, the cohesion needed to ensure a resistant mass is largely obtained through the lime setting in the mix, rather than through the compacting processes used in most rammed earth walls. Therefore, it is not unreasonable to surmise that the castle walls and vaults were executed using lime and earth concrete. Analyses carried out on similar walls from the late middle ages, for example Bofilla Islamic Tower in Bétera, Valencia, have shown a bonding agent content between 10% and 25% in the lime and earth mix (between 5% and 14% in cases where the lime was applied hot). Therefore, although the castle cannot be examined strictly as a rammed earth construction, it should be considered as a construction executed mainly using earth.

In the different constructive elements in the building, the lime and earth concrete in the walls is often complemented with other materials, using more complex mixed constructive techniques.

In the walls of the upper volume of the castle, both the outer corners and openings from the first construction period of the building were built using an ashlar construction of *pedra blava de Morvedre* which became part of the lime and earth concrete formwork at the pouring stage (Fig. 4).

The corners in ashlar are made up of two stone sheets 30 cm thick, and the outer sheet is of better quality than the inner one. A lime and large pebble mix similar to Roman concrete was poured between these two layers. The openings in the ashlar at times appear combined with brick arches, laid out as lost formwork for the rammed earth wall. This change in the material for the execution of the openings may have been due to the reuse of pieces from another construction (Iborra 2016) or to the need to cut building costs.



Figure 4. Meeting of two external perimeter walls of the castle, finished off with ashlar of *pedra blava de Morvedre* on the corner (Authors).

This volume is six rammed earth modules high. The first two, which correspond to the base under the rooms, slope lightly outwards. In the four upper sections the walls of the outer perimeter are 90 cm high on average, and the inner walls approximately 70 cm thick.

The lower volume of the castle is made up of three facades using three different constructive systems. The west elevation presents similar characteristics to the walls of the upper volume, although it was executed using different auxiliary devices. This could originally have been part of the wall around the castle vegetable garden, and archeological evidence has confirmed its presence, suggested by historians (Corresa 2016).

The east wall at this point is executed using formwork to build a coffered masonry wall, with a greater concentration of stone on the outer part of the wall.

In addition, in the south wall of the construction, the lime and earth concrete that can be observed from inside was poured against an outer sheet of masonry that served as lost formwork and is only one rammed earth module high. This is the springing point for the lime and earth concrete vaults over the interior galleries of this volume, adding to the impression that this mass has been dug out.

3.2 *Constructive techniques*

The walls for the upper body were built using a single constructive technique, using continuous rammed earth walls approximately one meter high and putlogs set 1.50 m apart. The constructive system used can still be observed from the imprints left on the walls by the stiffbacks and bonding strips of the formwork. The large distance between the putlog holes is striking, as is the extensive cross-section of wooden putlogs still remaining.

Although the openings left by the putlogs do not go right through the wall there are also stone slabs which acted as lintels after each section was completed, making it easier to retrieve putlogs. The large putlog holes, apparently too big for the size of the rammed earth wall sections, may in fact be as well the imprints for the supports of the scaffolding used during the construction of the wall, having been reused at different stages of the construction process.

The original openings are the result of two techniques combined: the use of ashlar elements

against which lime concrete was poured and the use of brick arches as lost formwork.

The constructive technique used to execute the west facade of the lower volume is similar to that used in the upper walls. However, in this case the size of the rammed earth modulation and the distance between the putlog holes is much smaller. Equally, the putlogs are smaller and the size of the holes does not suggest that these were used to put up scaffolding.

The system used for the construction of the barrel vaults over the lower volumes (Fig. 5) is especially interesting. A complex centering system using various pieces of semicircular falsework was used to define the cross-section of the vault. These elements were joined to create a resistant wooden framework of boards parallel to the generatrix of the vault, and reed was placed on top to avoid leakage of poured material. The imprint of the reeds used can still be seen on most of the surface of the vaults.

The survey carried out showed that the curvature radius for the circular tracing on the vault cross section is 2.10 m both in the galleries and the aljibe. Therefore, in the narrower space of the aljibe the barrel vaults may have been replaced with gentler curves, reusing the falsework for the outer rooms.

The U-shaped space defined by the three galleries of the lower volume is divided at several points by partition elements in formwork or stonework. Among these elements, poorly manufactured and of little interest, it is worth noting the north wall of the west gallery (Fig. 1) built in close relation to the constructive sequence of the vaulted spaces.

The entire height of this wall was executed with coffered masonry. This could not have been done in a confined space as the formwork couldn't have reached the upper part of the wall, leaving a free space to pour the material from above. Lately, that space would have been filled with common masonry. However, this element is not important enough to have affected the subsequent outline of the vaults. In addition, the partition wall rests vertically on the gallery wall all the way up until it separates to define the curve of the vault. This fact, along with the presence of imprints from reeds passing through the wall for the vault formwork makes it probable that this partition was built against the centering used to execute the vault, and was itself used as a support for the boards and reeds that were to shape the formwork in the vault.

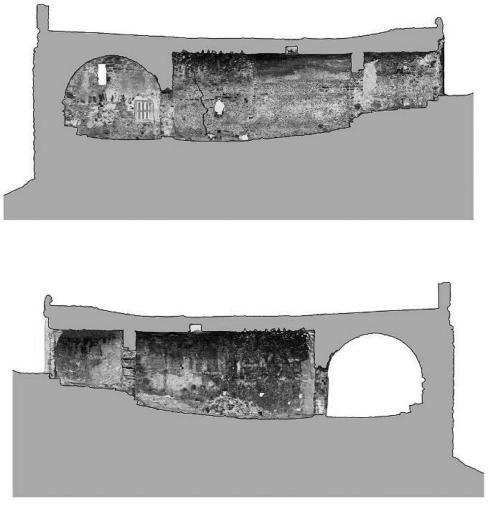


Figure 5. West gallery of the lower volume of the castle (P. Rodríguez Navarro & A. Pérez Vila).

3.3 *Stratigraphic analysis and hypothesis of constructive stages*

According to the results of the study of materials and the stratigraphic analysis of the constructive elements of the Petrés Castle a probable date was proposed for the different periods of construction (Fig. 6).

The original construction, coinciding with the first floor of the upper volume of the castle could correspond to the establishment of the Domain of Petrés in 1389 (Corresa 2016, Iborra 2016) with two different construction phases within the same architectural project.

The perimeter structure would have been executed in the first stage, while the interior walls could have been erected in a second phase. These inner partitions rest against the exterior planes without interlocking as are thick enough in themselves to be stable. Based on the way some walls rest against others it can be deduced that they were built in the following order:

1. Perimeter walls
2. Interior walls in North-South direction
3. Interior walls in East-West direction

In addition to the way the walls of the upper volume rest against each other, the manner in which the flat tile vaults covering these spaces rest on the different walls supporting them suggest that they belong to two phases within the same construction period. As can be observed in the points where even the tiles from the springings of the vaults have been lost, these rested on the inner walls of the castle thanks to the support grooves created with listels inside the formwork before building the wall.

In contrast, on the outer walls they rest on grooves made in the previously existing walls, suggesting that the decision to use tile vaults in the castle rooms was made by the builders at some point between the execution of the outer walls and that of the inner partition walls.

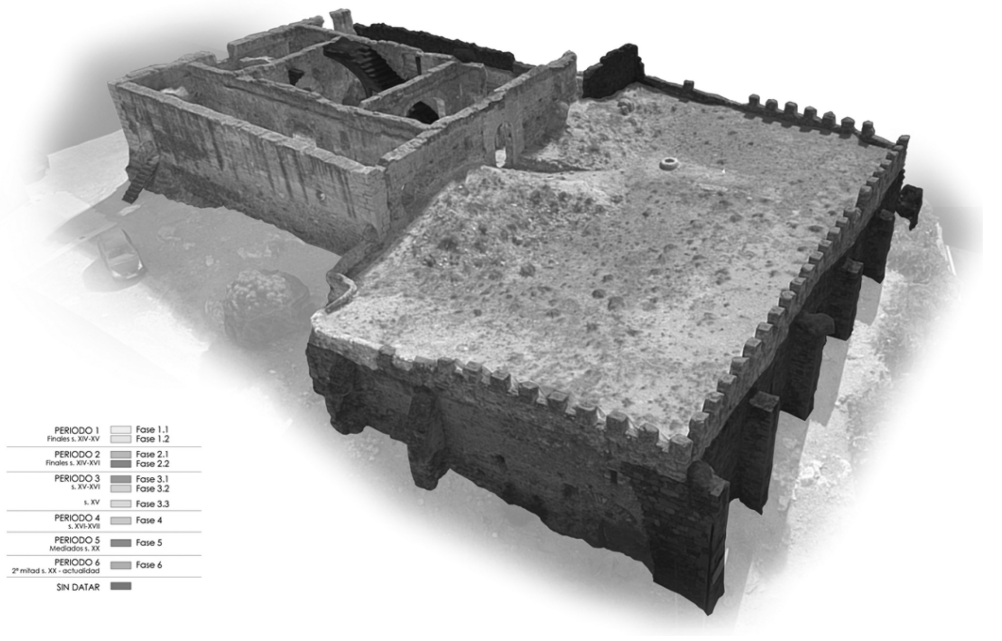


Figure 6. Hypothesis for construction phases of Petrés castle (C. Mileto, F. J. Gómez Patrocinio & A. Hueto Escobar).

According to I. Corresa, it was during this stage, or very shortly afterwards, that a perimeter wall in rammed earth was built around the castle vegetable garden and various traces of this have been found around the castle. From their materials and position in relation to the castle and the surrounding remains it is likely that the western facade of the lower volume was originally part of this enclosure.

The remaining part of the lower volume could have been executed in a second stage, also thought to have been carried out in two construction phases. The south facade of the volume, the south end of the west facade and the tower on the south-east corner, of which only the springing remains, could all have been executed in the first phase. The interior vaults and the east facade could have been executed in the second phase.

The upper volume would have been expanded after the construction of the galleries in the lower volume. Two levels of rammed earth and lime mortar sections faced with brick were added to this volume. These were demolished in the mid-twentieth century and at present all that remains of these are two courses of brick. The battlements crowning the lower volume, adding to its appearance of fortification, also date from a later stage in the construction. The chamfered southeast corner of the parapet shows that this was executed after the collapse of the tower which finished off the construction at this point.

4 CONCLUSIONS

A rigorous prior study is essential when tackling the intervention of a historic building, given that it is the only way to guarantee a comprehensive understanding required for well-documented decision-making at the design phase.

Before carrying out this study, it is essential to carry out a high-precision graphic survey to support the exhaustive processes of data collection and analysis for the job. Even though these examinations have been carried out by different professionals from different fields, the various tasks which constitute a prior study are a succession of approaches to the same set of elements and causes, and are all closely linked.

The results from each individual task help to shed light on, confirm, or refute the conclusions obtained in the other studies so that it is essential for the different specialists to collaborate closely.

The results of the constructive analysis of the rammed earth walls and vaults of Petrés Castle showed how during its construction the rammed earth technique was employed to assemble elements using similar materials with different treatments and varying resistance.

The imprints left by the auxiliary devices during the construction of the castle allowed extensive information to be extracted on the constructive

techniques used. Thus, based on data such as the marks left by the stiffbacks and bonding strips, separation and size of putlog holes, etc., the use of continuous rammed earth walls and half-putlogs or the possible reuse of putlog holes for installing scaffolding were all deduced.

Finally, based on a detailed interpretation of the building and a study of the graphic survey of the outline of the spaces, the reuse of auxiliary devices was observed in the construction of different elements, allowing them to be linked to the same historical period.

ACKNOWLEDGMENTS

The results presented in this article are part of the preliminary studies developed by a multidisciplinary research group from the UPV whose work has influenced the conclusions reached. The graphic survey of the castle was carried out by Pablo Rodríguez Navarro and Teresa Gil Piqueras.

NOTE

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Seismic Retrofitting Project: On-site retrofitting techniques workshops

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ABSTRACT: The Getty Conservation Institute (GCI) initiated the Seismic Retrofitting Project (SRP) in 2009 with the objective of adapting high tech retrofitting techniques to better match the equipment, materials, and technical skills available in many countries with earthen buildings. The first three phases of the project included identification and assessment of four prototype buildings in Peru, laboratory testing, in-situ testing, and numerical analyses of the four sites. The project is now entering its final phase where construction documents have been completed for two of the four prototype sites, the Cathedral of Ica and the Church of Kuño Tambo; and, the SRP techniques are being implemented at the latter. As part of this phase, the GCI is carrying out a series of technical workshops to demonstrate SRP techniques during their implementation at the Church of Kuño Tambo. The current paper describes how the on-site workshops were planned during construction, and the preparation involved in the dissemination of didactic materials targeted to mid-career conservation architects and engineers, site managers, and contractors in Peru.

1 INTRODUCTION

1.1 *The Seismic Retrofitting Project (SRP)*

During the 1990s, the GCI carried out a major research and laboratory testing program—the Getty Seismic Adobe Project (GSAP)—to develop effective retrofit methods for historic adobe structures. However, a GSAP colloquium held in 2006 concluded that although its developed methodology and techniques were reliable and effective, its reliance on high-tech materials and professional expertise was a deterrent in its widespread implementation in developing countries. In response, the GCI initiated the SRP in 2009 with the objective of adapting the GSAP guidelines to better match the equipment, materials, and technical skills available in Peru.

Using four Peruvian historic earthen buildings representing typologies across Latin America, the GCI—in collaboration with its partners the Ministerio de Cultura del Perú and the Escuela de Ciencias e Ingeniería of the Pontificia Universidad Católica del Perú (PUCP), and consultant the University of Minho (Portugal)—designed, tested, and is currently implementing seismic retrofitting techniques and maintenance programs with locally available materials that will improve the structural performance and safety of earthen buildings while minimizing loss of historic fabric.

The SRP methodology involves four phases: 1) identification and study of prototype buildings that represent key earthen historic buildings found in South America; 2) in-situ and laboratory testing of key building elements and numerical modeling of each prototype building; 3) dissemination of SRP techniques; and, 4) implementation of retrofitting techniques for selected prototypes while disseminating project results.

After all four sites were identified, surveyed and assessed, PUCP then planned and carried out the material and structural characterization of these prototype structures executing over 300 static tests at their facilities in Lima. The project also recently completed all numerical modeling work conducted by the University of Minho to analyze each prototype building in its current state as well as in their proposed retrofitted state using SRP designed techniques.

The SRP has disseminated results of the first two phases on the GCI website (Cancino & Lardinois, 2012); as well as in a series of articles (Ferreira et al., 2013; Quinn, N. et al., 2012; Torrealva & Vicente, 2016; among others). Results of the laboratory testing and numerical modeling work are expected to be published as part of the SRP publication series in late 2017.

The SRP now is now entering its last phase—where construction documents have been completed for two of the four prototype sites, the

Cathedral of Ica and the Church of Kuño Tambo (Figs. 1 & 2) and implementation has begun at the latter. Construction is being undertaken by the Dirección Desconcentrada de Cultura del Cusco (DDC-C), a regional office of the Ministerio de Cultura del Perú, with whom the GCI is partnering with to organize technical workshops to demonstrate SRP techniques during their implementation.

1.2 *The construction assessment*

In 2010, the four prototype sites were documented and assessed in collaboration with SRP—at the time—future partners (University of Bath and PUCP) in two field campaigns. This first phase of the project included an overall building survey and detailed assessment of each structure in order to obtain critical information regarding its configuration and construction techniques used (Fig. 1).

As part of this investigation, two non-destructive assessment methods, infrared photography and thermal imaging, were evaluated and considered for use; and of these, thermal imaging was identified for on-site trials. The latter was particularly useful in locating specific building materials such as *quincha* posts at the facade of Hotel Comercio and timber structural elements of vaults and domes at Ica Cathedral.

Annotated detailed drawings illustrating structural elements, systems, and connections were prepared for the four prototype buildings to complement the detailed structural assessment.

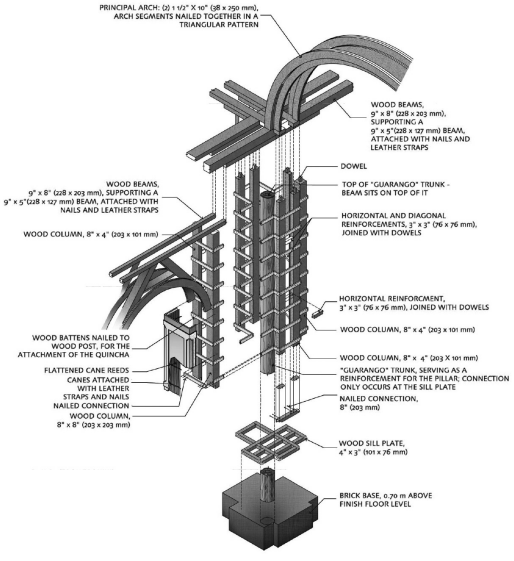


Figure 1. Exploded view showing a quincha pillar at the Cathedral of Ica. Drawing: GCI.



Figure 2. Sonic testing at Hotel el Comercio. Photo: GCI.

1.3 *The testing and modeling phase*

Between 2012 and 2014, a laboratory testing program was carried out by PUCP to obtain material and mechanical properties of each site. Over 300 material, mechanical and static tests were conducted of all four building prototype buildings. Some of these tests were performed for the first time on earthen materials and/or related structural components, providing valuable information to the field.

In 2015, in-situ testing was undertaken by the University of Minho of all four prototype buildings including dynamic identification and sonic tests (Fig. 2). These non-destructive tests were used to obtain mechanical properties of select structural materials and characterize their overall structural behavior under ambient vibration. Data collected from these tests were used to validate the numerical models of the four prototypes.

2 IMPLEMENTATION OF PROTOTYPE SITES

2.1 *Prototype sites to be implemented*

The final construction documents and technical specifications for two prototype sites, the Cathedral of Ica and the Church of Kuño Tambo were completed and delivered to Peruvian authorities in 2015.

There is great interest by the local regional government of Ica and Ministerio de Cultura del Perú to implement the project at the Cathedral of Ica, however the project is still moving through an administrative procedure involving the property title and has yet to commence.

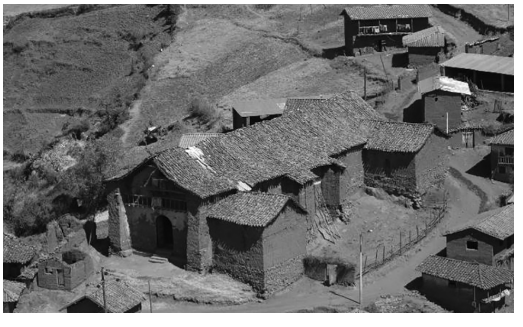
Fortunately, the close collaboration between the GCI and DDC-C has led to the successful start and implementation of the Church of Kuño Tambo project where construction began in September 2016. With the project in construction, this provided the perfect time to hold workshops to showcase SRP techniques being implemented.

2.2 *The Church of Kuño Tambo*

The Church of Santiago Apóstol of Kuño Tambo (henceforth referred to as the Church of Kuño Tambo) is the most prominent building in Comunidad Campesina Kuño Tambo, a remote agrarian village of 500 inhabitants located approximately 35 km southeast of the city of Cusco in the province of Acomayo. Owned by the Roman Catholic Archdiocese of Cusco, the church has been in continuous use as a place of worship since its original construction in the seventeenth century.

Constructed of thick adobe walls and buttresses over a rubble stone masonry base course and a wood-framed gable roof, the 500 m^2 church exhibits many of the design features and materials typical of rural churches in the region (Fig. 3). The entire church appears to have largely retained its original floor plan and mass, as well as its original wall paintings (Fig. 4).





Figures 3 and 4. Upper, general view of the Church of Kuño Tambo. Lower, view of wall paintings. Photos: GCI.

Current state numerical analysis was performed for this site and indicated the lack of lateral confinement, out-of-plane failures, lack of stiffness at gable walls and corners, and general lack of maintenance. Numerical analysis results corroborated damage patterns found on site. To address these conditions, the proposed design included the installation of: 1) three new buttresses on the south elevation and rehabilitating the two existing buttresses on the north elevation; 2) timber corner keys at two different levels, located below the collar beam; 3) timber collar beam and tie beam assembly with anchor keys above adobe walls; and 4) underpinning at existing stone base course of adobe walls (Karanikoloudis & Lourenço, 2016).

2.3 *The Cathedral of Ica*

The Cathedral of Ica was originally built in 1759 by the Society of Jesus, but its ownership was transferred to the Mercedarian Order in 1780 after the expulsion of the Jesuits from the Viceroyalty of Peru in 1767. Presently owned by the Roman Catholic Diocese of Ica, the cathedral was used as a place of worship until it was damaged in the 2007 earthquake. It is structurally similar to the Cathedral of Lima after its reconstruction in the latter half of the seventeenth century (Fig. 5).

The cathedral plan consists of a choir loft, one central nave with four structural bays, a transept, and an altar that are all covered with barrel vaults. Either side of the nave is flanked by an aisle that is covered with a series of small domes, and the crossing of the nave and transept is covered by a large dome with a lantern. The thick lateral walls are constructed with mud brick masonry over a fired brick base course and stone foundations. The side aisles are separated from the central nave by a series hollow *quincha* pillars and arches covered with painted mud and gypsum plaster. The barrel vault and domes are also constructed with wood arches or ribs and *quincha*.



Figure 5. Façade of the Cathedral of Ica. Photo: GCI.

The Cathedral of Ica was severely damaged during the 1813 and 1942 earthquakes, which led to the rebuilding of its façade and two bell towers, in fired brick masonry. The collapse of sections of the barrel vault near the façade, the central dome, the roof over one bay of the south side aisle, and loss of plaster at the pillar and pilaster bases, were the result of the 2007 and 2010 earthquakes.

2.4 *Implementation team*

The development of the conservation and seismic retrofitting projects for the Cathedral of Ica and the Church of Kuño Tambo began in 2013.

For the development of the structural component of both sites, the GCI worked with consultant PUCP engineers Daniel Torrealva and Erica Vicente (Fig. 6). For the Cathedral of Ica, the GCI also worked with consultant conservation architects José García Bryce and Mirna Soto, as well as a timber specialist, Mikel Landa to evaluate the existing timber structure. For the Church of Kuño Tambo, the architectural and conservation proposal was developed by the DDC-C under the direction of architect Etel Hania Cruz Moscoso; in collaboration with the GCI.

During the design phase for the Church of Kuño Tambo, the GCI had the opportunity to participate in meetings with both the DDC-C's design team and construction team. It became clear that neither teams communicated often regarding shared projects. These meetings provided the occasion for the GCI to facilitate discussions between both teams in order to clarify differences between the proposed structural details and actual details that are typically implemented in the field during construction.

One challenge in the SRP is the continual change in administration at the DDC-C, which follows the election cycle of Peru every four years. At times, the administration remains the same, however often times not. For the Church of Kuño Tambo, during construction the administration changed and along came the arrival of a new resident architect and supervisors overseeing all aspects of construction.

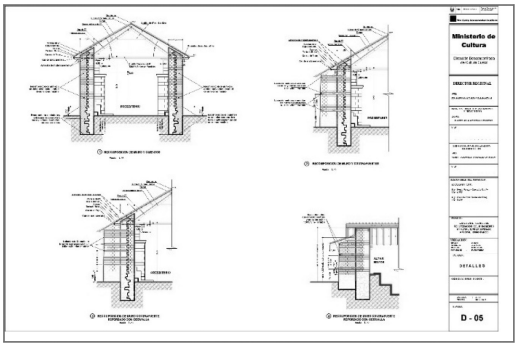


Figure 6. Structural details in the Church of Kuño Tambo construction documents. Drawing: GCI.

3 WORKSHOPS

3.1 *SRP dissemination phase*

The third phase of the SRP focuses on the dissemination of the project through various methods including technical guidelines, manuals for implementation, and technical workshops.

Discussions with the Ministerio de Cultura del Perú and the DDC-C regional office confirmed the need to share SRP techniques with the professional conservation community in Peru, specifically those working on similar project sites. Taking the opportunity of one prototype building, the Church of Kuño Tambo in construction, the GCI and DDC-C are currently working collaboratively on organizing technical workshops to be held in the summer and fall of 2017 with the objective of demonstrating the retrofitting techniques developed as part of the SRP for this specific site (Fig. 7).

3.2 *Workshop organization*

With any collaboration, clarity of roles and communication is key to success. Establishing regularly scheduled meetings with the DDC-C was essential to discuss all aspects of the workshops—objectives, audience, number of attendees, duration, dates, locations, content, types of media, specific on-site mock-ups, and desired didactic materials.

After the first few meetings with the DDC-C it was determined that two separate 3-day workshops held during the workweek would best serve the needs of the conservation community in the Cusco region. The workshops will be held in Spanish and divided into two components – 1) presentations of conservation theory and practice



Figure 7. The DDC-C and GCI staff in front of the Church of Kuño Tambo. Photo: GCI.

followed by an overview of the SRP including review of each phase of the project; and 2) on-site field observation of retrofitting techniques being implemented at the Church of Kuño Tambo. The first component would include a series of presentations and discussions, while the second component would require on-site visits and discussions with the DDC-C construction team and SRP team on the implementation of select techniques and the importance of specific details.

3.3 *Target audience*

Technical workshops are limited to the Cusco region due to the location of the prototype building, the Church of Kuño Tambo, under construction. Based on discussions with the DDC-C office and the objective of reaching a wide range of staff within this region, it was determined that the workshops would target two specific audiences within the DDC-C construction division—including 1) site managers and resident architects overseeing work on similar project sites; and 2) master masons overseeing a masonry crew carrying out work on similar building rehabilitation projects.

It is clear that these are two very different audiences, with different responsibilities on projects, and thus also require different delivery methods and information specific to each audience. The first day is targeted to both audiences in presentation format where everyone will learn about the importance of the project methodology and how this led to the development of retrofitting techniques being implemented. The second day is targeted to site managers and resident architects discussing not only the retrofitting techniques but will also address specific challenges they face during construction. And the third day is targeted to master masons and the challenges they face on site including how to ensure construction of specific details match proposed drawings. Specific activities for the second and third days will be tailored to the specific audience.

3.4 *Content*

Peru was selected for the project's location because of its wealth of current and historical knowledge of and interest in retrofitting earthen buildings, as well as its potential research partners and organizations that could implement new techniques through model conservation projects.

In the years of collaboration between the GCI and DDC-C, it has become increasing clear that no curriculum or training existed for professionals such as architects and engineers on conservation practice. Currently no regular curriculum exists at universities in Peru on conservation theory or practice. These technical workshops provided the perfect platform to share with local professionals current conservation theory and practice and its application in Peru.

The first day of workshops will consist of presentations starting with conservation theory and practice, followed by presentations of the SRP including its methodology and phases of the project—assessment, laboratory testing, and numerical analyses, and proposed structural design (Fig. 8). These presentations were made by SRP team members, which included partners and consultants that carried out these phases of the project. This day highlighted how the project's methodology and use of new tools for investigation and design contributed to the project's success.

The second and third days will consist of field visits to observe specific SRP techniques being implemented. Due to the limits of construction, the SRP techniques are divided into two sets of workshops. The first set of workshops focused on buttresses and underpinning; and the second set will focus on corner keys and collar/tie beam assembly.

Again, it was important for the GCI and DDC-C construction team to work collaboratively to provide the intended experience for each target audience. For each of the field visits—an area of the building will be left partially unfinished to show the implementation of a specific SRP technique. Workshop attendees will walk around the site to observe locations of specific components either already installed or to be installed in-situ. Since some techniques will already have been installed at elevations not readily discernable from the ground, mock-ups of the component will provide at ground level to allow attendees to review details carefully. Since specific elements such as timber buttress keys, timber corner keys, and timber bond beam are prefabricated off-site shop drawings will be produced to ensure partial mock-ups were available during the workshops.

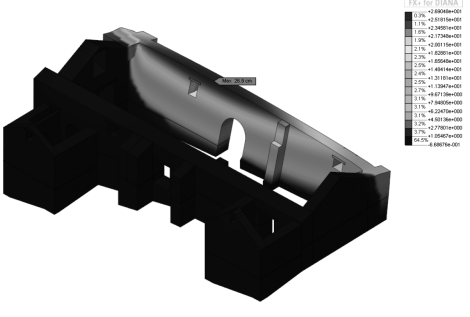


Figure 8. Pushover nonlinear analysis in the +y-y direction during the numerical analysis of the Church of Kuño Tambo. Drawing: Giorgos Karanikoloudis, for the GCI.

For the field visits on the third day, the workshop will focus on hands-on participation by masons. For example, instead of only observing the various mortar mixes used for underpinning at stone base and adobe unit replacement, masons would have the opportunity to mix the various components of the different mortar formulations in order to feel the differences of each. Moreover, an adobe test wall with stone base will be constructed for the workshops to allow masons to test these mortar mixes in-situ.

Below are the agendas for the two technical workshops.

Workshop 1 (Summer 2017)

Day 1: Presentations (All)
Conservation Theory & Practice Introduction & Methodology of the SRP Assessments of Prototype Buildings Laboratory Testing Program Numerical Modeling Analyses Proposed Retrofitting Design
Day 2: Field Visit (Site managers & architects) Proposed Retrofitting Design – *Buttresses & Underpinning*
Day 3: Field Visit (Masons) Proposed Retrofitting Design – *Buttresses & Underpinning*

Workshop 2 (Fall 2017)

Day 1: Presentations (All) *Same as Workshop 1*
Day 2: Field Visit (Site managers & architects) Proposed Retrofitting Design – *Corner Keys & Collar/Tie Beams*
Day 3: Field Visit (Masons) Proposed Retrofitting Design – *Corner Keys & Collar/Tie Beams*

4 NEXT STEPS

4.1 *Workshop organization conclusions*

Since these workshops are currently being organized and scheduled for summer and fall of 2017, it is not yet possible to share the results of their implementation.

The DDC-C has expressed the desire to produce didactic materials to showcase these retrofitting techniques. Their desire to disseminate the work of the SRP to their staff and community is a testament to the successful collaboration between the GCI and the Ministerio de Cultura del Perú.

The DDC-C envisions these materials to be in the form of pamphlets or booklet that explains the various SRP techniques with minimal text supplemented by graphics demonstrating the implementation of each component. The production of these didactic materials is to be further developed after the implementation of these technical workshops.

4.2 *Future workshops*

The Church of Kuño Tambo was selected as one of the four prototypes due to the presence of its wall paintings. A major challenge in implementing retrofitting techniques in historic buildings with decorated surfaces is avoiding the removal of finishes—a common practice in Latin America today, especially in locations where walls behind paintings are scheduled to be repaired. Since the start of the project the GCI has been fortunate to work with the DDC-C professional and technical staff, who have been willing to develop a new methodology to study the building, and propose and implement retrofitting techniques using local materials and expertise while preserving in-situ its wall paintings. As part of this effort, several past campaigns have been dedicated to the development of an earthen grout used to consolidate existing wall paintings to protect them during construction. Results of the wall paintings conservation work is expected to be published as part of the SRP publication series in 2018. The DDC-C would like to hold future workshops focused on the wall paintings conservation work.

NOTE

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Conservation of vernacular architecture, the case of the old town of Nablus/Palestine

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ABSTRACT: This paper focuses on conservation of vernacular architecture of the old town of Nablus, Palestine. It investigates examples of successful interventions in the historic site which has a large intact urban fabric that suffers from several problems. Lately more concern was directed towards revitalization of the historic core and upgrading of its urban environment. Some conservation projects were adopted to realize the vision of creating a lively historic environment. This paper investigates examples that contributed to enhance the urban environment of the historic city, support its residents and sustain its traditional inherent social, economic and urban qualities. It gives an overview of the conservation work and an assessment of the proposed activities. Lessons are to be learned from experiences that succeeded to preserve old buildings, enrich the vernacular urban environment and ensure preservation of traditional urban image and character.

1 THE OLD TOWN OF NABLUS

The old town of Nablus has a dense and compact urban fabric; its structure and form manifests all the characteristic features of an Arab-Islamic city. As an intact fabric with streets, alleys, buildings and public spaces, the old city is of value and significance to Palestinian cultural heritage. Evolved originally as a Roman city and developed later by Moslem-Arabs, the town has a continuous history for two millennia, with buildings from Roman to Ottoman times (Burgoyne 1987). Still, the present historic center overlays part of the Roman city "Flavia Neapolis" founded by Vespasian in AD 72 (Vogrin, 2001). By the end of the nineteenth and the beginning of the twentieth century, new urban expansions were developed beyond the traditional boundaries of the old city, and a new commercial center was established on the periphery of its northern edge.

The traditional urban structure of the old city is based on the division of its urban fabric into several entities, each of which is a neighborhood or a quarter. The greater part of the city is formed of quarters, composed of private houses and their access routes (Morris 1994). The old city has six quarters, each is connected to a primary street. However, within one quarter a network of secondary streets is connected to several cul-de-sacs, which in turn give access to individual houses (Hakim 1986). A track from the bazaar, the primary street with main commercial activities, with its animated and bustling nature leading to the quieter, residential quarters, reveals the hierarchical relationship between the public and the semi-private spaces within the city (Hugh & Robert 1979).

The old city has an intact urban fabric which has a well defined traditional urban pattern. The residential quarters of the historic city have maintained their importance as residential areas despite bad living conditions and degraded urban environment, while commercial streets that contain the main traditional covered bazaar, continued to demonstrate concentrated commercial activities in a well preserved traditional form.

By the end of 1990s and the beginning of 2000, Nablus Municipality started to develop proposals for preservation and future development of the historic center. The intention was "to create a lively historic center", which means preservation of the cultural heritage of the city and improvement of living and economic conditions of the historic site. The idea is to achieve the aims of preservation by supporting the activities of the historic core. Support housing as a basic requirement for preservation, and support the commerce and trade activities of old town. Furthermore, improve the infrastructure of the existing and future commercial functions and preserve cultural heritage as a base for tourism development (Hohmann 2003).

During the years 2007 to 2011 a comprehensive plan for revitalization of the old city of Nablus was developed by the technical office of Jerusalem old city rehabilitation program, Welfare Association, along with Nablus Municipality, An-Najah National University, General Popular Committee for the Governorate of Nablus, and Ministry of Tourism and Antiquities. The revitalization plan

took into consideration the fact that the old town is a living historic city that forms an important part of the urban fabric of the new modern city. The aim was to preserve the vitality of the city, support the different activities of the historic core and protect its cultural heritage (Welfare association 2011).

2 PROBLEMS FACING CONSERVATION OF THE OLD TOWN

The old town of Nablus suffers from several problems related to socio-cultural, economic, political and environmental conditions. The historic city lost its original citizens as a result of socio-cultural changes, which occurred in Palestine during the last century. Today old houses, occupied by poor residents, suffer from functional and environmental problems, dilapidation and decay, poor maintenance, negative image and lack of appreciation by citizens. Poor economic and social conditions contributed to devalue the historic site and degrade its urban environment.

The old town also suffers from problems related to aesthetic and physical shape as a result of decay of buildings especially those of high historic and cultural value, as well as disfigurement by inadequate new building additions and rebuilding (Hohmann 2003). The urban tissue of the historic core is subjected to chaotic and uncontrolled changes because of absence of a legislative framework for protection of architectural heritage. The old city manifests transformation of its urban fabric due to development of the historic core itself and new areas surrounding it.

Location of the old town in the heart of the city, surrounded by commercial areas, has put the historic urban fabric under tremendous economic pressure to be transformed into commercial uses (Fethi 1996). This threatens to change the diversity of uses that compose the traditional urban fabric of the old town. The pressure intensifies as the high value of land in and around the historic core threatens historic buildings by demolition.

3 CONSERVATION PROJECTS

Several projects were carried out in the old city of Nablus to revitalize its urban environment sustain its various functions and conserve the cultural heritage of the city.

3.1 *Khan Al-Wakalah project*

The project is a major conservation scheme for rehabilitation and adaptive reuse of an historic commercial building (Fig. 1). Khan al-Wakalah was built in late eighteenth century (Burgoyne 1987) to offer accommodation for traveling merchants visiting the city, and be a center for commercial, export-import activities.

It is a multi-level structure planned around an open to sky central space; the ground floor includes stables and storerooms, while the upper floors consist of several accommodation rooms. The building was partially destroyed by an earthquake in 1927 and was never rebuilt (ESSEC 2002). It was used for different purposes before it was abandoned and fell into destruction and decay.

Khan al-Wakalah is located on the edge of the old city of Nablus and is connected to one of its two main commercial streets. The building with an approximate ground floor area of 1,500 m^2 is part of the town's dense urban fabric. In traditional

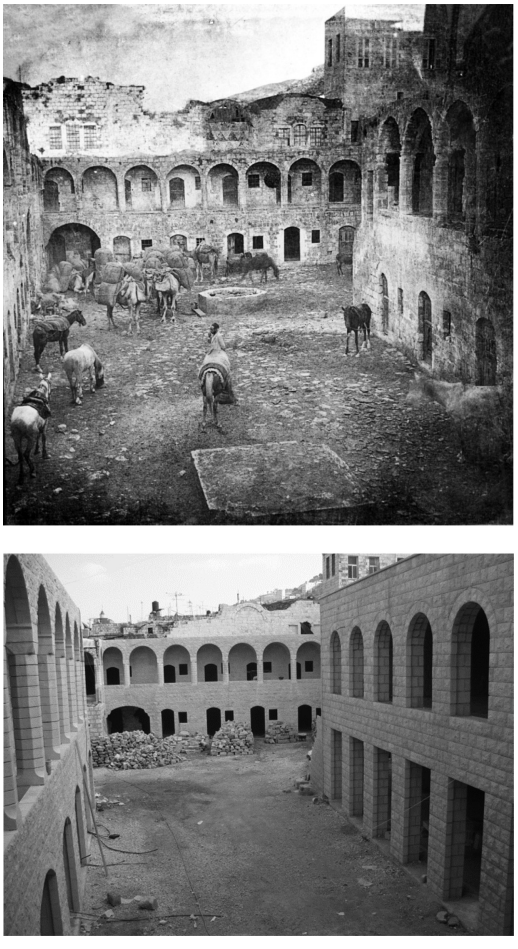


Figure 1. Old undated photo of Khan Al-Wakalah and a new photo taken during conservation (Eman Amad).

Islamic cities, these buildings were built as an integral part of the *suq* or market system (Michell 1995).

A proposal was developed by Nablus Municipality, the owner of the building, for rehabilitation of the historic site. The idea was to conserve and adapt the building for new uses that serve the old city and revitalize the surrounding areas. The goal, in addition to maintaining an historically valuable site, is to reuse the building for hand crafts, tourism and cultural services (shops on the ground floor, museum and a guest house on the first floor, and a restaurant on two levels).

A financial agreement was signed between the European Commission and Nablus Municipality, in 2000, under the title "Nablus Old City Center Renovation". Accordingly, funds were provided for the renovation of Khan al-Wakalah as well as of the existing surrounding streets. The project was implemented on two phases; the first involved conservation of the existing sections of the historic building, while the second was a reconstruction of the destroyed parts of the original structure.

An-Najah National University was nominated to implement the first phase of the project in direct coordination and corporation with UNESCO, Nablus Municipality and the European Commission.

Conservation was carefully carried out, during the first phase, using traditional materials according to traditional building methods. The main goal was to bring the historic building back to its original form. In the second phase, new materials were used to reconstruct the destroyed sections of the historic building. Old photos and traces of the missing structure were taken into consideration to design the new additions creating contrast between old and new structures.

Taking into consideration the various threats and challenges that face conservation of cultural heritage in Palestine, and the lack of skilled labor in the field of archaeological and architectural restoration, the project was intended to be an excellent opportunity for transferring the traditional know-how to a young generation of workers interested in building conservation.

An on-site training activity called "yard-school" was organized by the project and was carried out by a team of experts in different fields related to conservation. Moreover, to contribute to capacity building in the field of conservation in Palestine, the project supported the education of eight Master students of An-Najah National University specializing in architectural conservation.

Community outreach which aimed at enhancing public awareness towards the protection and conservation of cultural heritage was also an objective of the project. Several activities were organized to achieve the project objectives; public lectures that focus on conservation issues, site visits for professional and non-professional sectors of the community, and production of awareness materials (publications and internet website).

The project adopted an integrated approach which allowed revitalization of a dilapidated and neglected area of the historic core of Nablus, in addition to organization of training activities, and contribution to education and enhancement of public awareness towards protection of cultural heritage.

3.2 *Al-Yasmeen hotel and market*

The project which was established during late 1990s is one the first similar projects that were carried out as private investments in tourism in Palestine. The building consists of a small hotel of 24 rooms and suites, cafes and restaurants, two open terraces, a large multipurpose hall and 34 shops (Fig. 2). *Al-Yasmeen* hotel and market is situated in the city center in between old and new sectors of the city, adjacent to the northern entrance of the historically famous, lively and exotic Khan Al Tujjar which is the old town's main covered bazaar.

The complex was constructed on the first-floor level of existing old structures, adapting part of the historic fabric for new uses and introducing new additions. Historic buildings were rehabilitated and adapted to be reused for the project while new structures were fitted into the old fabric of the historic city. The intervention was carried out carefully to create a new axis that connects the old bazaar with other commercial streets outside the historic core.

The project ownership is mainly private with some public shares; the building is owned by three local families who are the owners of the properties



Figure 2. Al Yasmeen Hotel terrace (Eman Amad).

used for development. Also, Nablus Municipality has a share as the owner of part of the street used to create the main entrance for the hotel.

Dealing with property ownership was the main problem which the investors faced, as they discovered that more than one hundred persons were property owners. Another problem was the need to create a main entrance for the building, which was solved by using part of the street owned by Nablus Municipality. Also, the project needed other entry and exit points to connect the building with its surroundings, thus some small shops were purchased for this purpose.

The project succeeded to revitalize the area where it was established. It is an urban intervention which kept part of the old city alive and in continuous use during day and night.

3.3 *Nablus old city conservation office*

Constructed in 1890s–1900s, the building which consists of three floors and has a total built up area of around 1000 m^2, was originally built as a private residence for a local family (Fig. 3). It is located inside the historic core of Nablus, on a corner site in between two commercial streets and approached by one of the town's entrances.

The house was designed according to the central-hall layout with a large main hall surrounded by rooms. The ground floor consisted of eight traditional shops while the first and second floors accommodated the private functions of the house.



Figure 3. Nablus old city conservation office (Eman Amad).

The building was abandoned during 1950s and was left unused until it was purchased by Nablus Municipality in 1999. In 2007/2008 the building was restored and adapted to be reused as public offices to serve the city.

Rehabilitation of the building was funded by the Arab Fund for Economic and Social Development, and the conservation work was jointly supervised by Nablus Municipality and the technical office of Jerusalem old city rehabilitation program, Welfare Association. The building now houses offices for Nablus Municipality technical office for conservation of the old town, Welfare association and the General Popular Committee for the governorate of Nablus.

Adaptive reuse of the historic building was undertaken with minimal intervention to preserve its original artistic and architectural qualities. Consequently, building materials used in the process were the traditional materials themselves or other materials compatible to the original ones. Reproduction of the traditional wooden *Mashrabeias* and window shutters were carefully carried out by local craftsmen using wood, the original material. Worth mentioning that the conservation work was carried out by the team of professionals and craftsmen trained on conservation during the execution of *Kahn Al-Wakalh* project.

The project has a positive impact on the surrounding fabric; it contributed to the revitalization of part of the historic city and attracted people from outside the old town to use the newly established public offices and facilities.

3.4 *Residential urban units (Ahwash)*

One of the main components of the urban structure of the residential fabric of the old town is the cul-de-sac, locally called *Hosh* (plural *Ahwash*). It is composed of a number of private houses grouped around a narrow dead end alley connected to a thoroughfare. In the past, each of these urban agglomerations belonged to one large extended family or an ethnic group. More than 90 cul-de-sacs exist in old Nablus today forming the bulk of its urban structure; some of them are deserted and dilapidated and many are occupied by poor people.

Each *Hosh* has its own unique layout within the old city; each is composed of several houses that open to a narrow winding passage or a small court. For example, the number of houses in *Hosh Al Jeetan* is 16, in *Hosh Obeid* 11 and in *Al-Shwefieh* is 8, while the number of family members that live in each house ranges between 4 and 7 persons.

The complexity of design and the architectural quality varies between the different traditional urban units. While some include large houses with refine architectural details, moldings and decorations, others are composed of small humble houses.

To ensure urban recovery of the old town and sustainability of its traditional functions, an integrated systematic approach to urban conservation was adopted by Nablus Municipality and the technical office of Jerusalem old city rehabilitation program, Welfare association. The main purpose was to sustain the residential use inside the historic core by revitalizing the residential urban environment and supporting the old town's residents.

A number of residential units along with their access routes were rehabilitated to allow a convenient and decent living environment for the poor residents of the old town. *Hosh Al- Shoubi, Obied, Al-Shwefieh, Al-Jeetan* (Fig. 4) and *A-Atout* are few examples of an ongoing process to revitalize and upgrade the residential urban fabric of old Nablus.

Effective public participation was essential during the rehabilitation process; thus, residents of old houses were consulted before and during the course of conservation work. Users' needs and requirements were carefully understood by the team of experts and designers who carried out the conservation work. The work carried on old houses include repair, reconstruction, stone cleaning, plastering, painting, tiling, kitchen and bathroom upgrading, in addition to removal of new additions which were causing disturbance to the traditional image of the historic site.

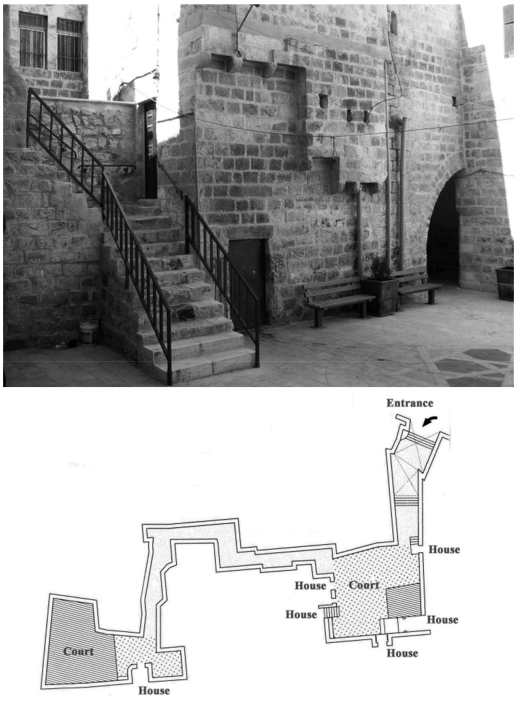


Figure 4. *Hosh Al-Jeetan* (Author: Eman Amad).

4 EVALUATION

Al Yasmeen project proved to be very successful in attracting people back to the old town. The project different activities and the exciting atmosphere of its different cafes and restaurants encourage people to visit the historic site during day and night. The project gave a good example for revitalization of the historic fabric, however, the shops which were designed on an elevated level from the street were not efficient in attracting shoppers and old town visitors.

The importance of Khan Al-Wakalah project is impeded in the comprehensive and sustainable approach which utilized the construction site to transfer conservation experience to young generations of professionals, workers and students. The building is a landmark in the city, a major conservation project with a significant location that contributed to rehabilitation of the urban fabric around the conservation site, revitalization of a traditional commercial area and creation of an active link between old and new fabrics of the city. Multiple activities which are taking place on the site are keeping it in continuous use by local people and tourists.

Khan Al-Wakalah project is a unique example in terms of the type of commercial building conserved, and the conservation process involved which contributed to enrich the conservation experience in Palestine. However, community participation was not considered an issue while planning for revitalization of the historic site, although the scale of the project suggested that people living around the site in particular and the historic core's residents in general should have been involved in the project.

Establishment of Nablus conservation office and the introduction of new public functions inside the historic core has a positive effect in terms of providing services for the old town and contributing to its revitalization, as well as attracting people to use and visit the old town thus ensuring the physical integration of old and new sectors of Nablus.

Protecting and revitalizing the old town involves maintaining the diversity of use and sustaining the urban character of the historic fabric. This necessitates preserving the residential use and enhancing

the quality of life for local citizens. Rehabilitation of the basic units of the residential fabric of the historic core contributed to maintaining the diversity of use inside the old town and preserving its traditional character. Moreover, the urban interventions were carried out following a comprehensive and integrated approach to planning and essentially the consideration of whole groups of structures not individual buildings. Conservation of residential urban units of old Nablus is an intervention that took in consideration the complex character of the historic core, and looked at the whole network of social, economic and physical interrelations. This integrated approach combines both conservation and development concerns in an integral manner.

5 CONCLUSIONS

All the examples investigated had a positive overall impact on the historic core in particular and the rest of the city of Nablus in general. They succeeded to enhance the urban environment of the historic city, support its local residents and sustain its traditional inherent social, economic and urban qualities.

These examples were established to serve the needs of the people of the city as a whole and to encourage residents of the new neighborhoods to use the new facilities established in the old town. Two of the studied projects (Khan al-Wakalah and Al-Yasmeen Hotel) located in transition areas between old and new fabrics of the city, created interesting links between the two zones and contributed to accentuate the physical unity between the two sectors of the city.

Investigation of these projects revealed the fact that the old town is badly in need for more similar investments in conservation. Means could be adopted by Nablus Municipality to encourage such interventions, and incentives could be offered to ensure that the lively and vibrant environment of the old town is maintained. However, any intervention needs to be controlled and carefully observed in order to preserve the authentic urban and architectural qualities of the historic core.

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The habitat of the nomadic shepherds in the Jbel Saghro, Morocco

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ABSTRACT: The Jbel Saghro located south of the High Atlas of Morocco, is a large mountain range sparsely populated presenting extreme climatic conditions during the warm seasons. In the winter rains it temporarily becomes an area rich in pastures, which provides optimal conditions for grazing. For this reason the nomadic shepherds who live in the High Atlas move on a scheduled annual cycle, temporarily occupying the collective settlements scattered in the territory. In these self-constructions, handed-down construction techniques and local materials are used to create flexible and efficient living spaces by making use of the available resources, which adapt to the great diversity of users that inhabit them annually. In the continuous movement of the nomads these constructions are their only footprints on the territory on which they've travelled and they've become the tangible reflection of their culture.

1 INTRODUCTION

1.1 *Territorial approach*

The Jbel Saghro, a wide mountain range, between 1,600 and 2,400 m high, is located south of the High Atlas of Morocco, separated to the north by the valley of the river Dades and east of the Anti Atlas the valley of the River Draa (Fig. 1). This territory is a complex system of large overlapping chordals that form small valleys inside it. It is a large and sparsely populated region and due to its proximity to the Sahara desert, it suffers extreme climate conditions during warm seasons.

Saghro, which in the Tamazight language means drought, it refers to the driest area of the entire Atlas mountain range. Due to its enclosed location, it's not aided by the Atlantic humid winds, and that makes it an arid, sub-desert region, with an average annual rainfall of 300 mm in the crests and 100 mm in the southern hillside.

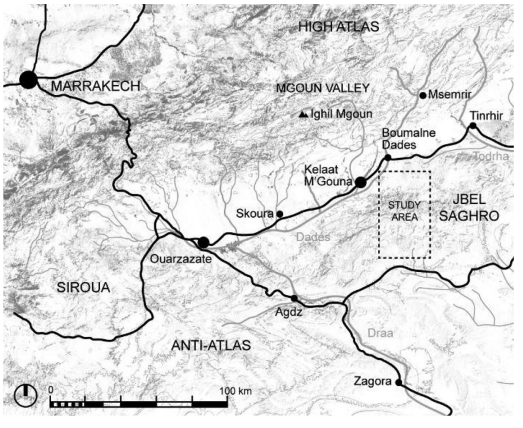


Figure 1. Jbel Saghro location and study area (P. Iranzo Navas).

However, the scarce winter rainfalls temporarily convert this arid mountain range into an area rich in pastures, which provides optimal conditions for grazing. So much so that the nomads, who in the warm seasons inhabit the High Atlas, emigrate to Jbel Saghro in the cold seasons, when the snow keeps them from carrying out their pastoral activities in the mountain.

Apart from the nomadic temporary presence, the Jbel Saghro is usually a sparsely inhabited territory.

In the southern foothills are located the oasis—villages of N'Kob and Tazzarine, which feature approximately 7,000 and 13,000 inhabitants respectively. And on the northern hillside, on the N10 road running parallel to the Dades river valley, are situated the Boulmane Dades and Kelaat M'Gouna villages, with approximately 12,000 and 14,000 respectively.

1.2 *Social approach*

The nomads of this region, of Berber origin, are organized into family units, which are the smallest cell within a complex social fabric that follows a segmental tribal structure, which is organised from major to minor in confederation, tribes, clans, fractions and sub-tribes. This family unit is usually a large group where sometimes more than a dozen people get together among parents, children and grandchildren, and very often with uncles, cousins and other relatives.

This family unit remains united in its migratory movements and they coexist under one roof. However, in case of long-term stays, which may reach up to four or six months in the Jbel Saghro region if the grazing season is good, some families send their school-age children to the nearby towns where their relatives live. Sometimes these family units see the number of working-age men decreased due to emigration in search for alternative resources, either to nearby villages, large cities in Morocco or, to a lesser extent, to Europe. It is not therefore unusual to find more women than men in the settlements.

1.3 *Habitat dimension*

Although this article focuses on the habitat of nomadic shepherds of a particular region of the Jbel Saghro (Fig. 2), it must not be forgotten that the territory encompassed in their migratory movements is broader, as it extends up to the High crests of the Mgoun Valley, with a distance of approximately one hundred kilometers between them.

Their lives are conditioned by the weather, the rain seasons and, therefore, the availability of graze for their livestock.

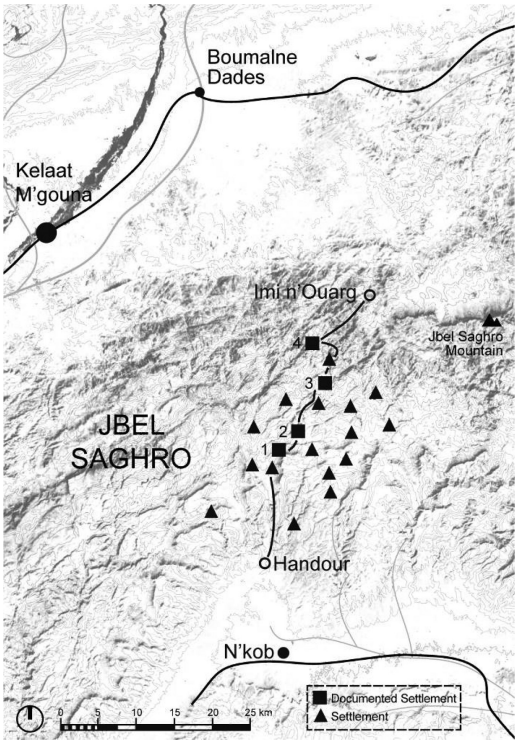


Figure 2. Location of nomadic settlements in the study area (P. Iranzo Navas).

In this large territory where they migrate, the altitude varies between 3500 m in the peaks near the Ighil Mgoun, 2200 m in the Jbel Saghro and 1,300 m in the plains of the Valley Of Draa, all this gives an idea about the environmental diversity and the logistic difficulty of the nomadic route.

During the summertime, family units take their livestock to graze in the highest parts of the Mgoun Valley. As the summer is ending it begins the descending to the south, occupying their migratory settlements, sometimes close to the villages. In this short stay the members of the family have the opportunity to receive medical assistance and contact with their families more.

At the end of this season the group migrates south again, sometimes renting a small truck to aid them in shortening the great distance to Jbel Saghro, where they will dwell towards the end of winter and spring, in search of better temperatures and coinciding with the rain season in which some temporary vegetation thrives in the sub-desert environment and will serve as graze for their livestock.

The stays in the Jbel Saghro last for several months, and it is usual to swap locations within this region, if the herd is too big, in order to preserve the graze in certain areas. In these migrations the nomads can take several days in long distances. They do them on foot and use mules to transport goods.

Their usual habitat reaches up to the villages close to the settlements (Nkob, Handour, Kelaat M'Gouna, Boulmane Dades), where they make the necessary purchases or receive medical attention. Some families own a motorcycle or bicycles, which help them in their migrations.

2 HOUSING DEVELOPMENT

2.1 *Study purpose*

This project, focused on the analysis and characterization of the constructions temporarily occupied by nomadic families, aims to get to know the patterns that are repeated, their beginning, evolution, occupation forms, environmental relations, construction techniques, materials employed, etc.

This study is also complemented by an anthropological component that analyzes their cycles, their way of life, migrations, customs and social values, this is done by participation as active observers through co-habitation with families during different times of the year. The architectural development studied here can only be understood by getting to know the social dimension in which is constructed.

The study area is limited to a central geographical area within the Jbel Saghro mountain range (WGS84, 31.0791118, –5.860945). In this place,

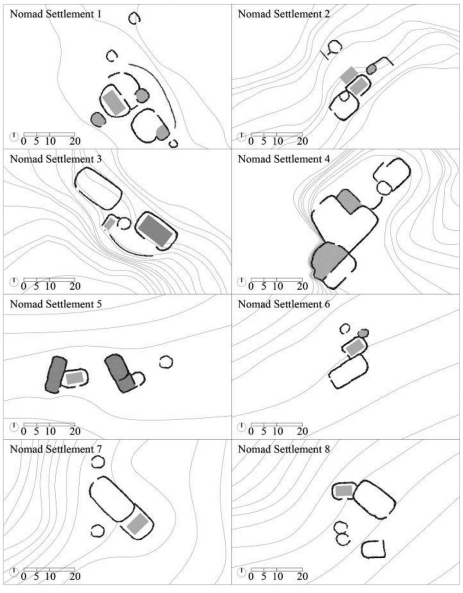


Figure 3. Schematic catalog of studied settlements (G. Cudeiro Baiguera).

the concentration of settlements is higher than in other areas, located a total of twenty (Fig. 2), of which ten have been documented by exhaustive planimetric surveys, presenting here schematically the most significant ones (Fig. 3). Of these, three settlements (1, 2 and 3) have been selected to elaborate on a larger scale and detail in this article, for reasons of space and interest.

2.2 *Architectural and constructional definition*

The settlements temporarily occupied by the nomads belong to a network of permanent dwellings built collectively and successively transformed by each family to adapt to their needs.

In the Mgoun Valley, due to its high altitude and as a measure of protection against the cold and the wind, the dwellings in the settlements have minimum openings and are roofed. However, in the Jbel Saghro, which enjoys better temperatures, the settlements are configured as an attachment of rooms, usually separated between them with open outdoors. Only, and for protection against the rain, a room is covered, that is normally used as a kitchen and for storing household goods. There is a separation of spaces of different usage, as can be seen in Figure 3, while the divisions are made of dry stone walls, which usually do not reach a height of more than one meter.

In these self-constructions are used the locally available materials like (stone, soil, wood and brooms). This situation, along with the constructive simplicity of using hand-down techniques, allows these settlements to be easily expanded and adapted to the family that dwells in it.

The size of the buildings and their programmatic composition is variable. The set is usually formed as a structure of attachments and rooms without a fixed pattern. These dwellings lack specialization, which grants some versatility and flexibility of usage.

As a protection mechanism against the sun and the high temperatures, fabrics made with goat and dromedary hair, forming a gable cover, are made into a tent. The stability is guaranteed by the simple wooden structures, and the assembly being tensioned by ropes anchored to the ground.

In contrast to the Mgoun Valley, it is rare to find enclosed caves in *ifrane*, or in its proximity, that would complement the settlements. The needs for storage, shelter and a haven for the cattle are met by the stone-fence system described above.

Settlements are usually built on the foothills in a position that favours protection against the wind and in proximity to a riverbed or a water source.

3 STUDY CASE

Three typologically different settlements have been selected for their meticulous development, all of them being composed of an attachment of rooms each of different usage (1. Stay, 2. Staying-dormroom, 3. Entry-hall, 4. Warehouse, 5. Oven-kitchen, 6. Yard). The practically non-existent room specialization allows a flexible usage, sometimes being able to simultaneously use them as living area, storage or bedroom.

3.1 *Settlement 1*

This is the most sophisticated of the three represented here because it has several rooms covered, one of them turned into a kitchen. The hallway, which acts as an outdoor living area, presents a carefully designed floor with gravels of different granulometries (Figs. 4, 8 and 9). It presents some complexity in its configuration and is endowed with specialised pieces, reason why it usually lodges families during long periods of time.

3.2 *Settlement 2*

It is a simple settlement of a smaller dimension and less complexity. The kitchen space is at a distance from the dwelling areas (Figs. 5, 10, 11, 12 and 13). It has several loops at a distance from the domestic pieces. The protection is only achieved using tents.

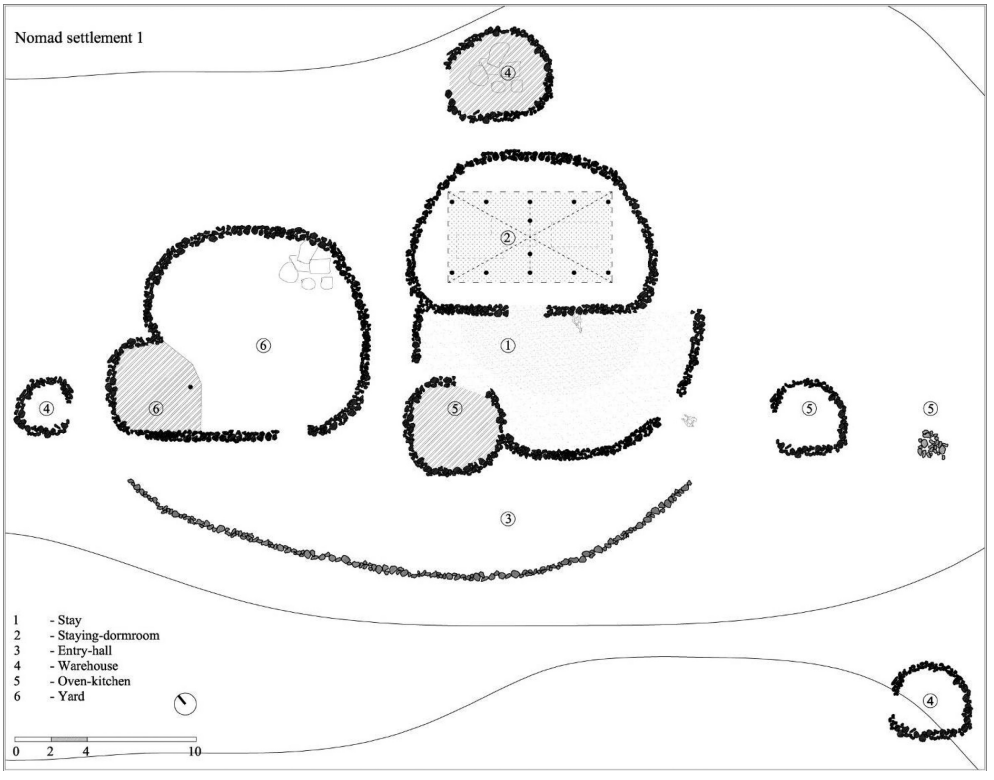


Figure 4. Planimetric survey (M.A. Porras Díaz).

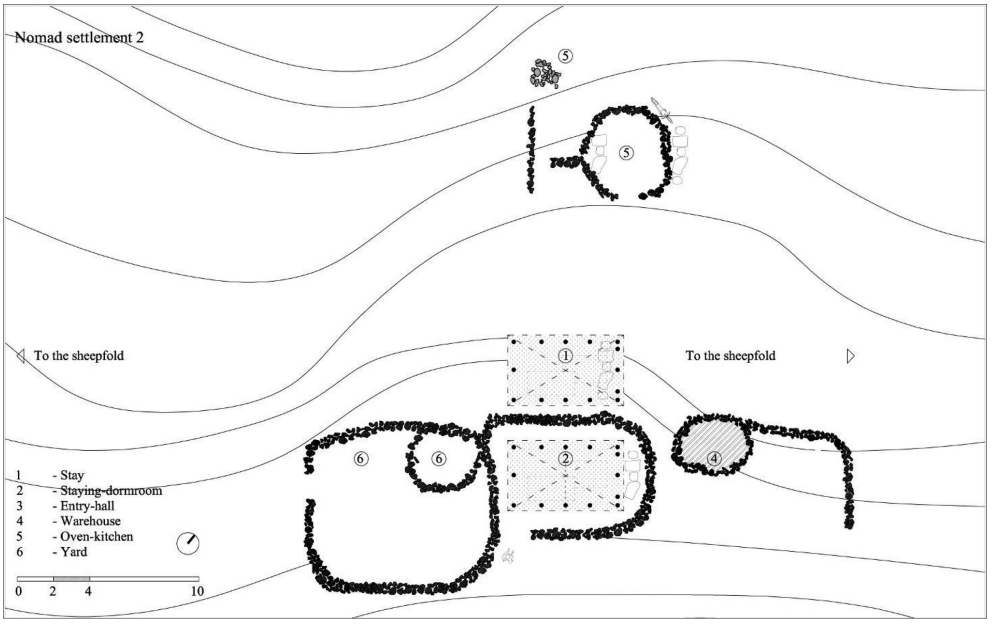


Figure 5. Planimetric survey (M.A. Porras Díaz).

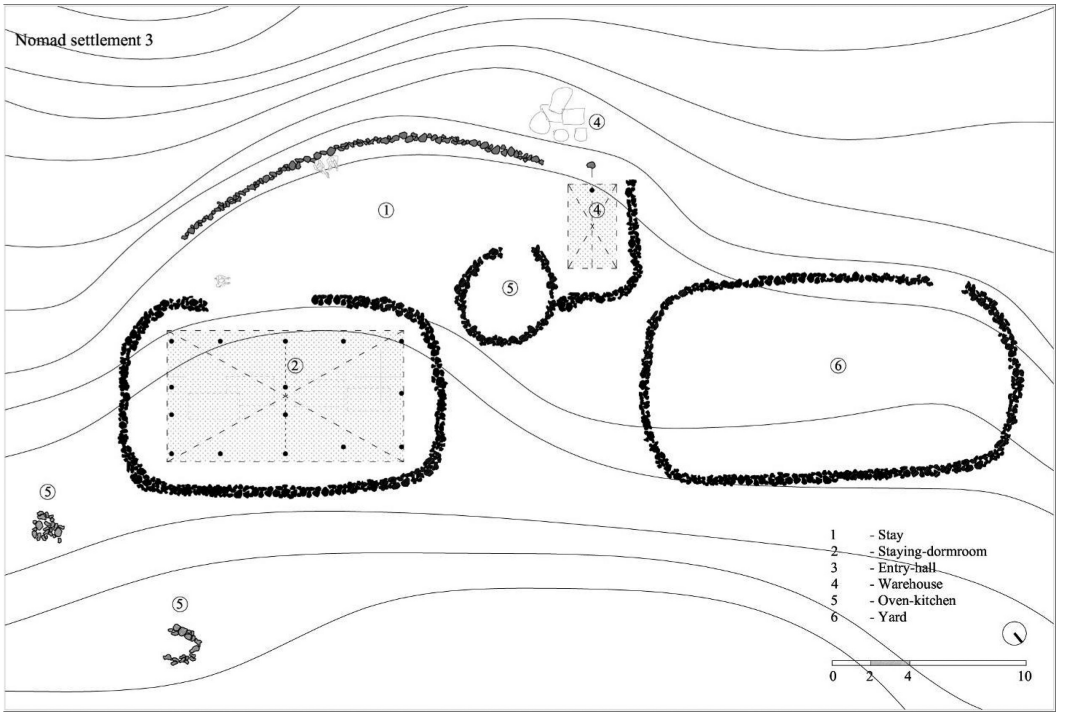


Figure 6. Planimetric survey (M.A. Porras Díaz).

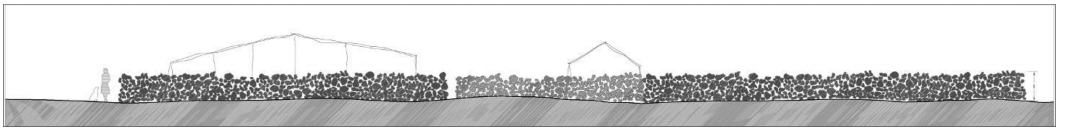


Figure 7. Planimetric survey. Elevation and section (M.A. Porras Díaz).



Figure 8. Settlement 1 (J. Asencio Juncal).



Figure 9. Settlement 1 (J. Asencio Juncal).



Figure 10. Settlement 2 (J. Asencio Juncal).



Figure 11. Settlement 2 (J. Asencio Juncal).



Figure 12. Settlement 2 (J. Asencio Juncal).



Figure 13. Settlement 2 (J. Asencio Juncal).

3.3 *Settlement 3*

Settlement of smaller dimension that lodges reduced families in short periods of time. It has a large outside space where the living is done, which functions as the core of the set. No place is covered, making the tent the only protection (Figs. 6 and 7).

4 CONCLUSIONS

In the continuous movement of the nomads these constructions are the only footprints on the territory which they've travelled and they've become the tangible reflection of their culture. Its ancestral activity is in accordance with its eco-system and assumes the origin of the first settlers in this territory.

In spite of the limited resources that the place offers for the building of their settlements, they present some typological diversity with bigger or shorter complexity and size. It allows to lodge varied families, being conditioned only by the time of stay for comfort reasons. Nevertheless, the proximity of the resources used for its construction and the simplicity of the construction techniques, allow to adapt the settlements according to the needs of each group.

NOTE

The research carried out presents part of the results of six work campaigns between 2010 and 2016, which are part of the project "The habitat of the nomadic shepherds in the High Atlas, Morocco" and is part of the activities of Univ. of Málaga Volunteers, International Cooperation for the Development of the International Relations and Cooperation Service, supported by the Andalusian Agency for International Cooperation for Development (AACID), in collaboration with the Ministry of Culture of Morocco.

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Vernacular nomadic architecture in the Mgoun Valley, High Atlas (Morocco)

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ABSTRACT: The Mgoun Valley, located in the High Atlas of Morocco, forms a territorial unit with a strong identity and an undeniable landscaping and cultural value. The population that inhabits this territory, mostly sedentary, is organized in villages or *duares* built on the lands around the fertile areas of the oasis. Nevertheless, in the highest areas of the valley, there is still a nomad way of living whose habitat is organized in small dispersed settlements, denominated *izghis*, temporarily occupied in their displacements. These self-built settlements, create livable, flexible and efficient spaces in harmony with the available resources. These constructions adapt to the great diversity of users who inhabit them annually. The analysis and characterization of these constructions have the aim of knowing the common patterns that are repeated in their genesis, evolution, ways of living, environmental relationships, construction techniques, local materials, among other values.

1 DEFINITION OF THE HABITAT

1.1 *Territorial description*

The Mgoun Pre-Saharan Valley is placed in the South of Morocco in the Souss-Massa-Draâ region, about 100 km North-East of Ouarzazate city, on the Southern slope of the High Atlas mountainous massif. This social construction is developed around the river that gives it its name, the Oued Mgoun, and is limited to the North by the Ighil Mgoun massif—where is located the second summit of Morocco stands at 4,071 m of altitude—and to the South by the basin of the Dades River at 1400 m of altitude and the sub-Saharan mountain massif Jbel Saghro. The great size of Oued Mgoun basin (Fig. 1), around 100 km, forms a complex reality of strong identity and a mosaic of landscapes of undoubted cultural value.

The population that inhabits this territory, mostly sedentary, is organized in villages or *duares* built on the lands around the fertile areas of the oasis. It is a territory that has historically been transformed by its inhabitants through the control of water and a great command of agricultural techniques. This knowledge has allowed the transformation of the river basin, the main source of resources, through agricultural exploitation.

Nevertheless, in the highest areas of the valley, above 2,000 m of altitude, the habitat is organized in small dispersed settlements, temporarily occupied by nomad families.

This research is focused on the study of the upper Mgoun Valley, at an altitude between 2500–3000 m, along the Oulilimt and Amougr rivers, where the highest density of nomad settlements is concentrated (Fig. 2).

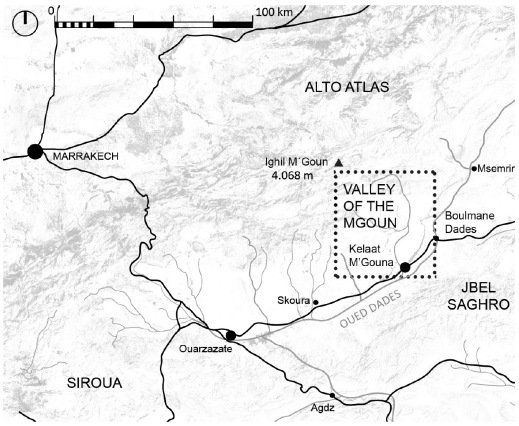


Figure 1. Mgoun Valley localization (J. Ramírez Bandera).

The territory covered by the activity of these nomad shepherds is not confined solely to these high parts of the Mgoun Valley. It is much wider, reaching to encompass the Jbel Saghro massif located at a distance of 100 km to the South.

1.2 *Nomadic as a way of life*

Nomadism is an ancestral culture strongly rooted in Morocco and specifically in the Mgoun Valley,

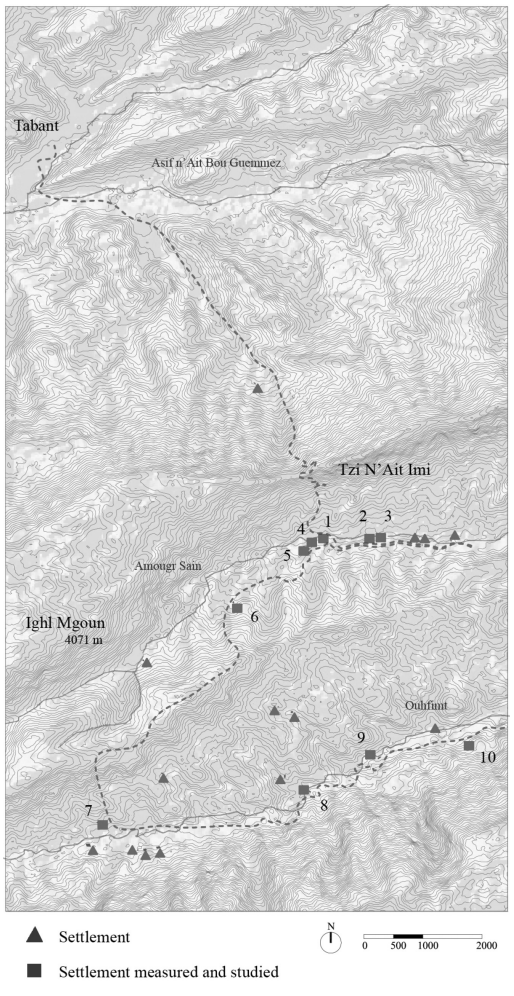


Figure 2. Location of nomad settlement in the high reaches of the Mgoun Valley (J. Ramírez Bandera).

which is characterized by the respect for the environment with a high degree of sustainability, efficiency and a responsible consumption of resources.

The nomad culture, based on shepherding in continuous movement, is conditioned by the climatic cycles and by the pasture availability for the cattle, for that reason they do not have a fixed home.

During the winter period and until the beginning of the spring, the family groups move from the top of the Mgoun to the Sub-Saharan mountain massif Jbel Saghro, in the south, where temperatures are more benign and the pasture for the flock is guaranteed as it is not covered by snow.

In their displacements, they occupy temporarily dispersed settlements of permanent character, denominated *izghis*. These self-built settlements, using materials from the landscape and traditional construction techniques, create livable, flexible and efficient spaces with the available resources, which adapt to the wide range of users who inhabit them annually.

1.3 *Fragility of nomad culture*

Throughout the time the dynamics of transformation have been adapting to the territory in a process of logical and 'negotiated' construction with the natural dynamics. This has led to the development of an environmentally sustainable model with very low rates of resource consumption and waste generation.

Earth and stone as building materials, along with other raw materials mainly from livestock, made it possible to cover the basic needs of shelter, food, and social space. It is, therefore, a subsistence economy.

Currently, the Mgoun Valley is undergoing multiple pressures that have to do with globalization and climate change. As desertification advances, global processes involve the introduction of models that violate the laws of physics and traditional social construction. This is putting at risk the survival of the preexisting types and landscapes. The negative aspects of globalization and cultural uprooting processes are producing the irreparable loss of local identity and the tangible and intangible values of this traditional habitat.

Despite the harsh living conditions, this vernacular habitat associated with the nomadic community still survives, although it is in recession due to the cultural and social changes described which leads to a loss of cultural values. For this reason, it is proposed the study of this ancestral culture and its architectural production, due to its anthropological and architectural value.

2 HABITAT DEVELOPMENT

This work has focused on the analysis and characterization of the constructions that are temporarily occupied by the nomad families. It has the objective of knowing the patterns that are repeated in their genesis, evolution, forms of occupation, relationship with the environment, construction techniques and materials employed, etc.

This study completes itself with an anthropological component, analyzing their cycles, ways of life, movement, traditions and social values. This added dimension has been accomplished by participating as active observers during different periods of the year. The architectonic production studied can only be understood by knowing the social aspect that helps to build it.

The area of study presents itself limited to a specific geographical area, the summits where the riverbed that gives birth to the Valley of the Mgoun is born. (WGS84. 31.581386, –6.384031). During the spring and summer seasons this location becomes rich with pasture; as a result, there is a bigger concentration of nomad settlements in this part of the valley than in any other. Its relative distance from the *duares* makes possible the coexistence between the agriculture and the nomadic life of shepherding.

In this area, twenty-three settlements have been located (Fig. 2), of which ten of them have been documented in detail with planimetric surveys, presented schematically here (Fig. 3). For space reasons, three of these (1, 6 and 10) have been selected for this article to be studied with greater scale and detail.

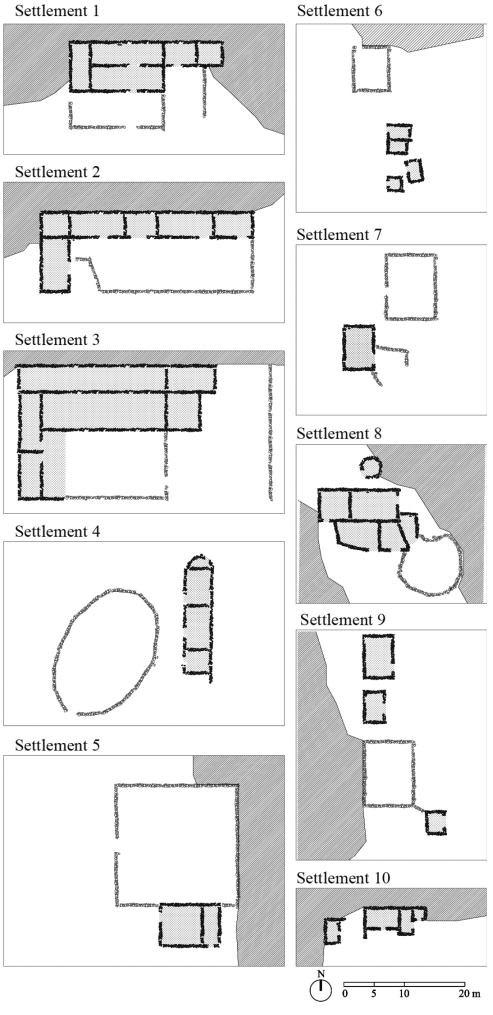


Figure 3. Schematic catalog of the studied settlements. (J. Ramírez Bandera).

2.1 *Architectonic definition*

The architecture associated with the nomadic habitat, of a communal nature, is used by different family groups in their displacements through the territory. In their seasonal movements, they resort to these vacant settlements that can satisfy their spatial needs. Sometimes they complement these constructions with removable tents or building new solid rooms or sheepfolds, known as *afergane*. As time goes by, these refuges are occupied by many families that modify the settlement, so the constructions are in constant evolution.

The settlements, known as *izghi*, are usually created by an addition of different rooms that are used for the family life, as well as for safe keeping of the cattle. The constructions usually have a small exterior wall around it to assure its protection.

Some of the settlements have caves, attached or close to them, called *ifrane*, either naturally formed of excavated, and that complete the needs of storage, shelter or sheepfold.

The dimensions of the refuges and their programmatic composition is variable. The ensemble is usually form by an addition of structure and rooms without a fixed pattern. These rooms lack specialization, which lends some flexibility and versatility to the ensemble. The only exception is the room used for cooking that usually has an oven made out of earth and the distinctive feature of having little holes in the roof or between the stones of the walls, which allow the smoke of the oven to pass through and improve the ventilation.

These refuges are usually built on the hillside of the valley, close to the river or water stream, facing south and taking advantage of the natural slope to protect the building from the wind, rain and possible snow accumulation. Often, they are partially buried in the hillside, giving them greater protection.

The climatological conditions and the availability of resources limit the configuration and materiality of the settlement. Even though they are only occupied during the summertime, since they are located at an elevated altitude where the temperature can descend quickly, the constructions are closed to the exterior and only have the necessary opening for access, as well as little apertures for the ventilation and evacuation of smoke.

It is interesting to point out the difference of form and constructive techniques between these settlements and their parallel settlements on the Jbel Saghro, where the temperatures are kinder and the refuges can stay opened to the exterior, consisting only on an ensemble of small walls without any cover. In those constructions, the necessity of shelter is eased with removable tents made out of hair from goats and dromedaries.

2.2 *Constructive definition*

This traditional architecture uses the natural resources available in its close environment: stones piled up for the construction of the walls, juniper or poplar wood for the columns and beams, and bushes to cover the roof with a finishing layer of earth. Recently, it has been observed the introduction of new plastic materials underneath the finishing layer of earth to help to waterproof.

The structural scheme is based on loading walls made out of stone, either simply piled up or with and earth mortar. Loaded over these walls a one-way system of wooden beams of different geometry is built, these beams depend on the available resources around the settlement and have no posterior treatment. Above these, a secondary set of wooden beams, smaller than the main ones and a large variety of bushes and sticks are placed to conform the roof that covers and isolate the ensemble. Finally, the roof is finished with a layer of earth mortar, sand and straw that confers some degree of waterproofing, allowing the water to flow over the rooftop to its edges where there are eaves made out of bushes and straw.

3 STUDY CASES

The different types of settlement are conditioned by the surrounding orography, they are the architectonical response to the characteristic ways of life of the nomads: Their family structure and size and the amount of time that they are going to stay in a location.

Three different typological settlements have been chosen for further development, being all of them formed by a union of spaces meant for different purposes (1. Room—bedroom, 2. Living room-kitchen, 3. Entrance, 4. Storage, 5. Handmade oven—kitchen, 6. Sheepfold, 7. Covered courtyard, 8. Homemade clothesline, 9. Leather drying place, 10. Abandoned sheepfold). The different rooms can often be used for various purposes at the same time, for example, as a living room but also as a bedroom or storage.

3.1 *Settlement 1*

Attached to the slope, with a union of domestic and livestock dedicated rooms forming a solid core

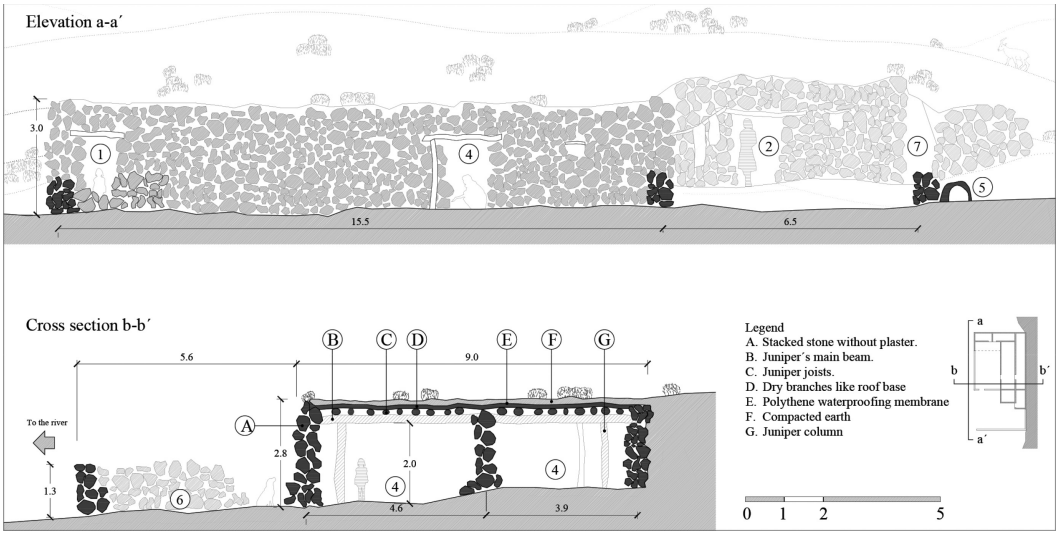


Figure 4. Planimetric survey. Elevation and section (J. Ingelmo Moyano).

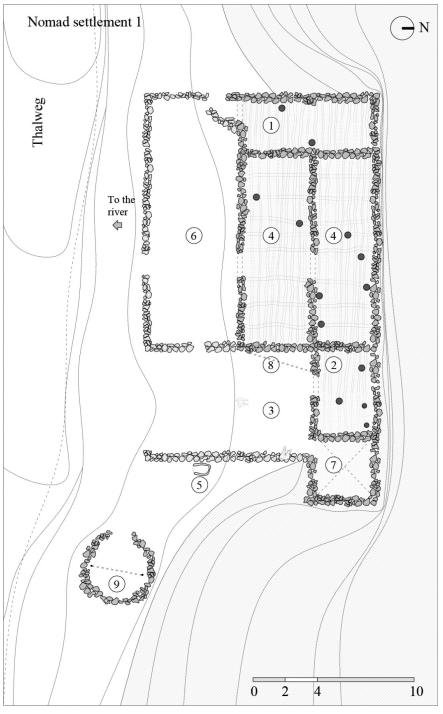


Figure 5. Planimetric survey (J. Ingelmo Moyano).

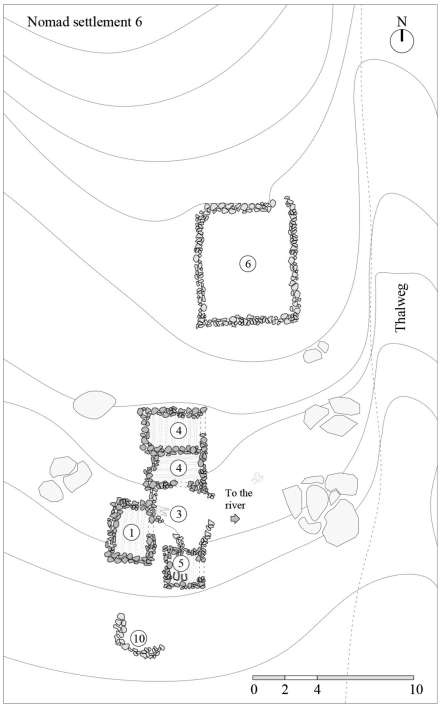


Figure 6. Planimetric survey (J. Ingelmo Moyano).

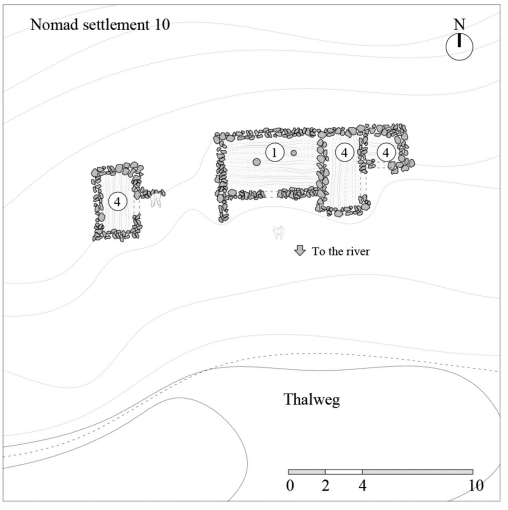


Figure 7. Planimetric survey (J. Ingelmo Moyano).

(Figs. 4, 5 and 8). Because of the number of rooms and their size, it is characteristic of a nomadic family with several children and a considerable flock. It is attached to the slope, but the absence of any near obstacle allows it to grow in all the other directions.

3.2 *Settlement 6*

Detached, with a union of rooms surrounding a small courtyard which functions as an outdoors living room and hallway. The space dedicated to the animals is separated from the rest of the domestic ensemble, but close to it. (Figs. 6, 9 and 10). It is a more compact typology that the previous settlement, but the livable rooms are clearly differentiated from the rooms for the cattle.

Its reduced dimensions impede its use for wider families. The orography and the rocky obstacles from the hillside where the constructions is located, condition its growth and the possibility of adaptation to the variable needs of its users.

3.3 *Settlement 10*

Detached smaller and less complex, for shorter stays or as an intermediate point during their cyclic movements between more stable settlements of a bigger dimension. The rooms don't hold and specific use. The sheepfolds used for the care of the livestock are organized at a certain distance from the domestic ensemble, in detached sheepfolds, and protected by the natural caves in the nearby slopes (Figs. 7–10).

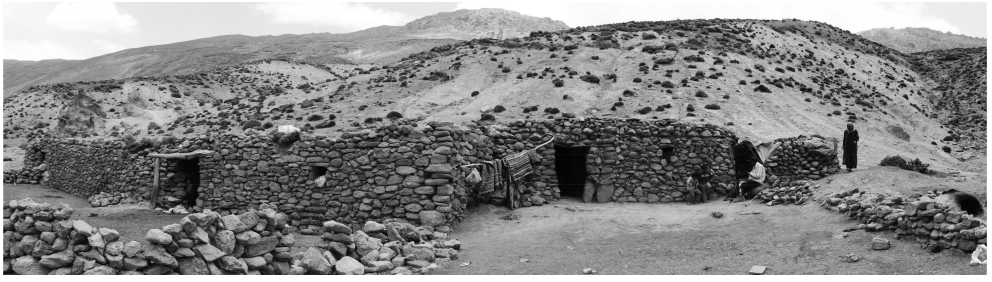


Figure 8. Settlement 1 (J. Asencio Juncal).

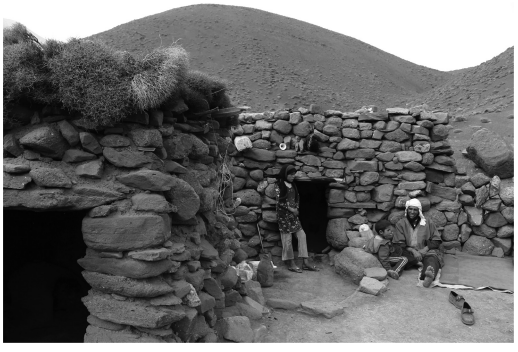


Figure 9. Settlement 6 (J. Asencio Juncal).

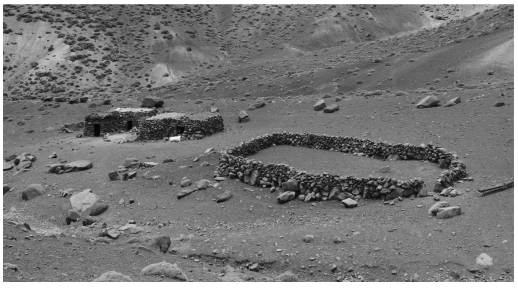


Figure 10. Settlement 6 (J. Asencio Juncal).

4 CONCLUSIONS

The architectural production generated by the practice of nomadism is based on the responsible management of the natural resources and it is built minding the scarcity of available materials, creating fixed patterns.

Nonetheless, said determinants allow the development of a vernacular architecture that is typologically diverse, although it presents some common patterns of organization: the addition of rooms or pieces attached, normally around a common exterior space. Said typological variations, in size and complexity, define the size of the family and the duration of the stay.

This architecture is alive and in a constant evolution because of its ability to be transformed and adapted, so it can answer to the needs of different families that occupy it temporarily.

NOTE

This investigation contains part of the results of six working campaigns between 2010 and 2016, which are framed in the project 'The habitat of the nomadic shepherds in the High Atlas, Morocco', carried out by 'Voluntariado Universitario en Cooperación Internacional para el Desarrollo del Servicio de Relaciones Internacionales y Cooperación' of the University of Malaga, backed by the 'Agencia Andaluza de Cooperación Internacional para el Desarrollo' (AACID), in collaboration with the Ministry of Culture of Morocco.

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Casa de los Cinteros: Constructive analysis of a traditional house in northern Valencia

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ABSTRACT: In the north of the region of Valencia there is a wide range of typologies of vernacular architecture linked to the land and traditional lifestyles. In the particular case of the region of La Serranía, the predominance of agricultural activities until the mid-twentieth century meant that most of the houses were farm workers' houses. Recent interventions in these buildings generally use modern techniques, non-compatible with traditional ones, modifying their original identity. The aim of this article is to establish the constructive features of the vernacular houses of the region through the detailed study of a representative and well-conserved example, *Casa de los Cinteros*. Literature about traditional constructive systems and local architectural catalogs have been consulted to characterize the constructive elements of the house. The results of this bibliographical approach have been compared with the constructive solutions of the house, highlighting the details that were characteristic of this architectural typology.

1 INTRODUCTION

The vernacular architecture of mainland Spain features a wide range of constructive materials and techniques varying according to the geography, climate, and society of a given region. Although heritage value is a clear reflection of the cultural, social, and economic situation of a given period, the progressive decay of traditional constructive techniques in the twentieth century due to new standardized systems has brought about numerous interventions mainly characterized by material, structural, and compositional incompatibility with the original buildings.

In addition, the abandonment of traditional trades and economic activities in the rural communities in mainland Spain led to the transformation of the spaces in which these were found. These were then adapted to the new needs of the inhabitants. Thus, with the passing of time, valuable architectural records of specific cultures have been lost.

This work focuses on defining a methodology for cataloging constructive solutions in historic buildings and subsequently applying them to the study of specific cases as *Casa de los Cinteros*.

2 OBJECTIVES AND METHODOLOGY

2.1 *Objectives*

The starting point of this hypothesis is that in order to ensure the recognition of the values and conservation of traditional heritage it is first necessary to understand it. This architecture is linked to the culture and the social situation of a given territory, with constructive techniques adapted to available local resources and to the economy of its inhabitants.

Based on this, the main objective of this research is to analyze and catalog each of the constructive solutions of *Casa de los Cinteros*, as a representative study of traditional ways of life associated with local agricultural activity. Finally, the aim is to enhance the value of this traditional heritage and lay the foundations for future research on intervention criteria and techniques compatible with the building's original solutions.

2.2 *Research methodology*

The methodology for this research is based on the classification of the constructive elements of a traditional home by comparing the information obtained through data collection in situ with information from the literature.

Thus, three research phases are proposed:

1. Selection and study of bibliography on traditional architecture in the region and specifically on *Casa de los Cinteros*.
2. Inventory of the constructive solutions in the house using previously prepared data sheets (Fig. 1) which include photographs and data relating to location, type of constructive elements, materials, measurements, construction details, state of conservation and damage.
3. Establishing conclusions based on the classification of the building's constructive solutions.

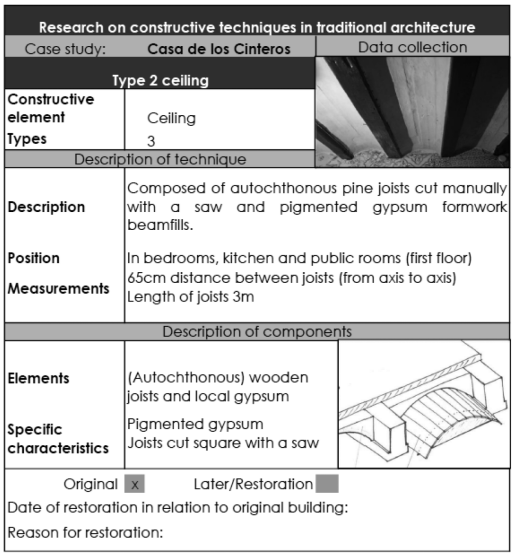


Figure 1. Sample fiche. Classification of Ceilings (Casa de los Cinteros) (S. Traver).



Figure 2. General view of *Casa de los Cinteros* (L. Balaguer & S. Traver).

This methodology could be applied to classify other case studies in traditional architecture.

3 CASA DE LOS CINTEROS

3.1 *Urban context*

The town of Villar del Arzobispo in the region of La Serranía (Valencia) is on a plain on the left bank of the river Turia. It was originally founded on an elevated medieval center, which subsequently grew to the west, adapting to local topography. More industrial than nearby towns, yet compatible with agricultural activity, Villar del Arzobispo experienced considerable demographic growth which was reflected in the urban fabric in the nineteenth and twentieth centuries. *Casa de los Cinteros*, the subject of this study (Fig. 2), is situated close to the medieval nucleus, right in the town's historic center.

The Subsidiary Norms of 1997 (Comunidad Valenciana 1997) which, in section four "Norms of Protection", regulate buildings with complete and part protection are currently followed by town planning. These regulations do not consider the protection of *Casa de Cinteros* or any of its nearby surroundings, and instead limit protected elements to local monuments in the city. However, in 1990 the Town Council took over the house to transform it into a museum, discounting interventions other than original constructive solutions.

At the time of writing, a new General Plan is being put together to establish three levels of protection (complete, partial and environmental) in order to promote the preservation and recovery of elements of cultural interest such as this building.

3.2 *Traditional farmworkers' houses*

According to oral sources and property records, *Casa de los Cinteros* on one of the main streets of the town and close to San José Square was built circa 1890 (Dir. General del Catastro 2017). A simple typical house of well-off farmworkers, it is one of the few historic houses in the town largely unaffected by modernization, with no running water or sanitary facilities, and still conserves all the rooms characteristic of a farmworker's house (Matoses 2015).

All the rooms include a collection of floor tiles, ceramic tiles and decorative tiles from Manises (a Spanish town historically famous for its tile production); harnesses and agricultural tools; and wooden, ceramic, and metal kitchen utensils which take visitors back in time.

Below is an account of the rooms in *Casa de los Cinteros* (Montero 1993), from the ground floor to the attic (Fig. 3).

– The entrance was the room where everyday family life took place. It was also used for entertaining local dignitaries, holding funeral wakes, etc. Before an early twentieth-century restoration it looked very different, with more basic finishes, as it was used as the entrance for carts (Montero 1999a).

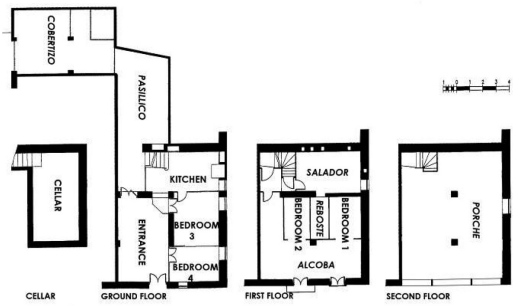


Figure 3. Floorplan distribution (L. Balaguer & S. Traver).

– The *pasillico* or small corridor, a long room with lower ceilings, was used as a stable for animals and storing agricultural implements. The basement cellar was accessed from here (Montero 1999b). The early twentieth-century reform opened the pasillico to the plaza de San José, creating a back entrance through the *cobertizo* or shed and improving ventilation.
– Carts entered the house through the *cobertizo*, rather than through the main entrance. There was a courtyard between this covered space and the *pasillico*.
– In this winemaking region the cellar was frequently found, and not confined to wealthy homes. It normally contained three barrels of wine: one for daily use, one for important visitors, and one for storage.
– The two ground floor bedrooms were built to supplement the bedroom space above as the family grew. These currently hold auxiliary archives for the local Town Council.
– The kitchen was structured around the fireplace, where food was prepared. In this room it is worth noting the various pantries for storing utensils and a variety of wall tiles which had been gradually replaced as they deteriorated due to use (Montero 2000a).
– The *salador* was used for different food preparation processes: sifting wheat, curing meat, etc. One of the walls had four wooden hatches which close off the *silos* connecting to the *porche*. *Silos* are vertical ducts, which allow the transfer of stored products from the *porche* to the *salador* (Montero 2000b).
– Next to the *salador* was the *reboste*, a small room used for other complementary tasks: killing small animals, cleaning food, storage, etc. (Montero 2000c).
– The *alcoba* was composed of an anteroom, with a living area, an area for personal hygiene, and some storage elements as well as two small adjoining bedrooms. The bedrooms opened onto the anteroom and were separated from it by a single curtain. The bedrooms were very small, only containing a bed and a small table (Montero 2001).
– The *porche* (attic) was on the top floor, used to store grain and other agricultural products requiring ventilation, and transported to the *salador* through the *silos*. The roof is currently in ruin and requires intervention.

4 CONSTRUCTIVE ANALYSIS OF THE BUILDING

The results obtained while cataloging the individual constructive techniques and elements are examined below. The constructive elements studied are walls, ceilings, coatings, balconies, staircases and joinery. Research is extended to furniture and unique elements, as some are essential to the atmosphere of each space and are the same age as the building.

4.1 *Walls*

The constructive technique of the walls can not be identified upon initial examination (indirect observation) given that they are rendered on both sides. Therefore a more in-depth analysis is required to establish it. It is necessary to use a thermographic analysis of the facades for the purposes of verification (Fig. 4). The data obtained from the analysis and a comparison with local traditional architecture were conclusive in establishing the constructive technique of the walls: rammed earth supplemented with masonry, where the stones are placed in alternating rows.

It seems that the walls are built using the same technique throughout the building, but they could

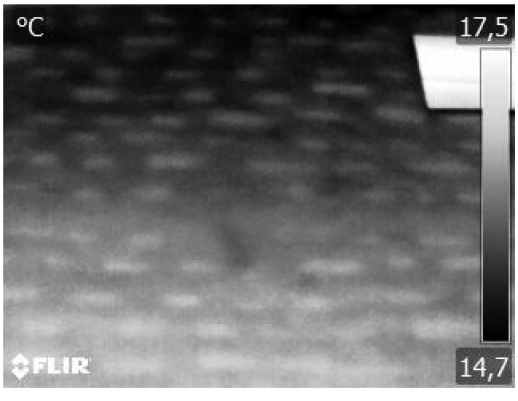


Figure 4. Thermal image of the wall. North-east façade (L. Balaguer).

be built with masonry on ground floor according to other vernacular buildings on the surroundings.

4.2 *Ceilings*

Three different types of ceilings are found in the entire house. All three are built using a wooden beam structure, but the cut of the wood, the features of the beam and the elements of beam spacing are different in each type.

Following the levels of the building, the types of ceilings are organized as follows:

- The first type of ceiling is found in the first level, above the *pasillico* and cellar. It is built with wooden logs most likely of local pine and gypsum formwork beamfills (Vegas & Mileto 2011), 85 cm apart. The logs are cut manually and irregularly and have visible toolmarks.
- The second type of ceiling is found in the bedrooms, kitchens and *alcoba*, on the second floor. The joists used here are also presumably made with local wood, cut square with a saw. Although the beam spacing used follows the same technique as the first, the gypsum has a different color and the joists are only 65 cm apart.
- The last type of ceiling is that of the roof. It is made of pinewood logs under a layer of reeds tied together and rendered together with gypsum mortar (Fig. 5). The exterior of the substructure is finished off using ceramic roof tile and probably lime mortar.

4.3 *Coatings*

Renderings have a great variety of designs and textures which enrich the construction, ranging from the first handpainted tiles to later standardized formats, reflecting the evolution of the ceramic industry of the area. The types of renderings found are described: paving, plastering and tiling.



Figure 5. Ceiling built with pine logs and reeds on top (L. Balaguer & S. Traver).

As with the ceilings, the pavings can be classified into three groups depending on location. There are different types according to the status and function of the room:

- Firstly, most of the floors are hydraulic cement tiles. These 21 × 21 cm tiles are found in the entrance, kitchen, and bedrooms. The pattern of each geometric floral motif is composed of four tiles. The patterns are different for each room, with some of the mosaics finished off with a cement tile border next to the walls. The border emphasizes the geometric pattern of the mosaic, giving the effect of a rug. In some rooms these tiles were replaced when damaged, forming random sets of mosaics.
- Secondly, the pavings of terracotta tiles are found in the cellar and on the cellar stairs. These pieces measure 31 × 31 cm.
- Thirdly, a type of paving characteristic in the constructive tradition of the area is a mix of clay, gypsum and straw that is spread on the surface to be paved. The mix sets to form a smooth homogeneous surface called *sindrea*. This type of pavement is found in the *alcoba*, *salador*, *pasillico* and porch.

Related to plastering, a single technique of plastering is identified using a single layer of gypsum with green natural pigments to plaster the walls of the rooms on the first floor of the house.

Furthermore, three types of tiling techniques are used in the building:

- Covering floor to ceiling in rooms like the kitchen. There is a great variety of different patterns of tiles, ranging from different models of elaborately decorated late nineteenth-century tiles, to handpainted ceramic tiles in typical blue tones. This variety of tiles is due to the fact that in these spaces the damp, major thermal variations, and constant use, made tiles drop off or break. These were then replaced with different tiles (Fig. 6 and Fig. 7), either leftovers from nearby construction sites or from demolition sites.
- The second way of tiling is to a height of 1.20 meters from floor level, finished off with a frieze at the top. This system was executed traditionally at ground level to prevent damp from appearing inside the house.
- The final layout for tiles is as edgings or decoration murals, finishing off elements in the kitchens and on cellar shelves. These are carefully finished off and are obviously handpainted.

4.4 *Staircases*

In general, the staircases are between two walls. All structures are made with tile vaults, while the steps



Figure 6. Kitchen, with a variety of tiles on the wall and hydraulic cement floor tiles (L. Balaguer & S. Traver).



Figure 7. Stairs leading to the cellar. Risers with different handpainted tiles and terracotta treads (L. Balaguer & S. Traver).

use ceramic floor tiles, except for the stairway from the kitchen to the first floor, which has stone steps. A flight of stairs goes down to the cellar and was dug out of the earth. This section is the most interesting due to its age and renderings (Fig. 7).

4.5 *Balconies*

The wrought iron balconies are horizontal structures anchored to the floor structure (Vegas, F. & Mileto C. 2015), and subsequently rendered with mortar and plastic paint. The molding consists of ceramic tiles which are also covered by the current rendering. The fissures of the lower rendering of the balcony are studied to identify the position of the structural iron elements, dating back to the original construction of the building (Fig. 8).



Figure 8. Fissures on the balcony with window and traditional Valencian shutters (L. Balaguer & S. Traver).

All the balconies have iron railings of the same pattern. These balconies are set into the facade, giving rise to metal corrosion inside the rammed earth walls which has caused cracks and damage.

4.6 *Joinery*

In terms of the analysis of constructive elements such as joinery, these are easier to date precisely than the techniques described above, as different studies and data relate the appearance of each type to a specific date in more recent times (Vegas & Mileto 2015).

The joinery studied is classified into interior doors, exterior doors, and windows. There is only one exterior door, but it is not the original. The original "Dutch door", which allowed the lower part to be kept closed while the upper part could be completely open, was very common in the area (Ruiz *et al.* 2001) and was replaced in the mid-twentieth century.

Although the interior doors are only preserved in some of the rooms, enough remain to carry out a comparative analysis with traditional door types. In this case the doors are Castilian-style paneled doors. Dating back to the eighteenth century, the inner and outer moldings of the door are characteristically made from the same piece of wood (Vegas & Mileto 2015).

Three different types of windows are identified. These are all original, from the second half of the eighteenth century, reinforced on one side in solid board following the typology of traditional Valencian doors of medieval origin (Vegas & Mileto

2015). The wooden shutters, for example the window of the *salador*, are simpler in some of the openings of the work rooms than in the openings of the main rooms. It is worth noting the *ventanuco*, a small window which provides some lighting and ventilation to the cellar.

4.7 *Furniture and other elements*

Casa de los Cinteros contains some some unique construction elements, together with a mention of the original furniture in the house. It is particularly worth noting unique construction elements such as niches above the doorway into the *alcobas* and kitchen; iron fittings on original interior doors; the *silos* used to transfer grain from the *porche* to the lower floors; the wrought ironwork; and the fireplace. All these are of considerable historic value given their age and state of conservation.

5 CONCLUSIONS

The work presented in this article is an initial analysis by the authors to research on architectural heritage, aiming to establish the foundations for future studies on the traditional architecture of different regions of the Comunidad Valenciana. This work is also the first step towards the establishing guidelines for its protection and conservation compatible with their constructive nature.

Instead of the limited data available at the start, it is possible to identify the traditional rooms linked to this architectural typology at *Casa de los Cinteros* such as the entrance, the stable, the kitchen, the bedrooms, the *salador* and the attic. Moreover, some additional rooms show the original owners' socio-economic status. The passing of time has transformed traditional ways of life in the region and this is reflected in the layout of the house although some original rooms are preserved.

The results of the cataloging of constructive system within the building indicate that there is a wide range of techniques, which adapt to the available natural and economical resources of the region while point out the variety and quality of traditional architecture. In the same way as the rooms, the traditional constructive techniques state the features of original solutions which can be part of nearby buildings in the urban area.

Although the Town Council is managing the building and setting it up as a museum, it is disheartening to see the state of conservation of some of the constructive elements of the building, affected by damp, especially on the ground floor, where some of the finishes are dropping off and present varying degrees of fissures and cracks. At present this damage does not pose a threat to the integrity of the building, but the managing organization is in charge of occasional repairs depending on grants received from larger organizations. This lack of immediate funding is a severe disadvantage given that degradation phenomena continue to appear as time passes, causing new damage which will inevitably be more difficult and costly to repair.

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S. Jerónimo de Cotalba. Strategies for the preservation of the monastic complex

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ABSTRACT: The Special Plan for the Protection of the Monastery of San Jerónimo de Cotalba (Alfahuir) was concluded in 2016. This document is the result of several years of research and documentation about this monastic complex to better understand its current situation and consequently design a proper preservation strategy. These preliminary studies have meant the revision of the main documental basis contained in different archives as well as an intensive in situ inspection with complementary works of stratigraphy, thermography and archaeological surveys. This updated corpus of data has meant a significant contribution to approach the preservation of the monastery. The present text documents and historically contextualizes the several architectural alterations suffered by the monastery in order to understand its evolution from the original rammed earth structure on. The four main constructive stages that have been identified are exposed as well as the main causes detected for its decay and the techniques and materials proposed for the preservation of this significant Hiberonymite construction.

1 INTRODUCTION

This present work emerges as a result of the investigation which took place as a consequence of the creation of the Special Plan for the Protection of the San Jerónimo de Cotalba monastic complex, edited between 2010 and 2016.

This Monastery is located in Alfauir (Valencia, Spain) and it is considered one of the most magnificient monasteries of the Hieronymite order.

Firstly, the monastery is historically contextualised, as a frame in which to analyse the architectural evolution of the building and so encompass its different construction phases and the consequences derived from these alterations. Subsequently, the text focuses on the foundation phase, built with rammed earth. Then, the decay suffered by these walls is evaluated and the strategy for its conservation and recognition is presented.



Figure 1. San Jerónimo de Cotalba. Conselleria de Cultura, Eduació i Esport. Àrea de Patrimoni Cultural.

2 BRIEF HISTORICAL OUTLINE

In 1374, a group of hermits settled in the Xàbia plain founded a Hieronymite monastery authorised by the Pope Gregory XI (1329–1378) and supported by Alfons IV, known as El Vell (1332–1412) (Sigüenza, 1600; Sucias, 1907).

In 1387, this monastery was assaulted by Berber pirates and a large part of the monks were kidnapped. Alfonso IV paid for the ransom. In 1388, due to the fear of the monks to return to their abode, the king acquired the village of Cotalba from the Muslims and donated this land to the Hieronymite community of Xàbia to buid a new monastery.

Pere March (1336–1413), father of the famous Valencian poet Ausiàs March (1400–1459), was sent to supervise the works (Castells 1757). The official foundation date, 1388, can still be read in the commemoration inscription in the tower (Delicado & Ballester 2000: 77).

During the 16th century, the the Hieronymite complex counted on the protection of the dukes of Gandía, the Borjas. The Duchess María Enríquez (1474–1539) is considered the main benefactor of the monastery.

In 1586, King Felipe II (1527–1598) visited the location for various days accompanied by his heir and by his daughter Isabel Clara Eugenia (1566–1633) (Osset Merle 1927). A new royal visit will be carried out on occasion of the marriage of Felipe III (1578–1621) with Queen Margarita (1578–1621). These visits are evidences of the protection that the monarchs, especially the Habsburg dynasty, offered to the Hieronymite order (Campos & Fernández 2001).

From the 17th, century and throughout 18th, century, a relaxation of the customs among the members of the community could be observed. This moral and spiritual crisis lead to the reformation of the government of the monastery in 1743 (Alonso López 1988).

After the French occupation during the War of Independence (1808–1814), the monastery was affected by the confiscation of the Liberal Triennium (1820–23) and that of Mendizábal in 1835, which will lead to its definitive closure and the dispersal of its heritage (Perles Martí 1989). After the expropriation, the Trenor family, who still owns it, bought the property for 62,100 reales (local currency at the time).

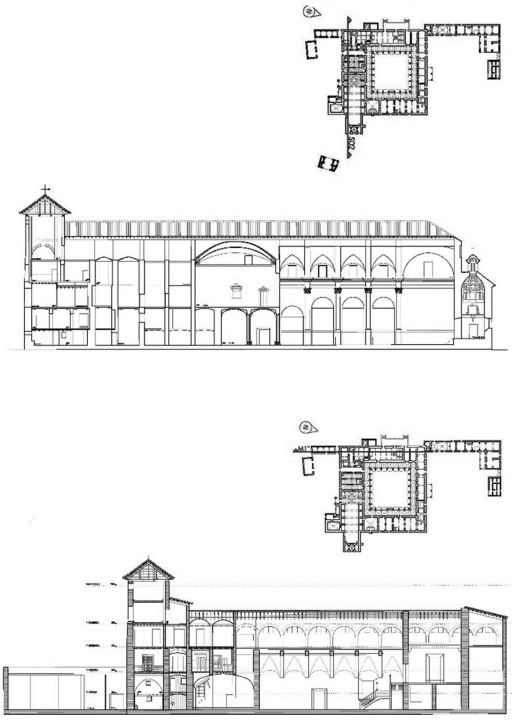


Figure 2. Sections of the current state of the monastery (Barrera Puigdollers 2015).

The Monastery of San Jerónimo de Cotalba was listed within the category of monument through the 93/1994 decree of the 24th May, by the government of Valencia (Mut Oltra & Palmer Terrades 1999).

3 THE MONASTERY ARCHITECTURAL EVOLUTION

The monastery is geometrically disposed in a 60 × 60 m square. Its configuration follows the same outline, metric and proportions that the ones built by the same Hieronymite Order in 1390 in Vall d'Hebrón (Barcelona) and in 1401 in La Murta (Alzira, Valencia) (López Yarto Elizalde et al. 1995). Synthetically, it could be described as a complex composed by four main architectural volumes with homogenous characteristics among which, the donjon and the two-storey cloister should be highlighted.

Since 2004, preliminary studies have been carried out to design a proper preservation strategy for the complex. These lead to the edition of the Special Plan for the Protection of the San Jerónimo de Cotalba Monastery, the document that sets the guidelines for its conservation, which was presented in 2016. In 2015, urgent works began to avoid any danger all along the public visit tour to the building. These actions are the precedent of the *Urgent Action Plan* to avoid the imminent structural decay, which is planned to be developed between 2017 and 2019.

The analysis that had been carried out revealed that the main causes that had contributed to severely damage the building are both the geotechnical particularities of the terrain and, especially, the various extensions of the building throughout history. As a matter of fact, a chronological analysis of the evolution of the building became essential to understand the current behaviour of the building.

On one hand, a complete identification and revision of the references related to the history of Cotalba and its Monastery was carried out. Direct and indirect sources of information as capitulary records and monastic manuscripts were reviewed in the following archives: Reino de Valencia, Cathedral of Valencia, Histórico Nacional and Histórico de la Nobleza (Osuna). On the other hand, a complete architectural and archaeological analysis was elaborated. The archaeological excavation carried out during the Archaeological Rescue Program enabled the study of three crypts: Crypt of the Chapter, Crypt of the March family and Crypt underneath the *trasagrario*. Its study has confirmed the formulated hypothesis regarding the building phases from its original founding structure.

The compilation and comparison of both archival and physically data allowed for the reconstruction of the chronological sequence of interventions and to represent it using infographic tools.

The original building was two floors high plus an attic used as storage space. Its structure was based on gothic transverse arches. Walls were crenelated. Roofs had a starting height of 10.70 m in the interior face of the lime-stabilized rammed earthen external façade, leaving a surveillance hall in its width beyond the battlement or rampart. Those original transverse arches left a free interior light of 9.10 m, and a maximum exterior light of 16.60 m at the bottom floor and 10.5 m on the superior floor as church space. This generated a practicable exterior terrace with discharging arches or exterior flying buttresses.

The first elevation consisted of raising the height of the ridge to around 80 cm, enlarging the space. This elevation is carried out with rectangular or octagonal stones placed on the transverse arch, building some smaller arches on the battlement, forming an upper lintel and newly tracing the roof. This allowed them to have three floors, the top one being in the shape of an attic. The height of the ledge increased from 11.3 m to 11.5 m. This alteration was used to create a two-storey lateral gallery. This facilitated the access to the tower. The interior configuration of the church remained gothic but the presbytery, that was extended and built higher (up to 80 cm less than its current height).

The second elevation was built in the 16th century (between 1546 and 1578, according to the capitulary records) in order to obtain more habitable space. The walls were elevated 1.5 m over the former level, so the ledge was raised up to 12.8 m. This corresponds, approximately, to the current level of the attic floor. This elevation allowed to build a third floor and an additional attic which could have been used as a storage or curing room or even as a dorm for young apprentices. This intervention in the South and Eastern blocks was not carried out symmetrically in every wing of the monastery at the time.

During the 17th century several earthquakes affected the Monastery. Not only punctual actions of conservation were carried out but even architectural modifications were maid to balance out the effects on its structure. In this sense, the addition of the atrium over the Church's Access was built to compensate the differential settlement; the *trasagrario* was added to compensate the breaking of the eastern end headwall or the addition of the original Virgin of Health Chapel in 1689, between the Main Chapel of 1578 and the Bell Tower of 1415, executed until 1753.

The third transformation came about in the 18th century (between 1724 and 1777, according to the capitulary records) and it is considered the most compromising for the stability and security of the building. Its final objective entailed the regularization of the roofs of the whole monastery. This pursued to shape it on a rural palace style, according to the taste of its holders, the house of Osuna. The Monastery at La Murta also suffered similar interventions between 1761 and 1762 which eventually lead to its ruin (Arciniega 1999).

In 1762, the transformation of the church into Neoclassic style initiated. This meant the elevation of the presbitery walls around 80 cm high over the former elevation during the Reinassance period.

A fourth transformation has been detected. This one did not imply another elevation, but pretended to correct and diminish the visual impact of the former elevations, especially from the Patio de los Naranjos point of view. Among the actions carried out, it should be highlighted the addition of a compositive and non-structural façade over of the original one of the Patio de los Naranjos, in 1795. At that time, also the walkable decks over the cloisters were covered with a sloping roof to create new galleries. However, this started to generate additional

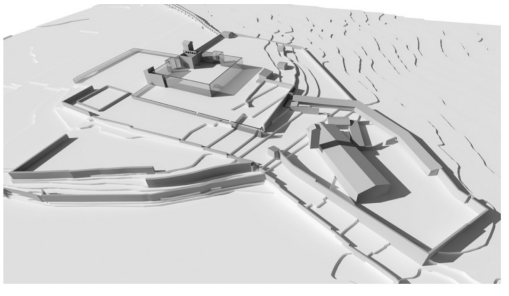


Figure 3. Virtual approximation of the state of the monastery in 13th century. Founding state (Barrera Puigdollers 2015).

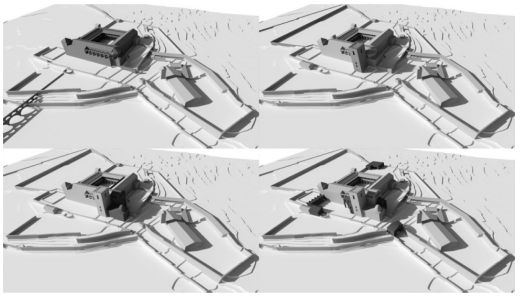


Figure 4. Virtual approximation of the evolution of the monastery from 14th to 17th centuries (Barrera Puigdollers, 2015).

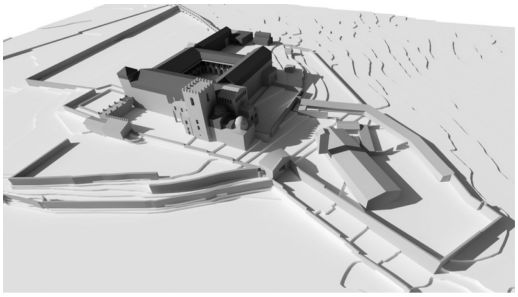


Figure 5. Virtual approximation of the evolution of the monastery in the 18th century. Barrera Puigdollers, 2015.



Figure 6. Founding wall (Barrera Puigdollers, 2015).

pressure on the ledge of the terrace and started to transmit horizontal forces towards the patio and the aforementioned additional façade. The result, far from being helpful, has become a focus for further deterioration and additional decay.

4 THE ORIGINAL RAMMED EARTH STRUCTURE

The present study focuses its attention on the first constructive phase of the monastery complex, which was built with rammed earth. As it has been introduced, the settlement of Cotalba, also known as Tossalet de Cotalba, already existed before the foundation of the monastery in 1388.

These buildings were partially used and integrated in the construction of the monastery. In fact, several elements can still be identified, as the baths under the Patio de los Naranjos as well as traces of an aqueduct.

4.1 *Identified typology of rammed earth walls*

The original structure of the monastery was basically built with lime-stabilized brick-faced rammed earth walls, also called locally Valencian rammed earth walls (López Martínez, 1999).

According to the archaeological studies carried out, rammed earth was exclusively used until 1580. Then, and up to 1650, the monastery extensions used brick walls as formworks for rammed earth walls. Between 1650 and 1730, masonry walls between embedded brick buttresses were used. Finally, the last additions used common masonry walls.

4.2 *Analysis of the current state of the foundational rammed earth walls*

In order to understand the structural system of the original structure of the monastery, several analyses were carried out. Firstly, a complete graphic survey was undertaken so as to document every trace of it. Secondly, a stratigraphic analysis was made to identify the building temporary sequence and to shed light to understand the decay process. A visual inspection, supported with manual means, was developed to document every wall. Damage detected was classified according to the following criteria:

- Superficial scarification caused by use.
- Superficial scarifications caused by capillary moisture.
- Scarifications caused by impacts, breaks, or human actions.
- Microcracking caused by use and excessive weight of the building extensions.
- Cracking without displacement.
- Cracking with displacement, but without compression.
- Displaced breaks

Subsequently, a complete geological analysis of the terrain was carried out using rotary drilling, test pits, geological and geotechnical cartography.

Finally, a 3D model was created for computer structural testing. The software used is called Architrave and it has been developed at the Universitat Politècnica de València by the GRyCAP and CiD research groups.

As a conclusion of these analyses, it can be stated that the current condition of the intrinsic materiality of the original monastery structure can be considered as satisfactory. However, several external factors are causing important damage to these walls and leading to a general loose state of the building.

Among these exogenous conditions, the influence of the subsequent extensions of the building, which have almost duplicated the original height of the monastery, should be highlighted. These additions have neither continuity nor connection with the original structure. Moreover, the aforementioned roof regularization in 1795 implied not only

the modification of the walls height and the change of roof typologies but also the embedding of beams without any structural backup. On top, the material hetereogentiy between the different building stages have lead towards a lack of continuity that contributes to a differential reaction of its parts.

Furthermore, a generalised constructive problem has been also detected. Most of the roof beams are disposed towards the walls, generating important horizontal forces against the cornices. This contributes significantly to the inclination of the walls towards the exterior and the consequent opening of the upper perimeter.

It should be added that the transformation of the building also included the elimination of structural elements as arches and even the creation of openings in non-appropriated places where they have implied mechanical problems.

Regarding the geological studies, it can be stated that more than 25% of the surface where the monastery is located (southeastern corner) corresponds to a geological stratum of filling terrain 4 m deep. Underneath the rest of the building and also below this layer, marl terrain has been identified. This kind of geological layer presents important variations due to hygrometric conditions. When humid, it expands and generates an ascending pressure of 0.9 kg/cm^2. This recurrent situation takes place at least twice a year, linked to the change of season and the associated rain regimen. This means at least two ascensions a year of 1.3 mm.

5 PROPOSAL OF CONSERVATION

As it has been exposed, most of the damages presented in the original rammed earth structure are due to exogenous factors that have derived into a severe structural destabilization. As a matter of fact, the interventions planned are devoted to recover its stability. Unfortunately, there is no overall future plan for the use of the building and the actions have been designed on an emergency basis just to pursue the consolidation of the monastery. The objective of this first phase of the Special Protection Plan, denominated Urgent Actions Plan, is to stop the rapid evolution of the fissures, cracks and ruptures that have been detected all over the building.

The calculation models and the subsequent strategy of intervention have been based on the hypothetical division of the monastic complex into nine squares. This responds to its inner geometric and compositional order deduced by the "stereometric mural" found in 2016 and drawn over an original rammed earth wall located in the west gallery of the cloister.

The philosophy of the intervention is to put in value the mechanic capacity of the original structure of the monastery. The normal compression

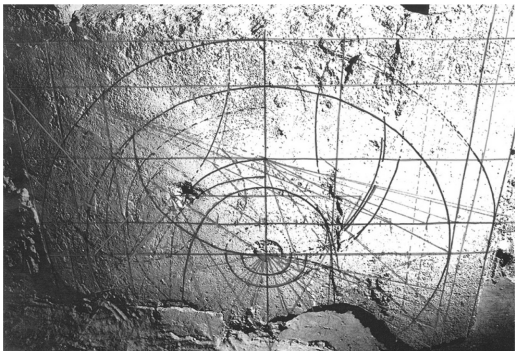


Figure 7. Stereometric mural (Barrera Puigdollers, 2016).

capacity of these rammed earth walls –1.20 m to 1.40 m wide and up to 10.20 m high—has been estimated of 490 T/m^2 (UNE41410–2008). This means that they could be capable enough to bear their own volume, if loads were exclusively vertical.

To achieve the integral structural stability that was severely compromised, a combined action of different measures has been designed to be implemented in three sub-stages that compose this first phase of Urgent Actions. Considering the loose state of the building, every action has a direct effect in the overall readjustment. The time lapse among the three stages lets the building to reaccomdate in a non-disruptive way after every intervention.

During the first phase, the building has been secured to avoid progressive leaning. Foundation underpinning and a general fastening of the building have been carried out to avoid the effect of horizontal forces. Elements affected by differential subsidence and important deformations have been structurally stitched together. This avoids the use of external scaffolding that would mean an important imputable cost for such a long process.

The second stage has pursued the general reinforcement of the building. Following the stereometric model aforementioned, the building has been divided into nine sections. Specific actions have been developed in every section to generate a resistant core that contributes to its stability.

The map of possible localisations for these nine operations has been calculated to permit the fastening of the whole complex without alterating the understanding of the architecture of the monastery.

Once the internal tensions have been accommodated, the third stage has pursued the general reinforcement of the building. The main reinforcement measures have become solidary with the secondary ones, forcing the building to work as a whole.

Simultaneously, rammed earth wall fissures and cracks have been repaired using glass fibre and

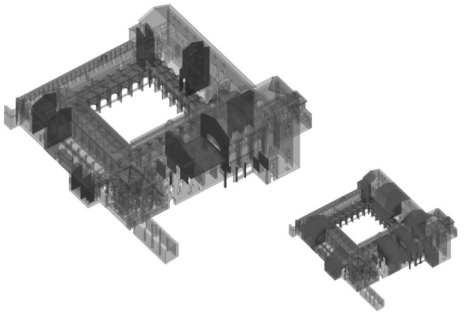


Figure 8. Identification of the most relevant operations of stabilisation (Barrera Puigdollers, 2015).

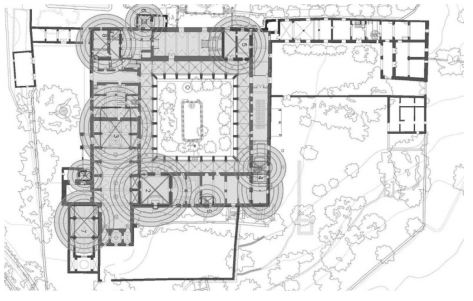


Figure 9. Implantation strategy of resistant cores (Barrera Puigdollers, 2015).

hydraulic lime injection. Scarifications have been cleant with a brush or vapour blowing. In order to eliminate the excess of humidity, an external perimeter drain trench has been disposed to favour natural evaporation. Wherever necessary, Knapen higroconventors or electroosmosis have been used. Unfortunately, these are isolated consolidation actions to be executed where urgent structural reinforcements have been carried out. Additional actions to globally consolidate and preserve the rammed earth walls will take place in future stages, but it is desired that they remain in their original state, showing the vicissitudes of history.

6 CONCLUSIONS

The elaboration of the Special Plan for the Protection of San Jerónimo de Cotalba has meant a unique chance to analyse, for the first time, the architecture of this monastic complex. The continuous feedback between the documental research and the information obtained in situ has significantly contributed to the existent corpus of data. This information has unravelled relevant questions that shed some light to its chronological constructive evolution and, consequently, has allowed a better understanding of its current situation and the causes for its decay. Only by understanding the history of the building, adequate interventions for its preservation can be designed.

Thanks to this data, the strategy to recover the compromised structural instability of the monastery complex is based on putting in value the supporting capacity of the original rammed earth structure of the complex.

The Special Plan for the Protection has meant a unique opportunity to approach the reality of this magnificent Hyeronimite construction and has involved the first steps for the preservation of the San Jerónimo de Cotalba Monastic complex.

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Life cycle assessment for the earthen heritage center (Pabillonis, Sardinia)

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ABSTRACT: Raw materials and natural resources saving and recycling are a pillar of sustainability in building and construction. In particular, adobe and raw earth structures built using natural local raw materials which come straight from the same area of the construction site have a lower energy content and a better environmental performance in comparison with bricks or concrete. In this issue a case study of a restoration of an adobe historical building, the Earthen Heritage Center in Pabillonis, Sardinia, was carried out using a life cycle assessment approach. The study analyses and compares a first bearing wall, built with a traditional adobe raw material, with a common brick wall. Furthermore, the environmental impacts related with the utilization of two different mortars (raw earth and cement) have been included. The LCA analysis demonstrates the environmental benefits related with the vernacular adobe technique applied to the restoration of an historical building.

1 INTRODUCTION

The interest in raw earth building technology is increasing mainly due to the low environmental impact of the material and the energy performances of the buildings. Even if the earthen brick (adobe) buildings belong to a traditional culture, this material can be employed both in restoration and in new architectural project.

Nowadays designers and producers have to face the decrease of world stocks of natural resources, such as fossil fuels, and the environmental damage caused by the use of artificial substances. We must use resources more efficiently, polluting as little as possible. Sustainability has to involve all the life-cycle phases of construction, even if there are "natural" materials used as construction materials (Bonoli et al., 2014).

As well known, LCA is an objective process that assesses the environmental impact related to a process or to anthropic activities. LCA could be an excellent tool for analysing the environmental impact of building materials (Simion, I. M. et al. 2013). It measures and compares the environmental impacts of anthropic activities, giving a comparison of the environmental impacts of several scenarios (Bonoli, A., 2014) or in the case of different kind of building materials, as also in recycled inert waste utilization (Cuenca-Moyano et al. 2017).

2 THE CONTEXT

Pabillonis is a little village of Sardinia of about three thousand inhabitants, located halfway between the towns of Oristano and Cagliari, on the Campidano plain in Sardinia, at 42 m above sea level. Thanks to the characteristics of the territory and the economy, the earthen buildings are part of the tradition of the country. Many houses are still existing and inhabited, but many more are in need of major renovations. All earthen buildings present in Pabillonis are made using an adobe construction technique, which in Sardinia is called Ladiri (Vado 2003).

In 2006 the City of Pabillonis joined the "Cities of Raw Earth National Association" during The same year, the City of Pabillonis, together with six other entities, participated in a POR (Regional Operational Plan) 2000–2006 - called Civis—with the pilot project 'Routes of Earth'. The idea is to enhance the potential quality of life inherent in the universe of raw earth tecniques, with its content of healthiness, naturalness, link with the local values and sustain-



Figure 1. Planimetric layout of the building.

ability. And it is in the context of this notice, that the City of Pabillonis presented the plan of restoration and reorganization of the House of Virginia Matta, an earthen building, specifically bought for this purpose (Vado 2013). The building, owned by the Matta family for decades, seems to have been initially made to be used as a cowshed, adjoining the factor dorm. The house, situated opposite the main church, was later adapted to main house (Fig. 1: Planimetric layout of the building).

3 THE EARTHEN HERITAGE CENTER PROJECT

At the time of purchase by the municipality, the House of Virginia Matta was in poor conditions, subject to vandalism and structurally unsafe. The initial conditions of the structure are visible in Figure 2, which highlight many problems such as the fracture of some parts of masonry, the detachment of many parts of plaster due to the inappropriate use of industrial materials inside the little earthen walls, the state of deterioration of the roofing and flooring package. The necessary interventions were numerous and significant, also because of the will of the designers to safeguard and enhance as much as possible the existing building. It is Also for this reason that most of the processes have been performed manually or strictly using small mechanical instruments.

3.1 *The bricks*

The existing walls, when stable and in good condition, have been preserved, and only remedial measures have been taken. In addition, 241, 71 cubic meters of new brickwork of clay have been manufactured, purchased from a local factory, which produces bricks obtained by the earth following the construction of its production plant. This earth was analyzed by a working group at the University



Figure 2. Initial status of the building.

Table 1. Materials and quantity for each brick.

Material	Quantity
Earth	4.135 kg
Sand	8.654 kg
Water	0.385 l
Straw	0.169 kg



Figure 3. Adobe brick of the Casa Virginia Matta project.

of Cagliari, who then proposed to the brick plant a recipe of the mixture to form the bricks (Table 1). Each brick has a dimension of $10 \times 20 \times 40$ cm and a weight of 12.9 kg (Fig. 3).

3.2 *The plaster*

In order to assure breathability, adobe bricks have to be covered with a non-cement mortar (Platts 1997). In particular, a straw and raw earth plaster assures good thermal and technical performances, such as lower environmental impacts than a cement plaster (Rizzo et al. 2015).

Table 2. Materials and quantity for 3 m^3 of plaster.

Material	Quantity
Raw earth	1.25 m^3
Straw	1.1 m^3
Sand	0.55 m^3
Hydraulic lime	0.1 m^3

A straw and raw earth plaster of 3 cm has been applied on most of the interior and outside walls (Table 2). The raw earth of the plaster comes from the excavation works of the site.

4 THE LCA OF THE EARTHEN HERITAGE CENTER

4.1 *LCA of an adobe brick*

In order to assess the sustainability of the retrofit of the "Casa Virginia Matta" and identify the environmental hot spots of the system, a Life Cycle Assessment compliant with the ISO norms on LCA (ISO 14040, ISO 14044) has been performed. The assessment was carried out using a "from cradle to grave" approach considering the raw earth brick (adobe) with a not defined life span as functional unit. The life cycle has been divided in 3 different phases:

- the production of the brick (including the raw materials extraction, their transport to the production plant, the necessary instruments, the emissions due to this phase)
- the use phase (including the transport of the bricks to the construction site, the construction phase of the adobe wall and the land occupation due to the brick during his whole life)
- the end of life (EOL)

Several interviews with designers and responsibles of the brick factory have allowed the data collection needed to perform the LCA. When primary data have not been available, literature data and the Ecoinvent database have been used.

In the construction of the production phase, the extraction and production of all the raw material used have been accounted, as primary data for clay, sand and straw. Moreover all the transports needed to move the raw material to the construction site, the used instruments and the energy consumed have been inventoried in the use phase.

A selective deconstruction has been presumed for the end of life of the earthen wall analyzed and a recovery process has been supposed. In fact, the whole adobe brick will be used as primary material for the recovery of a clay quarry. The fuel and the energy consumed during the deconstruction process have been also included in the end of life phase.

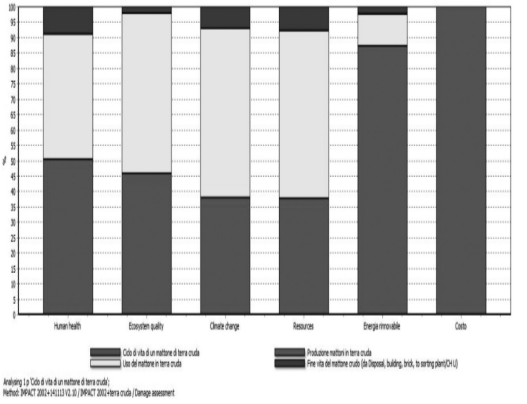


Figure 4. Results for the Damage Assessment.

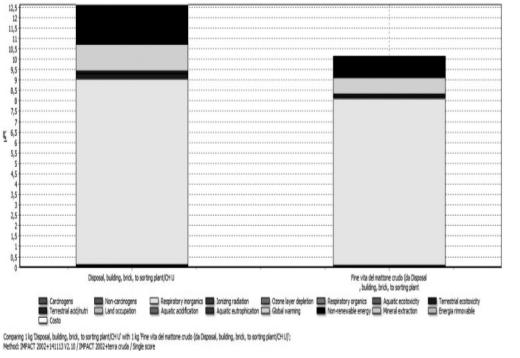


Figure 5. Comparison between the EOL of a brick and an Adobe.

In Figure 4 the results for the Damage Assessment using the Impact 2002+ evaluation method.

In particular, in the Human Health and in the Renewable Energy the production phase (in green) produces the highest impacts. This is due to the emission of particulates during the production phase and the energy consumption. Referring to the Human Health category, this hot spot of the system can be reduced using an appropriate individual security device during the bricks production, and improving the environmental safety of the manufactory plant.

The use phase contribution (in yellow) is higher for the Ecosystem Quality, the Climate Change, and the Resources. This is mainly due to the energy consumption during the construction.

The considered EOL shows lower impacts than an "usual" process of Construction and Demolition Waste (C&DW) recycling "conventional" bricks as construction material (Fig. 5). In fact, an

earthen brick can be recycled for the recovery of a clay quarry as it is, closing the cycle of the raw material. This assures a virtuous cycle according to a circular economy approach.

4.2 *Comparison of an adobe wall and a brick one with the same load-bearing capacity*

In order to deeply investigate the environmental benefits of an adobe wall, a comparison between an earthen wall and a "conventional" brick wall, including the mortar, have been assessed.

The system boundaries can be found from the collection of raw materials to the end of life of the components.

The functional unit is 1 m^2 of wall.

The life cycle of the walls consists of:

- the production of bricks and mortar
- the use of the walls (included the thermal energy needed to maintain during the winter an internal temperature of 20°C and a temperature of 26°C in the summer)
- the end of life of the earthen wall (same as that used for the adobe) and the brick wall (C&DW recycling).

A wall in adobe bricks, which can withstand a static load of an interfloor and a cover, was taken as reference. To obtain this result, (1–2 N/mm^2) (Achenza, Sanna, 2006), a wall with a minimum thickness of 40 cm is required, because of the resistance of adobe to compression. A wall made of raw earth bricks with these features can not be considered in accordance to the law in areas subject to seismic action since, in these, it is necessary that the wall has a minimum compressive strength of 5 MPA.

Furthermore, two different mortar have been included into the LCA comparison (Table 3).

The Figure 6 shows the results of the Single Score for the comparison between the adobe wall and the "conventional" brick wall.

The damage of the adobe wall is 37.66% of that produced by the brick wall. The higher impact of the conventional brick is due to long distance transport and firing of the bricks.

Table 3. Mortars.

Adobe wall mortar materials	Bricks wall mortar materials
Clay	Cement
Sand	Sand
Straw	Water
Water	

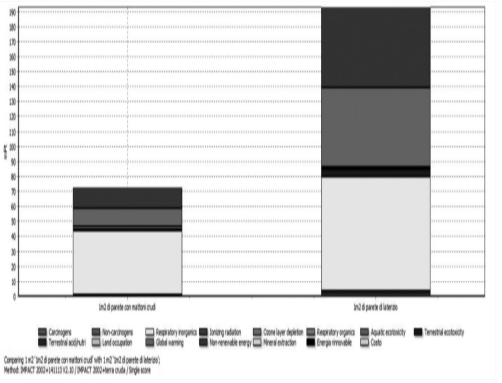


Figure 6. Comparison between the EOL of a brick and an Adobe.

5 CONCLUSION

The LCA highlights significant environmental benefits in using an adobe wall instead of a fired brick one. The importance of the results is linked to the innovative proposed study: it compares two different walls, in terms of production process, but with the same load-bearing capacity. That means that the function of the wall is the same, both in the case of an adobe, both in the fired brick one.

We can state that producing building materials on the same site of the construction assures sustainability. The environmental benefit is due to the absence of fossil fuels linked to the road transport, and, consequently, this signifies low environmental pollution and low impacts on climate change.

At the same time, raw earth does not need an additional amount of energy for cooking, avoiding impacts linked to bricks firing, that are responsible of climate change, as demonstrated by the LCA.

Furthermore, the End Of Life of an adobe wall assure sustainability and circular approach, in terms of re-using the hearth as raw material for a restoration of a clay quarry.

In this study it has been demonstrated that raw earth represents a good solution to enhance sustainability in building and construction in terms of energy saving, local supply promotion and natural resources consumption and harmful impacts reduction.

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The Tiburtino II district in Rome (Italy). Proposals for preserving the modern architecture

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ABSTRACT: This research focuses on the IACP district of Tiburtino II (1927) in Rome, a type of architecture recognizable by the forms, the volumes and especially by the attention to construction's details and to the architectonical language. Nowadays, a century after their creation, these buildings are in decay and their materials have become obsolescent. They have been interested by significant and incongruous transformations of their original characters. The aim of this work is to research a method of operation on these particular type of buildings directed to the regulation of compatible transformations rather than to the restoration of the original characteristics. The challenge is to inflect the principles from traditional and critically-meant conservation on modern materials and on particular needs of these architectures which are in a constant state of domestic use, adopting a forward-looking vision for their preservation and transmission to the future.

1 INTRODUCTION

Nowadays, conservation of "minor architecture" is a field of study and application increasingly debated and investigated. "Minor architecture" connotes a set of buildings recognized as "setting" of monuments ("major architecture"), and has the ability to manifest the character of a city identity. This field of study is particularly linked to the rediscovery of Italian social housing of the first three decades of the '900.

In the second half of 20th century Roberto Pane, one of the greatest theoreticians of critical restoration's principles, expressed his support in favor of the minor architecture's conservation introducing the concept of "architectural literature". It is based on the distinction between poetry and literature theorized by the Italian philosopher Benedetto Croce. Ever since then minor and monumental architecture have both been considered as mutually necessary parts for the constitution of urban structure.

This research arises from the awareness of the importance of these architectural expressions especially in Rome, where studies on other best-known social neighborhoods (such as Garbatella) begin to spread. After nearly 90 years from their creation these buildings, just like every other monument literally intended, begin to experience the signs of the passing of time, being in poor conditions as well as material and typological obsolescence. Because of their being "living monuments" they are also continuously subjected to spontaneous adjustments by users, which risk to affect their original forms.

The stimulus for this research comes from the need to study a subject not well investigated but highly typifying Italian cities: modern social housing. It generates the need to develop a theory to an approach of intervention, respecting the principles from traditional and critically-meant conservation.

2 RESEARCH METHODOLOGY

2.1 *The objective of the research*

The purpose of the study was to verify the real and technical applicability of the principles from traditional and critically-meant conservation on a case study representing the popular social housing. In fact, the Roman neighborhood of Tiburtino II (Fig. 1), also called "Portonaccio" district, is identified as semi-intensive intervention by IACP (the



Figure 1. Overview of Tiburtino II.

Italian acronym stands for Autonomous Institute for Social Housing), within the realization of popular building program developed throughout the course of 20th century.

Completed in 1927, it shows highly sought elements such as ornamentation, decoration, the variety of façades and different organization of public green spaces. All these characteristics allowed the study of this never investigated district though historical analysis and comparison with other IACP districts.

2.2 *Research phases*

After an in-depth research and survey, the project was graded on several scales of intervention. Starting from the traditional structural integrity analysis and from a classification of elements and building types, the research focused on finding solutions linked to the function of these buildings as places for daily life and aggregation. The complexity of the final project was developed in three main areas: the study of façades' colors and planning for a comprehensive review of them, the reorganization of the common green areas and outdoor lighting functional redesign.

3 CASE STUDY

3.1 *Historical background*

The Tiburtino II was almost entirely designed by Giorgio Guidi in 1927 and, partly, by Innocenzo Sabbatini. It extends between Via Tiburtina and Piazzale delle Province and it is made up by the combination of 6 lots articulated on different altimetry. The district was built outside the city planning in force (Nathan and Santjust' Urban Plan of 1909) in an area intended for "villini" (buildings of 4 or 5 floors surrounded by gardens) and subsequently, with the Plan of 1931, converted into "palazzine" (buildings of 5 floors with attic). Though born out of the urban planning project, the district observes the criteria of the unified city maintaining a definite shape.

As a social housing product it reflects the unique character of the IACP, due to three factors: the urban role of the interventions, the use of a pre-rationalist language and the ideology of elevation-integration of the poor population. In fact, until the '30s, the institute's policy was to integrate the proletariat and workers residence within the city.

The result is an adaptation of the social housing to private building types, got through the first experimental use of modern materials and technologies.

The IACP defined Tiburtino II as a semi-intensive intervention, with pre-existing building types already tested in the Garbatella neighborhood onwards. The lots have a united and compact appearance, with buildings themselves that delimit the shape of the lot

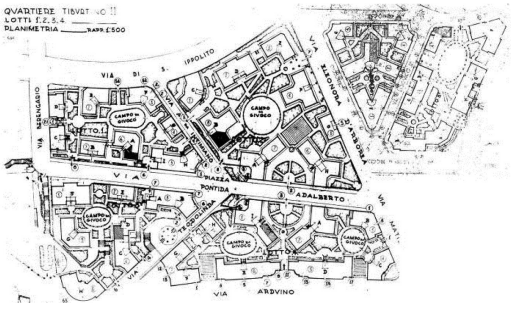


Figure 2. Historical project of Tiburtino II from ATER Archive (Edited by the authors).

solving irregular corners through volumes' adjustments or through juxtaposed concavities and convexities; internal areas are semi-public with gardens and playgrounds. The apartments of the Tiburtino II are divided into a maximum of two or three rooms, some apartments are actually made up of a room and a service. Although the accommodations are kept on "minimum" standards, ornamentation, decoration, facades' variety, buildings' manufacture and the organization of common green spaces are all highly refined items.

Among the 6 total lots, the lot n° 4 was chosen to deepen the study (Fig. 2), because it has the simultaneous presence of the most used types of buildings in it: the "casa a ballatoio" (a building with accessing galleries), the "y shaped" building and the front building.

3.2 *Metric and material survey*

The survey, supported by an in-depth historical research, has been essential to achieve an objective understanding of the lot. Different survey methods were used, both direct and indirect, each one was adopted according to the benefits that it would have brought on the fieldwork. Overall volumes were obtained by a celerimetric survey (Fig. 3); 13 total stations have been necessary for covering the entire perimeter of the lot, giving some information on the internal volumes and on roofs' shapes too. The survey, both internal and external, was then supplemented with direct measurements also for the communal garden. The graphic representation of the buildings was made starting from the two-dimensional restitution of urban fronts, deepening with the information from the direct survey and photo-rectifications. More detailed representations were made for the three building types chosen; thanks to the historic plans found in archives, because of the impossibility to get access into the apartments, it was possible to get an indication of the internal distribution and especially of all visible

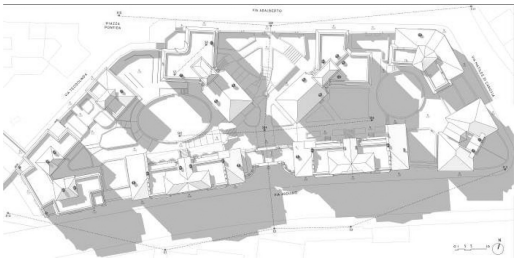


Figure 3. Celerimetric survey of the IV lot (Edited by the authors).

changes occurred over time (for ex. new windows and internal walls, elevators).

In the drawings found at the ATER archive (ATER is the current name of IACP) does not appear any indication about constructive details so any information about the textural and structural characteristics of the neighborhood was obtained by comparing what found in historic handbooks with direct observations on the site.

We know that the complex of Tiburtino II was built in a period of transition in which traditional techniques and modern materials such as iron, cast iron or reinforced concrete gave rise to the so-called mixed structure.

The analyzed buildings are constituted by bearing walls in tuff and bricks and from reinforced concrete pillars; observations on the floors workmanship were obtained by analyzing all the cantilevers, especially those who are in conditions of material decay. It was possible to identify two common techniques: double T shaped iron beams with brick vaults or with hollow clay tiles.

Most of the original fixtures have been replaced by chrome fixtures in anticorodal and pvc. The only original fixtures appear to be those ones made up by iron in the stairwells, characterized by a simple profiled metal frame with single glass. The few original wooden framings present on facades have, in addition, a high degree of woody essence rot.

Other original elements are iron grates outside some windows of via Teodolinda and via Arduino' façades made of rods with rectangular draws; while the grates on the windows of the "edificio a ballatoio" (building with galleries) in the inner court are modern.

In the buildings analyzed in detail, the double flight of stairs is made of concrete and brick and has undergone a change following inclusion of the elevator shaft.

3.3 *Analysis of decay*

It was conducted an observation of the decay affecting the prospects of the three buildings taken into sample; these phenomena mainly affect the plaster, the wooden window frames and iron elements. In addition to the strict sense of decay events, it was paid special attention in highlighting all the man-made alterations that mutated the image of the buildings as incongruous additions, concrete additions and, above all, an inconsistent and disfiguring distribution of machineries and ducts on façades.

Because of the higher incidence of plaster pathologies, it was analyzed in greater detail what kind of material was used and which was its composition; from investigations conducted on plaster samples taken in situ, it was considered fairly reliable the hypothesis that it was the so-called "Terranova" plaster, patented in Italy in the late '20s of the '900. This particular type of plaster promised both the characteristics of natural stone (strength, durability) and the specific quality of industrial products (light weight, low cost, hygiene, speed of use, uniformity, polychromy).

4 THE CONSERVATION PROJECT

4.1 *Choosing operating fields*

Analysis and research carried out on the Tiburtino II have identified three fields of application in order to achieve the proposed goal: the study and restoration of façades' colors and planning for a comprehensive review of them, together with the reintegration choices of missing parts, the reorganization of the common green areas and outdoor lighting redesign.

In fact, the private nature of the buildings, together with the Italian regulation on cultural heritage (which is based on the "public interests declaration" which means that whoever has interest to have a private building under protection must send a report, later verified by the Authorities) does not allow to have a strict and detailed control of the transformations and adaptations in dwellings.

It was chosen to operate on fields that define the characteristics of public housing of the early Italian 20th century following a path that leads from the outside of the lots (in fact façades represent the linking point between the city and buildings), up to the most intimate and private dimension of common green areas among buildings, in accordance with material values and main figurative characteristics.

4.2 *The restoration of the façades*

The restoration project of façades includes both material integrations, interventions of shallow cleaning, strategies to remove gas pipes and electrical cables from streets' façades and mainly the chromatic project.

The actions resulting from the decay's analysis were distinguished in 6 categories: cleaning,

protection, consolidation, removal, repair and integration. The line of action adopted in the form of current maintenance, involves the demolition only for the incoherent parts of material and the reconstruction for missing or demolished ones with materials and techniques compatible with the original. It was adopted a critical approach to the subject and tried to limit the changes to those required to make more readable the original characteristics, nowadays hidden by incongruous changes, like concrete additions occurred over time.

Specific mention should have the interventions on shelves and balconies, often having missing parts because of their nature and exposure conditions which have defined their conditions as critical points of the structure.

The overhangs are made of reinforced concrete and adorned with hollow brick moldings coated and shaped by stucco. Where there was concrete cover spalling due to the excessive weight of the filling of hollow bricks, reinforcement of the moldings was provided with FRP bandage and a consequent stucco work, in this way all the weight wouldn't fall on the armor, avoiding their deformation and the possible fall of material. Where the molding is so degraded that it can't be established nor reintegrated through simple plastering, it is provided the insertion of a shaped support armature constituted by welded steel mesh and coated with plaster compatible with the originals.

After having considered the most common situations of lacking material on façades and having decided strategies and methods of operate, it was considered the biggest problem of historical building: how to restore the plastered and colorful surfaces without remove or cover completely ancient plaster and undo the effects of time, giving the building a "feeling of novelty".

From the 80s to the present color-planning for the Italian historical centers has spread; talking about color-planning it means to define a design tool to control the paintwork on the walls using a clear, proper and unambiguous reference. The planning aims to set up a proper "grammar" of the color, for the tint tone, paying attention to never lose sight between the color distinction of the ornamentation from the background.

The first step of knowledge of the current color state was created thanks to the discovery of original documents in the ATER archive together with the comparison with other ATER's district of those years, and a chromatic survey of the façades. This detection was conducted through a visual comparison, based on the human eye's ability to identify the analogy of a particular color present in the façade with one of the colors of a reference sample (being careful to disregard any state of decay that could alter visual perception). For sampling the dominant hue it was used palette "4041 Color Concept" by Sickens. It was formulated an hypothesis on the original coloring based on an analysis of the plaster portions not subjected to leaching and through a comparison with the adjacent Lot II, whose colorings are recently restored according to the original design. The design choices, however, have departed from the historicist recovery currently used that considers the plaster as the main and immediate element for an aesthetic and critical redefinition of the image. In order to a more conservative approach in the case of paintwork in lot IV was proposed to:

- delete discolorations resulting from decay by acting on the causes;
- save original plasters and colors where still present;
- redo the colors of portions painted in a non-compliant way;
- apply as a finishing glaze made with putty lime and natural earth pigments, recalling the original paintwork, in order to make visible traces of original plaster;
- apply on ornamentation a glazing that looks like travertine color, contrarily to the existing one in yellow; in this way these elements can demonstrate more correctly their vocation of lithic structures over the bottom.

4.3 *The lighting project*

The residential function of the lot and the resulting aggregation flows make necessary an adequate rethinking of enlightenment. The first approach to the topic was analyzing the actual state through the recognition of 5 different types of light fitting: on walls rectangular neon, on walls square neon, on the ceiling, lighting on pole, non-functional historical light, non-functional modern light. This analysis in addition to the observation of the lot during the night, highlighted various problems such as: the presence of lighting fixtures with dissonant color temperatures, the lack of suitable equipment to signal preferential paths or steps, the poor lighting of rest areas and the inadequate lighting of the main entrances.

To understand how to redesign the light system it was surveyed the historical apparatus through the lamps still in *situ* and the traces left by the removal and it showed a very frugal illumination of the paths, mainly concentrated only at the main entrance of Via Arduino and on the playgrounds.

The principle that guided the planning choices was to decide not to restore the original state slavishly, but to develop a new enlightenment scheme more tailored to the changing needs of the neighborhood, required on routes and other entrances in order to improve the safe use of gardens at night. To develop a comprehensive batch lighting project was drawn up a sampling of these critical issues, identifying for each one the most appropriate light fitting with all its related technical specifications.

Six situations were picked out with their interventions:

– The absence of façade lighting is surveyed.
  Two light points were placed in the facade at the lateral parts of the entry. The chosen applique, a single-emission LED lighting installation on wall, sheds light over the vertical walls valuing the particular architectural composition.
– The high beam lighting of the main vaulted entrance passage is positioned on the impost, pointing to the intrados. This passage was enhanced by the insertion of linear lighting recessed within the ground. This lighting installation has an asymmetrical projector whose luminous effect tends to empty the volume of vault from both sides.
– The western staircase appears without any lighting fixture that makes visible the way. In order to value the path, LED lighting was installed in the boiler walls, directed downwards.
– In the playgrounds lighting on pole were replaced by asymmetric reflector on pole; this lighting will be turned off at midnight, and only security lights marker will be turned on, in order to avoid interference to ensure respect for the privacy of the residents.
– Common green areas and all paths are enlighten by installation of marker at a height of 35 cm from the ground, to allow a smooth continuous illumination but not dazzle the upper floors.
– Other common resting areas were projected in abandoned drying racks with pergolas illuminated by new linear applique recessed inside a metallic C-shaped profile tin, with symmetrical reflector to the optic diffusion.
  The final effect of global illumination and the control of the superposition of luminous fluxes was been rendered by a photorealistic simulation.

4.4 *Project of common green areas*

Starting with the analysis of the flows within the neighborhood, it was noticed that the common green spaces are currently perceived just as passing places, betraying the spirit in which they were designed. In fact, inner courtyards of the popular districts were designed with the aim to create aggregating places, a "city within a city" obtained by modeling the interstitial spaces among buildings and articulating them in playgrounds, gardens and spaces as common drying areas. The passing of time and neglected maintenance has led to the lack of a rational design of green, which is left to spontaneous and arbitrary decisions of the inhabitants. All these critical issues led to neglect the vegetal element as reconnection tool of space and social gathering. The project of green areas, therefore, comes from the need to rearrange the plant species by proposing a rational combination between the new and the existing.

The first step, also in this case too, was to make an accurate survey of over 150 species of trees, shrubs and plants present within the lot IV and identify, among these, those probably dating back to the original construction. After a study sun illumination throughout the year, were identified the original species in good health to be preserved or replaced according to the principle of reorganization, the species to be explanted due to an incorrect exposure, inconsistency or lack of maintenance and the species to be implemented. Green thematic areas were created respecting characters and rules of the original composition. As the lighting project, were identified 4 focal elements:

– the former drying racks became design opportunities to create new meeting points. Alluding to the shape of their frames, they became pergolas in painted galvanized steel that incorporate a seat and a lighting system.
– On opposite side of the lot were created two other meeting points, needed to increase vitality through flow ways. The eastern intends to create a symmetrical element on the opposite side to the entry of via Teodolinda (the original design of the lot was, in fact, based on symmetry). The western one was projected echoing the original draw and the subdivisions of flowerbed still present, protecting it from the street with an oleander thicket (the historical common shrub in the garden).
– It was decided to rethink the main entrance to the lot on via Arduino and restore the symmetric view, now compromised by incoherent additions. It was removed the additional porch and the perspective was underlined by flowered parterre and steel pergola covered by Rosa Banskiae.
– It was considered as necessary to redesign the aesthetic of the boiler in order to mitigate its image of technological element and integrate it with its surroundings in a better way (Fig. 4).

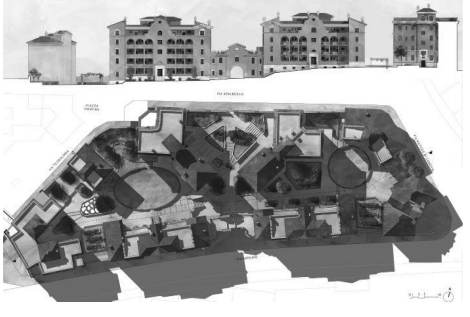


Figure 4. Photorealistic simulation of the project (Edited by the authors).

5 CONCLUSIONS

The research presented has shown that it is possible to approach the conservation of these residential and popular buildings, as if they were monuments literally intended. In fact, the challenge was following the traditional path to create a restoration project generally used for historical monuments and applying it to modern buildings still inhabited.

The project showed the possibility to follow a direction aspiring to regulation of compatible transformations paying attention both to building's language and inhabitant's necessities, not forgetting to make clear the historical project's characteristics. In order to reach this purpose, a maintenance plan was drawn up to take into account the possible increase of the performance quality, not using genetic procedures but specific solutions for each technological and structural element of the buildings (structures, slabs, balconies, window's frames, systems, finishing, gardens and green spaces).

Particular attention was given to the maintenance, preservation and conservation of plasters and coloring. In fact, these interventions need to be considered as a problem of conservation and not a mechanical and auto-repeat operation, because they affect the significant of the buildings and city too.

The conservation approach on these buildings needs specific strategies and awareness to distinguish the items to conserve and those to be transformed compatibly both with original elements and necessity of use. Social housing, in fact, represents a place for life and daily aggregation, contributing to the reorganization and decorum of the city as monuments literally intended.

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Vernacular tradition and modernity. New scenarios in urban living

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ABSTRACT: In today's world, characterised by megacities of banal repetitive buildings, the logic is being reviewed of minor settlements and vernacular architecture, including those made of earth; sinuous, heterogeneous, 'poor' but virtuous, sober and eco-friendly, for decades neglected, abandoned, shattered by new cultural layouts. Still used in marginal regions, through bottom-up processes pursued through collective rules, these are increasingly being reconsidered in more advanced countries, thanks to bio-architecture and a type of development which looks at the past. This is all within project actions open not just to aesthetics and a humanly deeper dimension which can encourage relationships between people through the cohousing formula; facilitate community service; tackle abandonment of historical settlements and sprawl; avoid the transformation of the territory into a museum and, instead, regain from the past still living modern elements to relate to innovation and stimulate resuscitation of local identity. Even in a peripheral region like Calabria.

1 INTRODUCTION

The change in the rapport between settlement system and environment transforms cities and small towns in most of the world. The original balance is broken and new locations and layouts are determined. In this way, there is a movement away from processes of balanced settlement growth, as a function of specific cultural, economic and physical parameters, as well as the quality of interventions and opportunity of solutions, to processes of uncontrolled urban expansion, cut off from the deep reality of these contexts. The result is the emergence of residential areas, assimilated, banal and sprawling, which in most cases undermine the old layouts, isolating and depriving them of life. Gigantic megacities, mega-regions, mega-corridors and varying urban regions grow while their surroundings become deserts, are abandoned to the consequent, not always 'natural', catastrophes; the passage is, then, from a complete metropolitan entity to an impoverished and subjugated territorial void.

In particular, the process towards forms of economic 'expansion' has now become definite; forms which cancel the usual organisation of territories, culture, centuries-old mentalities, local spaces, neighbourhoods and ideal urban settings. The trend is, then, towards new standards of housing, for fast and easy relocations, mixed with contrasts, resentment, afterthoughts and guilt because it is difficult to abandon the routine of one's normal life, customs, long held effective knowledge and place of origin. Everything within a scenario increasingly open to travelling, moving and creating new experiences in new territories because of a work life that is no longer connected to one's homeland; this means, on one hand, amplification of the space of experience and, on the other, living through disarticulated, detached from cyclic, time and a confused, contradictory, in part less strong and passionate, rapport with memory.

The rapport with tradition, procedural slowness and the sense of senses is being lost, as is the ability to perceive what the territory communicates. Every thing changes deeply in such a way that places that were vital, creative, palpable, concrete and rich in tastes and smells, healthy places dominated by the comparison between nature and human work, besides the beauty of landscape, have been replaced by an era where citizens identify less with their homeland. Consequently, settlements are distorted and become something different with increasingly disintegrated and fragmented communities.

Therefore, work on historical architectural heritage, sullied as it is by general as well as personal history, torn apart by natural calamities and wars, has been heavy handed. This is particularly true with regard the "minor world" (houses, roads, alleyways, squares, buildings for working purposes, etc.), considered outdated, unsure, primitive and marginal, in contrast with modern aesthetics, but, in fact, more widespread and important than "cultured" testimony of the past because the outcome of a choral, intelligent and collective work. Striking examples of this can be found every day in the unfortunate works of renovation on the lesser urban fabric, more than big buildings, because of greater operational ease and more modest economic investment.

These *modus operandi* include destructive, distorting intervention on earthen architecture, in contrast with the ancient and on-going practices

in various regions around the world, regardless of regime and economy, tribal or market, and including various religions: Christianity, Judaism, Islam, Hinduism, Buddhism.

Man's responsibility is, therefore, great. We need immediate action to protect and re-propose works of ancient identity before they are completely cancelled. Superficial, "hit and run" recipes should, though, avoided. Efforts should be directed at heritage education to preserve cultures that can express values, customs and methods, although obviously reworked with a modern twist.

2 AN EARTHEN 'WORLD' BETWEEN PAST AND PRESENT

From the simplest techniques to its most evolved uses in the form of bricks, there are numerous architectural typologies in earth and every single type of building has been realised from this material: from defensive structures to religious buildings, from palaces to popular housing and industrial architecture. There are even hydraulic examples or structures linked to the presence of water. An infinite universe of houses, huts and other 'minor' buildings, defines the varying cultural characters of the urban and rural, traditional and modern, landscapes in every corner of the planet. It is, therefore, an unlimited heritage, so much so that, according to UN sources, 40% of the world's population, slightly fewer than 3 billion people, still live in earthen houses, between traditional customs and new uses, respect, maintenance, negligence and misuse.

In any case, there are many projects through which, among great difficulties, an attempt is being made to apply this culture, particularly bricks, which, for reasons of economics, heating and insulation, and easy adaptability, are used in new houses in the poorest parts of the planet, as well as in bio-architecture in the more evolved areas.

Some examples may be cited. For instance, in Peru, 60% of buildings are made using adobe, together with other techniques and anti-seismic systems. In Africa, recent statistics register millions of new earthen houses in villages and large towns, like Kingali and Nairobi, although the latter is often referred to with regard the sad phenomenon of slums made of this very material. In India, 72% of buildings, old and new, that is 67 million structures inhabited by nearly 400 million people, are made of earth. The reuse phenomenon also involves the United States, where nearly 200,000 earthen houses, 97% of which in the south-west, have been built in recent decades: in California, where adobe buildings increase by almost 30% every year; in New Mexico, thanks to the "pueblo revival style"; in Tucson, Arizona; in Kansas; in the central states and in Manhattan, where earth is used to refine straw bale houses, but also to fill truck and car tyres to be used as foundations for other structures. In Europe, Sweden, Denmark, Germany, England, Spain, Portugal and France have been some of the first countries to reintroduce the earth architecture, both to protect existing historical sites and to experiment with building techniques linked to eco-friendly architecture, and, consequently, to include it in eco-museum and tourism programmes.

2.1 *The Italian situation*

In Italy, earth was already used in the Etruscan and Roman periods and it continued to be used for two thousand years: in Sardinia, especially in the hinterland of Cagliari; in Piedmont, particularly in the Piana di Marengo; in some areas of Lombardy and Emilia Romagna; in the area of Macerata in the Marches; near Cortona in Tuscany; near Foligno in Umbria; in various urban and rural settlements in Abruzzo, Basilicata and Sicily.

In Calabria, where the oldest examples are the archaeological remains in Vibo, Reggio and Locri, earth has been used for two thousand years in both rural constructions and urban buildings, with



Figure 1. Walls in adobe bricks of *Rhegion*, VI century B.C. (R. Chimirri).



Figure 2. Row of earthen houses in the province of Vibo (R. Chimirri).

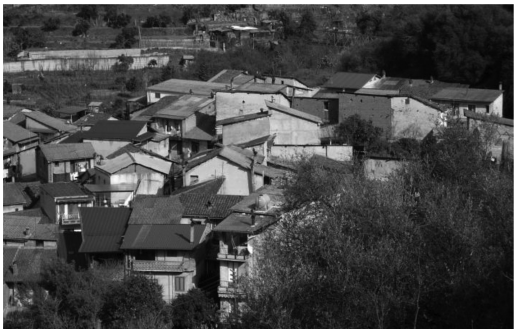


Figure 3. Metal and asbestos sheets disfiguring an earthen settlement in the province of Vibo (R. Chimirri).



Figure 4. "Concreting" of an earthen house in the province of Cosenza (R. Chimirri).



Figure 5. House made of adobe bricks sandwiched by cement in the province of Vibo (R. Chimirri).

interesting technological and formal applications: various forms of terraced houses, isolated palaces, industrial buildings, farmhouses and boundary, cattle sheds, retaining and defensive walls which, although very old and highly neglected, still show how resistant this material is.

It is, then, a heritage which is still worthy of great consideration today; but, if it was still 'alive' until the mid-20th century, expressing national identity in an intact cultural context, as it is extremely sensitive to the changes in society, it is now moving quickly towards forms of abandonment and erosion. There are many reasons for this: the growth of "new production models", development of outsourcing processes, establishment of the middle class, diffusion of new building materials and, last but not least, the insistence of a new lifestyle. In addition, there has been an increasing use of industrial products and this traditional material is considered by many as an obsolete archaism.

The image of villages in which stories, traditions, architectures and people's relationships were explicit is long gone; there is a different way of interpret the countryside and its buildings, once linked to specific agricultural activities or surveillance tasks. Finally, the sacred aspect of the territory is now almost absent, as shown by the disappearance of historical places of worship and the dependent relative network of pilgrim's routes and symbolic points of reference such as churches, aedicules, roadside crosses and calvaries, all now hidden by the modern.

So, apart from wide-ranging cultural initiatives and a still difficult, uneven and discontinuous 'rediscovery', the use of earth is now almost an "archaic technique" and certainly no longer choral.

It is no coincidence that the phenomenon is poorly known. The attention given by politicians in their environment and landscape protection programmes is not sufficient.

Entrepreneurs' indifference towards both recovery and building with earth is remarkable, and citizens remain highly indifferent, both because they are not informed and because they are eager to definitively abandon something that, for most, was synonymous with poverty and insecurity.

Scepticism about adobe is, then, strong, radicalised in the general mistrust of so-called alternative culture. Demand for healthy, thermo-hygrometric dwellings made with eco-materials is still weak, as is the movement towards a reduction in energy consumption during the whole building process, from production to construction, from management to disposal. The much-lauded idea of a return to local settlement in small villages is still far from becoming reality, since living in isolation, independently, in solitary houses forming the sprawl has gained a foothold.

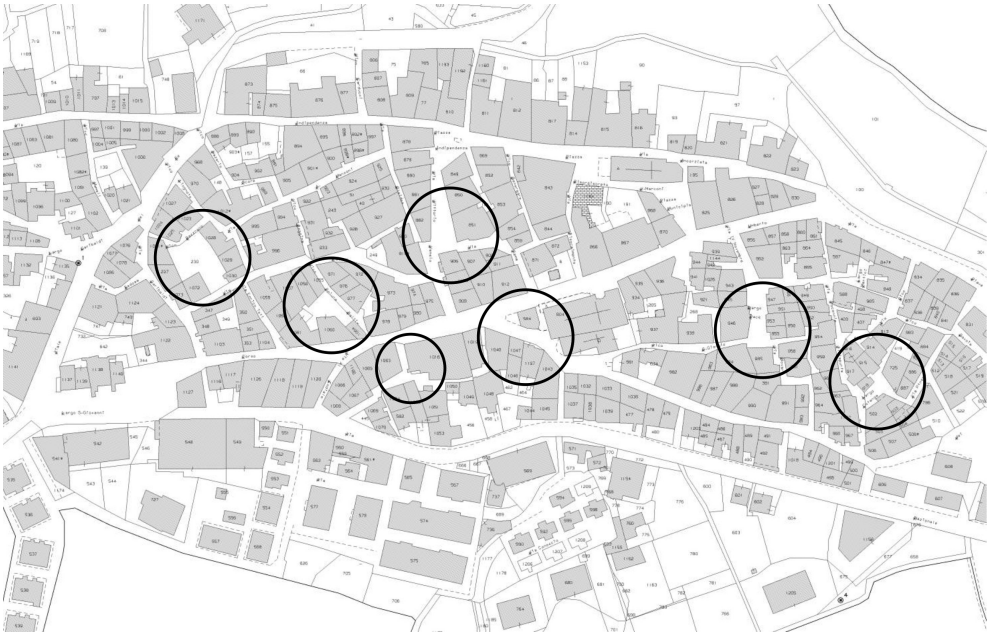


Figure 6. Idea of earth cohousing in Dasà (R. Chimirri).

2.2 *Calabria and the 'return' to cohousing*

The situation in Calabria, a peripheral region out of step with progress, is even more difficult. Given the real danger of a definitive cancellation of vernacular architectures and settlements, there is an immediate necessity to start cultural and territorial development programmes, through socio-economic, architectural-constructive and demo-ethno-anthropological contributions and landscape planning with in-depth analysis of the interactions between human history and landscape.

The essential actions upon which attention and consequent operations on the territory have to be focused are consequential: to "review" places, recognising them for what they have become, between light and shade, respecting and not disfiguring them, being close to them and their authentic traditions; to recuperate within inhabited spaces the *genius loci*, *genius rei pubblicae* and *genius gentis*, establishing new bonds with the historical and physical context of buildings and territory; to intervene in the landscape by combining ecological awareness and identity defence; to work hard so that each community considers its spaces as a manifestation of itself and its culture – there is a difference between residing and fully living in a place –; to make architecture integrated and recognised as a value, like music, fashion, cinema, etc., without reducing interventions to a mere objective, geometrical, measurable act; to involve the community in the growth process, investing in education as a formative training effort, from starting school on, towards a more rational attitude to life and work; to innovate rurality, revisiting historical sites with greater attention and dedication; to open up new development processes based on integrating agriculture with the other sectors; to renovate cultural resources with the support of public action, new local entrepreneurships and well-off activists, attracted by and respectful of that culture (gentrification); to prevent the old town from becoming just a receptacle of cultural activities unrelated to everyday life, such as religious and popular festivals or local markets, entertainment outside the shops, children playing in the street, etc. – a village with no community would have no sense –; to solve problems of isolation and poor services, improving and incrementing fixed structures possibly, in synergy with the landscape, through networking and distance communication, to the benefit of the residents, foreign visitors, entrepreneurial activities and new investments; where possible, to encourage synergy among small municipalities (urban policy) to render them more competitive and stronger in a global environment; to increase traditional activities that are open to innovation and quality tourism within a context of internal action rooted in local places, but necessarily open to the outside world; to discourage sprawl by trying to repair the urban structure and tie it to the old town; to carefully analyse the preserved vernacular habitat, re-embellishing it, eliminating plastic and metal to reintroduce traditional materials; to open up to new eco-friendly forms able to

meet socio-cultural and socio-economic principles of environmental sustainability through awareness of its values and qualities.

It should be underlined, though, that some facts are fundamental to positively correlate vernacular architecture with sustainability. Attention cannot be limited to technical features of buildings, making the understanding of architecture distorted and partial. It has to be considered within its environmental, historical and cultural, as well as economic, political and religious context, as architecture is an integral part of the societies and cultures that produced it. A holistic and integrated perspective is necessary to understand which traditions are sustainable and which are not. It has to be understood what, within tradition, is compatible with today's requirements in terms of safety, comfort, dimension of living spaces, privacy, etc., considering the possibility that one cannot preserve everything. This architecture has to be seen as original, beautiful and pertaining the environment, context and climate.

This is done, while avoiding erroneous generalisations, with the main aim of learning from and being inspired by the past, so as to plan the future more competently, so contributing to the preservation and promotion of a cultural heritage that risks of disappearing completely. This approach should meet the population's needs through urban preservation policies and functional economic objectives, not simply for global tourism, but mainly aimed at the local people.

Therefore, it is important to put effort into keeping the entire historical construction vital and authentic, not just restoring houses for a hit and run use. All this should help us understand the meaning of each other's heritage better and improve planning for future generations.

There is, in any case, a certainty that the re-evaluating and reviving of places, simply because they were lived in and moulded by human beings, should not be guided by large abstract projects imposed from above, dictated by building restoration or renovation, road or square resurfacing, by a contrived, temporary and folkloristic revival of processions, religious and popular festivals, ancient crafts, or by a stifling, mummified conservation of monuments to be contemplated as beautiful images in terms of a rhetoric of identity.

On the contrary, such actions should be based on an industriousness fed by the community's proactive participation, seeking new sensory experiences, new bonds, new economics and quality production; it involves, that is, the recovery of those vital resources scattered over the territory which, drawing on memory and roots, are also able to rediscover a recently-lost, interior dimension. In this way, the scenario could open up to legitimate expectations and, in some cases, certainties.

Furthermore, more and more citizens, tired of today's alienating urban dimension, are in search of silence, nature which is less subject to human impact, and simplicity and serenity of spaces to live and settle in as part of a community.

Numerous new generation tourists/travellers who do not like the usual tourist destinations are also eager for the community life of these places, where they often buy a house and return several times a year. From all this emerges a great regard for the "new formula" of ecomuseums, as a development strategy of the territory, and museums, meant as places where cultural heritage and community meet and of education in the values of landscape and cultural tourism.

A return to forms of *cohousing* associated with forms of *coworking* might also be of particular importance within urban and rural historical contexts. Indeed, the both anthropological and geometrical nature of these spaces, already the expression of a similar modality of traditional living in *rughe*, cul-de-sac, *gjtonie,* which are the neighbourhood units of Greco-Byzantine, Islamic and Arberesh cultural matrices, would render them easily reusable. These modes could be exported to newly-built areas, where the nature of tradition could be an aesthetic-functional guide.

This would be a return to an interweaving of work and domestic life, in a context where there is no division into specialised areas, but houses built above shops, workshops and other activities in a flourishing of industriousness. It would be working towards new generations of residents, keen on living autonomously and freely but at the same time "in the national system"; young, elderly, tourists/travellers, people who reside for much of the year, a new immigrant population.

This would bring the practical and economic advantages of living together traditionally, but with a decidedly contemporary approach thanks to greater opportunities offered by technology and "good" modernity, establishing ways of living that overcome the distinction between urban and rural, city and countryside.

Starting from the conviction that dwelling is not an individual practice—the failure of models of independent living confirms this—but rather a collective one, such an approach suggests the renouncing of the myth of the city in an attempt to establish a new concept of living and producing together, laying the foundations for "neighbourhood workshops". These would be areas of active aggregate strength which would send messages and create networks through which people could communicate. It is, indeed, in the common areas that the highest number of users concentrate, so expressing the identity of the place.

The action of architects has, therefore, to be strong and decisive, both on a large and small scale;

they need to be open, not only to aesthetics, but to a more profound human dimension and, consequently, to interdisciplinary exchange. The result will be work based on continuous debate and connection between old and new cities, suburbia and city centres. Thus, it is fundamental to interpret the continuous modification process of communities so as to make them desirable, that is they make people happy. To achieve this, it is necessary to transform these places into instruments for development, of urban bonding, social integration and cohesion between people, even those belonging to different cultures, as well as community services to fight desertification and abandonment of the historical centres, and the consequent loss of their anthropological features.

3 CONCLUSION

The consequence of this is that vernacular architectures, including those made of earth, could become new focal points for the territory, human relationships, interaction, social integration and cohesion. This would all follow attentive planning, open to the territory and knowledge of local cultures, to a scrupulous projection addressed at how and what has to be saved or modified, to economic evaluation of costs and benefits, and to creativity and civil planning. The only obligation would be to succeed in rendering these systems structurally safe, technologically advanced, easily accessible and compatible with new living standards, besides being inviting and welcoming. Obviously, such intervention should not negatively affect local identity or the typical character and protection of the environment, while also avoiding the reduction of these areas to sterile museums or false spaces for "out of the ordinary" people.

This is a gigantic work, but it is not impossible to begin. These areas can still be recovered from the abyss and reinvent a future for themselves, on condition that their structures become more and more that of a strong society, able to avoid fragmentation, isolation and localisation, but, rather, be open to the territory, building networks to improve the quality of services, knowledge and economy so as to present themselves in a global context.

Finally, it is clear that, to revitalise this culture, numerous committed actions and actors are needed and, consequently, it is almost impossible to talk about the vernacular without synergy with and links to memory. Cultures of the past, though, should not be faithfully revived within a completely different world. The "usefulness" inherent to the past needs to be kept and the planning should be carried out with respect for those immutable and irrefutable parameters: the sense of community, participation, healthiness, the economy and a coherence to the lifestyle. Furthermore, modern materials, now part of our lives, could obviously substitute traditional ones. The dream is just to offer an alternative and some integration, especially in an époque when the whole world, through its inappropriate and exasperated use of modernity, is losing its identity, maybe forever.

This is the perspective from which these notes were conceived. They are not, then, the product of strenuously defending traditions, resubmitting already-covered themes in more or less similar models or theorising about the importance of protecting this patrimony, but, above all, of an approach that might encourage a communal collaboration between research and management, interdisciplinary exchanges and horizontal cooperation.

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Sustainable proposal for the conservation of Castillejo of Monteagudo (Murcia, Spain)

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ABSTRACT: The Qasr Ibn Sa'd or Castillejo of Monteagudo is an Islamic construction from the middle of the 12th century. The rammed earth wall castle is located in Murcia, Spain. Today, the Castillejo is quite worn and deteriorated. This work presents an extensive study of the monument, including its history, construction techniques and damage assessment. The aim is to restore the rammed earth walls and to enhance the cultural heritage and attraction of the monument, while ensuring a respectful conservation and sustainable approach. A conservation proposal is presented herein for the sustainable conservation of the Castillejo, which reinforces historical elements and recovers its use and value as a historical and cultural monument of the city. Several proposals are suggested for the sustainable maintenance of the Castillejo, such as enhanced access roads, recreational areas, viewpoints, and the musealization with information boards and signage panels. Additionally, a detailed economic analysis was performed for the different stages of the intervention proposal.

1 INTRODUCTION

Rammed earth architecture or construction is a technique that is generally linked to traditional and humble architecture. But there are lots of examples of architectural monuments built with this technique that are still standing. In Spain, this architecture reached its peak during the Muslim domination (8th-15th centuries), and a clear example of this is Qasr Ibn Sa´d (Muslim name) or Castillejo of Monteagudo, in Murcia, subject matter of this work.



Figure 1. Aerial view of the monumental ensemble of Monteagudo, in which the Castle of Larache (left upper corner), the Castillejo of Monteagudo (centre) and the Castle of Monteagudo (right lower corner) stand out (M.J. Serrano).

Qasr Ibn Sa´d or Castillejo of Monteagudo is a castle-palace built in the 12th century, which forms part of the monumental ensemble of Monteagudo and is approximately 5 km north-east of the city of Murcia. This historical ensemble had originally a great agricultural estate, many hydraulic works and three main buildings: the Castle of Monteagudo (the defensive fortress), the Castle of Larache (the minor residence) and the Castillejo of Monteagudo (the palace of the Emir Ibn Mardanish).

2 RAMMED EARTH. A MILLENARIAN AND SUSTAINABLE BUILDING TECHNIQUE

Earth is a natural resource existing all over the world, which due to its abundance and availability has become the quintessential building material. Its extraction and handling do not require a high energy cost and do not contaminate. Its transport is quite inexpensive, since buildings are usually constructed with earth extracted locally or from a nearby area. Furthermore, its selection, handling and use do not require extensive knowledge or expertise, and consequently the worker does not need any specialized training.

If earth is properly compacted, it is a construction resistant material that has a long useful life. It can be easily reused, without the need of any

complex industrial processes for its recovery. Finally, it is a natural residue, and thus it does not have a high environmental impact.

The characteristics of earth are not particularly suitable for its use as a building material on its own. It is a quite hygroscopic material and shows low mechanical, wear and erosion resistances. However, when this material is transformed by means of the rammed earth technique (earth selected and compacted), its resistance is increased (especially if it has additives such as aerial lime), since its environmental exposure makes it become more resistant over the years. On the other hand, the appropriate compaction of earth layers making up the rammed earth wall and the lime coating prevent moisture from penetrating the walls easily, which makes this material quite resistant. Another issue is the high thermal inertia offered by this material. It behaves like a good environmental regulator. Given that indoor humidity is kept stable, it keeps heat in winter and cold in summer. That is why this material was widely used by Muslims for their buildings.

Environmental and sensorial adaptation was very important in Islamic architecture. Water and vegetation combine as ideal elements for the Muslim paradise. But these elements also generated a series of other environmental determinants. Water was used as a thermal regulator and, at the same time, it generated relaxing sound effects when moving. For its part, vegetation gave shade and supplied food for the inhabitants.

For all these reasons, rammed earth may be considered as a sustainable building technique, i.e., an environmentally friendly technique. It does not require high energy costs for its implementation or for the handling of earth. It does not contaminate or produce any waste. It is an inexpensive, abundant and reusable material that is available anywhere. Its use in the building process adds great thermal and sound qualities; that is why energy installations and consumption of the dwelling are minimized.

3 COMPREHENSIVE STUDY OF THE CASTILLEJO OF MONTEAGUDO

The Castillejo of Monteagudo is an Islamic building, with a rectangular floor plan and with salient towers. Five towers on its longest sides and three on its shortest sides. Its corners are recessed corners instead of protruding corners typical to defensive architecture. On its southwest side, it has a lower enclosure (approximately four meters below the first one) that encloses it as a barbican. There are six towers on its longest side and two towers on its shortest sides. Although it has a defensive nature, its main function is more related to residential purposes, and it ended up being a pleasure palace for the Murcian emir that lived in that building.

3.1 *Historical context*

This building, known as Qasr Ibn S'ad by the Muslims, is believed to belong to Ibn Mardanish, known as the Wolf King in the Christian chronicles. He took control of the city of Mursiya, currently known as Murcia, from 1147 to 1172 (Torres 1933). The emir settled in that city after having taken control of Sarq Al-Andalus, and elevated it to second capital of Al-Andalus during the second *taifas*; thus, this period is considered as a golden age for the city.

This gave rise to an important economic development and an important urban transformation: the fortification of the city of Murcia with the construction of a great wall; the construction of a new fortress on the north-east side and within the city walls (Seguir Fortress); and the construction of a great *almunia* (pleasure residence) in a privileged and elevated place of the farming estate, in the north-east part of the city, in Monteagudo, to which the Castillejo belongs (Navarro & Martínez 1998).

3.2 *Functional and constructive configuration*

According to some studies published about the Castillejo of Monteagudo, the functional organization of the building revolved around a great cross-shaped courtyard. The courtyard also had crossed sidewalks that stood out from the garden floor. On its shortest sides, there were two small ponds that led to two reception rooms. This configuration and the period in which it was built make this building be considered by historians as a first referent for the architectural symmetry in Andalusi palaces (Torres 1958).

The courtyard dimensions, as well as its main elements, are practically identical to those of the Courtyard of the Lions in the Alhambra of Granada. That is why Torres Balbás described it as a previous model for the Granada courtyard in the evolution of Hispanic-Muslim architecture.

The internal layout of the Castillejo established a clear differentiation between public and



Figure 2. Current aerial view of the Castillejo of Monteagudo showing the upper and lower enclosures and their salient towers.

private spaces. This gave a character of privacy and respect to the residential area, which was so widespread in the Islamic culture. The public, official and representative area was located at the reception rooms and the cross-shaped courtyard. However, private rooms were located in the four corners of the main enclosure, with small private courtyards. They were only accessible from the corridors located on the longest sides of the building (Almagro 2008).

In the cross-shaped courtyard, the transversal sidewalk stood out due to its greater breadth as compared to the longitudinal sidewalk. According to the latest studies, this is due to a matter of functionality. This greater breadth facilitated movement and communication between the areas. Moreover, various experts in this building are of the opinion that the layout that the Muslim master builders designed for the building derives from an eight-pointed star. The walls of this palace were apparently built based on two squares, one rotated 45 degrees from the other on the same centre, and by means of a quite ancient geometric system (Navarro & Jiménez 1995).

The technique used to build the Castillejo of Monteagudo was the rammed earth technique. This is a concreted rammed earth wall, with an internal lime layer, rough stones of different sizes and external lime mortar coating (Mileto & Vegas 2014). During the visual inspection performed, it was checked that these rough stones are laid out in the wall faces more orderly than in the internal part. This was usual when they wanted to increase the resistance of rammed earth walls of defensive buildings.

A building aspect that has not been explained yet by historians is why the measurement unit used to design and build the Castillejo was the *vara* of Aragon, equivalent to 0.777 metres, given that no other cases like this one are known in the Region of Murcia, because the measurement unit normally used was the *vara* of Castile or of Burgos, equivalent to 0.836 m. In fact, the *vara* of Castile was the measurement unit used to construct the other buildings making up the monumental ensemble of Monteagudo (Martínez et al. 2007). In the absence of a research that may definitively clarify this aspect, it seems reasonable to think that the use of the vara of Aragon is due to the fact that the emir Ibn Mardanish, who ordered its construction, came from the Valencian-Aragonese territory and that the Muslim master builders in charge of the works also came from the said territory or simply followed the traditional building techniques of that territory (Serrano, M.J. (2014).

3.3 *Current state of preservation*

The Castillejo of Monteagudo has such a historical, architectural, social and cultural relevance that it was declared a monument (currently, an Asset of Cultural Interest under the category of Monument) in 1931 and, since 2004, it is included in the declaration of Assets of Cultural Interest under the category of Historical Site of the area known as Monteagudo-Cabezo de Torres.

Significant remains of the earth rammed walls of this emblematic and historical site are still standing, despite the state of neglect and lack of maintenance on the part of its owners, which has caused the dilapidated state in which this site currently is. It is necessary to bear in mind that the hill where the Castillejo is located belongs to a private owner and is divided into four plots of land belonging to various owners. This implies lots of problems for its study, preservation and enhancement, given that permits must be requested and agreements must be reached.

On the other hand, the lack of maintenance of the area and the natural exposure to weathering, without any kind of protective treatment for the wall stretches, are causing lots of damages to the monument. The average height of walls still standing has been approximately decreased by 1.00 metre in less than 100 years. That is why it is essential to implement a proper maintenance and conservation plan for the monument that ensures that the original structures still standing are preserved.



Figure 3. Detail of concreted rammed earth wall of the Castillejo of Monteagudo (M.J. Serrano).



Figure 4. Current northeast elevation of the Castillejo of Monteagudo (M.J. Serrano).

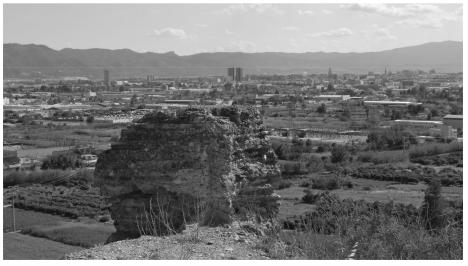


Figure 5. Panoramic view of the city of Murcia from the Castillejo of Monteagudo (M.J. Serrano).

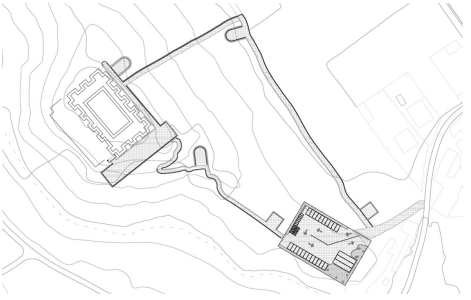


Figure 6. General ground plan of the intervention proposed for the recovery and musealization of the Castle of Monteagudo (M.J. Serrano).

4 SUSTAINABLE INTERVENTION PROPOSAL: MUSEALIZATION

As a starting point for the preparation of a sustainable intervention and conservation proposal for a building such as Qasr Ibn S'ad or Castillejo of Monteagudo, it is necessary to take into account historical, architectural, landscape, social and cultural matters. Additionally, accessibility and the necessary maintenance of the building and its surrounding area must also be considered.

Monteagudo is a reference historical site in the Region of Murcia. Remnants from various periods (primitive, Roman and Muslim) have been found, of which the Hispanic-Muslim period is possibly that with the greatest splendour. Furthermore, it should be borne in mind that it is an important and strategic viewpoint of the city of Murcia, since the whole Murcian valley and part of the area known as Vega Baja del Segura can be seen from its high hills.

Bearing in mind the heritage and landscape relevance of this environment and based on social and economic demands on which the regional investment is being recently focused, it seems reasonable to suggest that this monument should become an archaeological and natural park of the Murcia orchard area by enhancing it as a heritage, landscape and touristic-cultural referent of Murcia.

4.1 *Social, environmental and landscape balance*

Over the last decades, the municipal district of Monteagudo has been subject to a remarkable population decline. The creation of new infrastructures and communications with the area of Alicante, the industrialization, the abandonment of the agricultural sector and the job shortage are some of the causes for the decision made by the inhabitants and the owners engaged in the service sector to emigrate and to move to other places in the city. On the other hand, the investment in the promotion and dissemination of culture, not only in the municipal district, but also in the whole town, seems to be insufficient, since very few people know the heritage of this spot in the orchard area.

This is a quite relevant historical and architectural heritage that must also be considered as an important landscape, rural and ethnographic heritage for the city of Murcia. The cultivation of citrus fruits and vegetables, together with cereals –to a lesser extent– configure the traditional landscape of the Murcia orchard area. Monteagudo has also historical infrastructures (drainage ditches, irrigation ditches, wells, mills…) and natural areas of a remarkable environmental value (Navarro & Jiménez 1995).

The proposals made for the full conservation and the architectural and archaeological recovery of the Castillejo of Monteagudo may give rise to conflicts with this rural and ethnographic heritage. Consequently, it has been taken into account that the intervention should be focused on the full conservation and musealization of the monument, its accessibility, as well as the environmental and landscape improvement of the surrounding area. Likewise, it is necessary to implement a Heritage Conservation, Promotion and Management Plan, so that the intervention has the appropriate social and cultural significance.

This intervention would imply the creation of a public or private entity, so that the economic investment necessary to start this project not only re-establishes all the heritage values of the landscape and monumental ensemble, but also becomes something that can be maintained and even generate a cultural, social and economic benefit for the city. Murcian traditions, the orchard environment and the agricultural activity would be enhanced. The conservation of this monumental ensemble would hold back the abandonment of the area, since jobs would be created for the inhabitants, both in the agricultural sector and as regards the maintenance of the architectural ensemble. Service sector would also be restored, together with the business opportunities generated by tourism. There would be even new opportunities for research at the historical, architectural, archaeological and environmental levels. And, as an ultimate goal to

be considered, social awareness, cultural education and heritage pride of citizens would be increased.

4.2 *The intervention: conservation, maintenance and management of the monument*

An intervention must not necessarily be subject to the restoration of the monument. This "intervention" must be understood as an action that is not aimed at the full recovery of the building or its transformation into a unit that denatures its identity. In terms of heritage, a minimum intervention would be carried out, without the absolute need to recover the use that the building originally had and, of course, without the need to transform its symbolic and identity value. In fact, the Law 4/2007 on Cultural Heritage of the Region of Murcia establishes that the total reconstruction of the monument shall be avoided and that any heritage intervention must be aimed at its consolidation and conservation.

The proposal for the intervention of the walls is designed to stop the deterioration. The conservation plan is aimed at stopping the deterioration suffered by the monument, in particular, the deterioration that affects the structural stability of its walls and the disintegration of materials.

After the analysis of deterioration it is proposed the most adequate intervention for the monument, In this case, it is suggested to repair the walls at their top, up to the following wall course in order to make up for the existing lack in each section, which would facilitate the understanding of the monument and its conservation. As well, it is necessary to act on the important section losses and to repair them in order to prevent any eventual collapses.

The consolidation of the stonework and, in particular, the thorough cleaning, recovery and consolidation of the remains of original stuccoes are deemed essential; these tasks are quite delicate and must be carried out by specialized professionals. Likewise, herbicides, biocides, consolidating elements and water repellents shall be applied to all the walls in order to prevent, as far as possible, any deterioration and damage risks derived from the exposure of the wall structures to weathering.

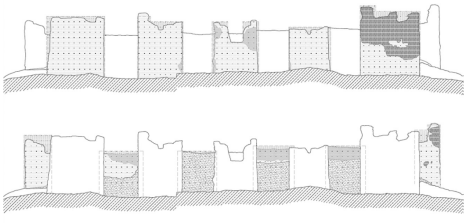


Figure 7. Intervention proposal for the conservation of wall structures (M.J. Serrano).

However, an intervention proposal must not only be limited to the intervention scope. It must also include the maintenance of the building and the procedure to spread out this intervention over time. A proper maintenance is the most efficient treatment for the survival of buildings and prevents huge economic investments in their restoration. Cleaning and the application of consolidation and water-repellent treatments, as well as other biological treatments are essential to a case like this. Consolidating elements facilitate the adhesion of materials and prevent erosion, water repellents protect from moisture, and biocidal treatments prevent the appearance of vegetation and, thus, the disintegration of materials.

Nevertheless, it is necessary to bear in mind that these treatments are not effective for an indefinite period of time, and they need to be reapplied from time to time. If cleaning and the application of biocides are obviated, it is possible that, within one year, vegetation comes up again. On the other hand, the still standing remains of the Castillejo are very sensitive to weathering exposure. Without the regular application of consolidating elements and water repellents, erosion and disintegration of materials would appear again. Therefore, it is essential that the intervention is designed as a joint action, both for conservation and maintenance purposes.

Likewise, the intervention must also take into account the heritage management and promotion. An intervention is necessarily aimed at its reuse and at its respect on the part of citizens. Thus, if there is not a proper management plan that includes a cultural dissemination programme, the intervention shall be doomed to abandonment and social lack of interest.

4.3 *Project approach*

The musealization of Qasr Ibn S'ad or Castillejo of Monteagudo is proposed as a sustainable intervention for the historical ensemble and the rural environment in which it is located.

The adaptation of access roads is considered as one of the priorities for the ensemble. Visitors need a safe route enabling a quick access and preventing any risk or physical handicap. In this case, the intervention suggests the development of two paths: one that already exists and another new path. The already existing path could be related to the original access and, thus, its maintenance and improvement for visitors is taken into account. Furthermore, the intervention suggests the creation of a new access path for disabled people, which represents an improvement in terms of accessibility and cultural benefits for them.

These two paths include recreational areas. With an eye towards musealization, the intervention takes into account the creation of rest areas for

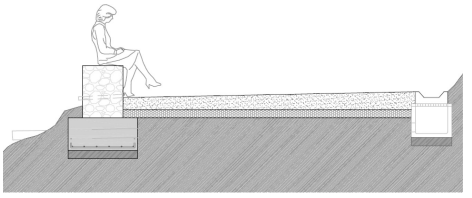


Figure 8. Construction detail of the access path with the small side wall (M.J. Serrano).



Figure 9. Detail of one of the designed display panels including QR codes (M.J. Serrano).

visitors. These areas could serve as meeting points for groups as well, so that a guide can offer explanations to visitors according to the panoramic views of the environment. Likewise, it includes the construction of small walls along the path with a dual purpose: to prevent visitors from falling down the steep slopes of the hill and to comfort and give a break to visitors during their ascent (Fig. 8).

On the other hand, the Castillejo is considered as a part of the historical ensemble of Monteagudo and, in the intervention, it is proposed as an archaeological park of the said ensemble. Bearing in mind this need to enhance the three historical buildings, a nearby car park has been planned in order to facilitate the access of visitors.

Finally, so that visitors can properly appreciate the buildings and in order to promote all of their values, a series of information boards and explanatory panels have been designed. They would offer information to visitors from the very beginning of the tours as regards their location, history of the site and other details relating to the monument. With the implementation of QR Codes on the panels, visitors may obtain the translation of this data or they may simply obtain more information.

5 CONCLUSIONS

First and foremost, we are of the opinion that any intervention on an asset of cultural interest must be based on knowledge and be aimed at the recovery and conservation of all values inherent in the monument. Moreover, the purpose of a sustainable intervention is not only the economic balance, but also the respect for the monument and for the surrounding architectural, landscape and natural heritage; moreover, such an intervention must not generate any polluting waste.

A musealization plan is not always the best intervention, given that it usually implies a significant economic outlay. In many occasions, without a management programme supporting it, such a plan is doomed to oblivion. Likewise, the intention is not to create a massive tourist attraction, since this would be detrimental to the monument, instead of being useful to revitalize it. That is why the study and the implementation of a *Heritage Conservation, Promotion and Management Plan* are deemed an essential instrument for the recovery and enhancement of the historical and cultural heritage.

For a sustainable heritage intervention project, it is necessary that these two mechanisms (intervention and management) operate jointly in order to ensure the compatibility of actions and so that the investment generates the proper results for society. We hope that this Project may be started in the very near future and may be useful to preserve and promote all the heritage values of the Castillejo of Monteagudo and its surrounding landscape.

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Perceptions of earth in the age of global architecture

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ABSTRACT: As much as one third of the global population lives in traditional unfired earthen housing, and the past fifty years have witnessed a resurgence of interest in earthen materials in contemporary architecture. Building with earth can reduce environmental impacts of construction while expressing unique local geophysical characteristics. From a design perspective, earthen materials can be used by architects to express "genus loci" or "spirit of place" that is emerging as a critical aspect of sustainability. Paradoxically, as the popularity of contemporary earth architecture grows, many current inhabitants of traditional earthen housing are abandoning their traditional dwellings in favour of materials more aligned with conventional notions of progress. The paper investigates the reasons behind these trends of adoption and rejection of earthen architecture, and speculates about the role of architectural design in changing perceptions about earthen materials.

1 GLOBAL VERSUS LOCAL

1.1 *The end of weird architecture*

On October 15, 2014, Xi Jinping, the President of the People's Republic of China, called for an end to "weird architecture" in China. According to the state-run Xinhua news agency, he singled out CCTV Headquarters and other high profile projects, mostly by western architects, at a literary symposium in Beijing aimed at encouraging cultural producers to act in the service of Chinese values (Li 2014). Although president Xi's blunt statement caused a ripple across architecture blogs, it echoed and amplified sentiments that had recently been sounding within the global architecture community itself. Two years before Xi's statement, the Pritzker Prize, architecture's highest honour, was awarded to Wang Shu, an accomplished Chinese architect who works primarily in his native country using local materials and craft traditions. Shu's approach is a stark contrast to the trend in recent Pritzker laureates, such as Zaha Hadid (2004) and Thom Mayne (2005), both whom forcefully embody the figure of the global architect, and whose designs for which they were awarded the prize employ a baroque computational fluidity seemingly disconnected from regionally specific concerns of materials and craft. The choice of Shu suggests a turn away from the rarefied preoccupations of global practice toward a deeper understanding of local concerns. This shift is reflected in the theme of the 2016 Venice Biennale of Architecture, "Reporting from the Front," which refocuses the gaze of architecture on peripheral areas typically ignored by contemporary architects, such as urban slums and rural villages. Perhaps not surprisingly, earth as a material for construction features prominently in Shu's work, as well as the exhibitions of the *Biennale*, giving expression to these local concerns.

1.2 *Return of the local*

A similar desire for the local explains the surge of popularity of rammed earth architecture over the past fifty years. Rammed earth is one of the world's oldest building technologies, and earth building traditions have persisted for thousands of years in various regions (Jaquin et al. 2008, Lowe 2012). Avrami & Guillaud (2008) have speculated that one third to half of the work's population lives in unfired earthen housing. Nevertheless, the traditions of building with earth in the Global North were all but lost in the three hundred years since Cointeraux published his treatise on building with earth in France in the eighteenth century.

This changed with the emergence of the countercultural movements in the 1960's, which sought a return to simple values and a greater connection to the land, perhaps best expressed by Stewart Brand's publication of the *Whole Earth Catalog* in 1968. Around the same time, a small number of independent innovators in the United States, France and Australia began to experiment with constructing with earth and pioneered new installation techniques appropriate to the Global North. Many early publications on earthen construction methods including rammed earth and adobe focused on instructing do-it-yourself homeowners. These efforts accompanied shifting attitudes about earth housing concurrent with growing interest in what came to be known as environmental sustainability.

Like the broader environmental movement with which it was aligned, the resurrection of earth



Figure 1. Kräuterzentrum, Herzog and de Meuron, 2014. Photo by Iwan Baan.

construction began on the cultural periphery in the 1960's, but was eventually assimilated into mainstream culture. The completion of the Kräuterzentrum in 2014 (Fig. 1), designed by Herzog and de Meuron, one of Europe's leading architecture firms, for Ricolah, a corporate client with annual earnings of €240M (Neue Zurcher Zeitung 2014), might be read as evidence that rammed earth has finally entered the mainstream in the Global North after decades of niche popularity among the counterculture and sustainability movements.

1.3 *Environmental benefits of earth*

The environmental benefits of building with earth can include reductions to operating as well as embodied energy. Globally, the built fabric accounts for as much as 40% of all energy use (Perez-Lombard et al. 2008), of which perhaps 80–85% is due to building operations and the remaining 15–20% is attributable to the energy embodied in materials (Dixit et al. 2010). The dominant role of operating energy will reverse in the future, as building operation becomes more efficient (Pérez-Lombard et al. 2008), making the transition to low energy materials a key aspect of constructing more sustainable buildings.

Earthen construction methods, which use natural mineral subsoils with or without additional binders and amendments, can be used to create durable buildings with lower embodied energy than conventional masonry or cast in place concrete buildings (Reddy & Kumar 2010, Lax 2010). The environmental advantages of rammed earth come into sharpest focus when it is compared to concrete, the material it most often replaces. The production of cement and concrete accounts for 6–7% of CO2 emissions worldwide, and each ton of cement manufactured releases approximately 900kg of CO2 into the atmosphere (Chaturvedi & Ochsendorf 2004). In contrast, rammed earth using unprocessed clay binders and soils sourced at or nearby the building site lowers the energy profile even further.

While unstabilized rammed earth does not have the compressive strength of concrete or fired masonry, with appropriate design it can be used to create safe, efficient and enduring structural systems that require only a small fraction of its available material strength (Dahmen & Ochsendorf 2012). Moreover, in climates with large nocturnal/diurnal temperature swings, earth buildings can reduce energy required to heat or cool buildings due to the presence of thermal mass, which passively regulates interior temperatures as well as humidity (Pacheco-Torgal & Jalali, 2012) Earth buildings can reduce the environmental impacts due to building operations and materials, requiring less energy to build, and less energy to operate, while offering healthy interior environments.

1.4 *Cultural benefits of earth*

Earth architecture offers cultural as well as environmental benefits. Soil, although a controlled material in many jurisdictions, is costly to ship long distances. In contrast to the global supply chains from which contemporary architecture typically draws its materials, building with earth remains for the most part a staunchly local practice, inextricably tied to place. The ability to express "genus loci" or "spirit of place" is emerging as an important aspect of sustainability, particularly in the area of regenerative design (Cole 2012), and building with earth, which expresses the unique geological attributes of soil, fulfills this aspiration. Particularly in areas with low

wages and plentiful unskilled labour, earth can be an affordable construction material that can be an effective source of employment (Cianco & Boulter 2012). Due to its performance, architectural expression, and sociological factors, earth buildings offer unique advantages over other materials.

2 PERCEPTIONS OF EARTH ARCHITECTURE

2.1 *Traditional earth architecture*

The technique of rammed earth originated in the Global South, where the majority of traditional earth buildings are still located. In the past several decades, many examples of striking contemporary earth architecture can also be found here: seven of the ten projects awarded prizes in the 2016 Terra Award for earth architecture are located in the Global South, in countries such as Burkina Faso, Morroco, New Caledonia, and Sri Lanka (Terra Award, 2016). However, despite its deep cultural origins and the efforts of contemporary architects to update the use of earth as an architectural material, many residents of traditional earth dwellings in the Global South are vacating their homes as fast as circumstances allow.

The reasons for abandoning traditional earth houses are vexing, and not immediately apparent. From a material perspective, the low cost of building with earth would seem to be ideally suited to many regions in the Global South, where the relative cost of construction materials like cement is high, and large pools of unskilled labour exist. Likewise, the high cost of energy ought to favour the use of materials capable of providing passive heating and cooling. Both of these points are made by La Voute Nubienne, an organization promoting vaulted earth structures for the Sahel region of Sub-Saharan Africa (Association La Voute Nubienne 2017). However, the reasons for migrations are complex and influenced by sociological as well as economic factors, as indicated by Smets & Va Lindert (2016). Although no formal studies have been conducted that look specifically at the reasons for the desertion of traditional earthen housing, informal interviews conducted by the author with residents of the Ouagadougou, the capital city of Burkina Faso, and Kieryaoghin (Figs. 2, 3), a small collection of traditional earthen buildings with around 80 inhabitants approximately 30 km from the capital, indicate that traditional earth dwellings are undesirable to some inhabitants, who perceive them to be impermanent, primitive, and uncomfortable (Dahmen 2011). In contrast, materials such as concrete, steel and glass, convey positive perceptions of technological progress and sophistication through their strength and permanence. In short, it is likely that among the reasons that traditional earth structures are being abandoned in favour of dwellings constructed of other materials are the associations these new materials have with more conventional notions of progress.

Material perceptions provide some of the rationale for abandoning earth dwellings, but sometimes more tangible issues are the issue. The degradation of raw earth construction, in which supplemental binders are not used, can be very real and immediate if structures are not detailed correctly (Bui et al. 2009). However, even where this is the case, abandoning earth architecture often entails economic sacrifices and a willingness to endure considerable discomfort.

This was the case in the village in Burkina Faso, where residents leaving traditional earth dwellings for expensive homes constructed of concrete block with uninsulated tin roofs endured stifling rooms each afternoon under the tropical sun (Dahmen 2011). The willingness of these residents to endure the withering heat of their "modern" concrete block house attests to the power of the perception of progress, ever where it entails considerable sacrifices.

2.2 *Contemporary earth architecture*

Ironically, associations with traditional practices and the "primitive" that diminish the popularity of





Figures 2, 3. (above) Traditional earth buildings at Kieryaoghin, Burkina Faso, (below) Courtyard at Kieryaoghin. Photos by author.

traditional earth dwellings account for the growing popularity of contemporary earth architecture in the north and south alike. Beyond its advantages in sustainability and occupant comfort, earth is identified with a kind of authenticity that is lacking in the age of global products. The desire to sustain some form of regional specificity in the face of increasingly homogenized global culture running on the liberated flow of capital and commodities recalls Kenneth Frampton's influential essay "Critical Regionalism," (Frampton 1983), which responded to the currents of globalization in the early 1980's. The essay is a reaction to global universalist culture, which together with the corporatization of the International Style in architecture threatened to impose a kind of homogeneity of architectural form on the world. Informed by Paul Ricouer's concern about the mediocrity of universal consumer culture, Frampton proposes an architecture of resistance, whose style and tactility are capable of reasserting a sense of place without retreating to a reactionary nostalgic historicism. Following Frampton's logic, the thick walls of earth architecture, so inextricably tied to region through the unique geological character of local soils, would seem offer a kind of regional authenticity that would be an ideal antidote to global universalist culture, embodied through its thin materials.

Those that by necessity inhabit traditional earthen dwellings often associate earth as a "backward" material not aligned with conventional notions of (forward) progress, while wealthy patrons who commission leading architects to design contemporary earth houses recast those same attributes as "authenticity" tied to place that provides a kind of bulwark against globalization, and sustainable performance that can provide visible bragging rights to one's neighbors. When did earthen architecture begin to accumulate such positive associations in the Global North? As it turns out, not so long ago. Many of the grand rammed earth residences constructed in the Rhone Valley of France during the 19th century hide the earthen walls behind a layer of lime-based plaster, suggesting a desire to humble origins and, in some cases, even pass off rammed earth as more expensive stone through the use of quoins at the building corners. The more utilitarian rammed earth agricultural buildings of the same region are often left with earthen walls exposed, suggesting that the owners considered rammed earth a material more fit for sheds than grand estates. Similar negative associations of earthen buildings were likely the reason for the discontinuation of the Works Progress Administration rammed earth residential project Gardendale, Alabama during the 1930's. In that project, the negative bias of inhabitants that resulted from housing the "dirt poor" in houses constructed of soil overwhelmed the the favourable thermal performance of the houses, which by many accounts exceeded expectation (Carpenter 2010).

By the late twentieth century, however, these earlier negative associations had changed dramatically. In the global North and South alike, wealthy patrons commission leading architects to design rammed earth houses that proudly show their soil walls as a badge of honour and a commitment to sustainability. This suggests that the economic prosperity of its inhabitants may influence the cultural perception of earthen architecture more than the context of Global North or South. The rich, regardless of their location, can afford to fetishize a return to the earth, whereas the disadvantaged can't leave it soon enough for materials that represent progress in one form or another.

2.3 *Crossing the north/south divide*

Despite the pervasive spread of global culture, most regions of the world retain deep relationships with local materials, reflected by the use of the materials themselves, as well as the cultural practices and knowledge that arise around them over centuries. Witness the stone work in Italy, the traditions of building with wood in Scandinavia or the high alpine regions of Switzerland and Austria, and earth in Mexico. These techniques often call on deep cultural traditions handed down through generations. The apparently simple art of stonemasonry requires the existence of quarrying operations, shaping, polishing, finishing, all prior to the material arriving on the site. Installing the stone at the building requires an equally nuanced set of operations and techniques that must be learned and handed down from generation to generation. The medieval guilds that once orchestrated this flow of knowledge may have given way to professional and trade organizations, but it is no less regional in character.

The projects of Wang Shu and other architects operating close to their places of origin demonstrate that using local materials and expertise can open new possibilities for design that might otherwise remain inaccessible. This type of design requires a balancing act at the intersection of materials and information. On the one hand, the close collaboration with craftsmen with a deep knowledge of materials requires accepting material limitations. On the other hand, it requires a willingness to depart from traditional forms to experiment with new morphologies that this knowledge makes possible.

The challenge presented by Frampton's argument is to apply it in a way that does not marginalize developing areas. Compelling as his argument might be, Frampton's "Critical Regionalism" has been correctly criticized because of the uneven way it was applied to the currents of globalization as they

swept across the equator, from the Global North the the Global South. As the critics maintain, in Frampton's argument, the Global North becomes a universalist culture defined by the flow of commodities and lacking local variation, while the Global South is defined as the repository of local authenticity that has been lost in the North. This amounts to projecting what has been lost or forgotten in a dominant culture (the Global North) onto another that is perceived to be at once less civilized and more pure (the Global South). This projection amounts to the notion of the "Other" in the social sciences (Sarukkai, 1997), which at best suggests a patronizing attitude toward the regions where indigenous architectural forms are the strongest, and at worst might be expressed as a desire to discourage those "authentic" regions from fully embracing the cultural, economic, and material developments (read: "progress") that have benefitted the Global North.

Why should developing nations be restricted from participating fully in the global flows of materials and skills? The answer is, of course, that they shouldn't. As Keller Easterling points out in *Extrastatecraft*, (2014) those nations and regions leaping most wholeheartedly into the flows of globalization are often in the most precarious in terms of economic circumstances. The prospect of access to the liquidity of global markets is made even more alluring by its contrast to the dire economic realities in rapidly industrializing countries. It is rare that free economic zones and other experiments of neoliberal capitalism return much in the way of tangible benefits to communities in the Global South that experiment with them. Nevertheless, they speak to the same desire to better one's circumstances that leads residents of comfortable traditional earth dwellings to leave them for concrete houses with tin roofs that perform like ovens in the afternoon sun. The human desire to improve one's circumstances is powerful, and regardless of the outcome, standing in its way rarely turns out well.

3 ROLE OF DESIGN IN RE-CONTEXTUALIZING MATERIALS

Cultural perception is an important material in the hands of an architect, alongside more tangible materials such as earth, wood or concrete, and design can play an important role in presenting traditional materials like earth in a new light. As the work of Wang Shu suggests, design that uses traditional materials in new forms contains the possibility of re-contextualizing traditional materials so they don't seem retrograde, reversing negative associations and suggesting a new relationship with traditional materials. The idea is not to repeat traditional styles, but rather to use traditional materials in in new ways that are informed by performance without being straitjacketed by it.

This type of thinking might be best exemplified by three examples. The work of the Block Research Group in Ethiopia deploys local earthen materials in new structural configurations to provide low cost building to countries in Africa (Fig. 6). Likewise, Kéré Architecture's Gando School (Fig. 4) optimizes traditional clay bricks and uses them in new configurations to provide more comfortable interior environments. Finally, Atelier FCJZ designed the modernist volumes of *Split House* (Fig. 5) to accommodate the imprecise working methods of



Figure 4. *Gando School Library* Kere Architecture, Burkina Faso, 2012. Photo by Kéré Architecture.

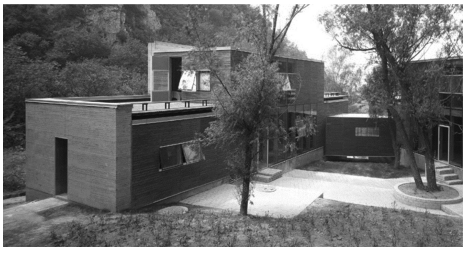


Figure 5. *Split House* Atelier FCJZ, Yanqing, Beijing, 2002. Photo by FCJZ.



Figure 6. *Droneport* Earth masonry shell by Block Research Group and Norman Foster Foundation. Venice Architecture Biennale, 2016.

local masons unfamiliar with rammed earth. The architectural design of these projects re-contextualizes the traditional earthen materials used in their construction, reprogramming the cultural associations attached to the materials in new ways.

4 CONCLUSION

The global flows of architectural materials have environmental as well as cultural implications. Minimally processed earthen materials are local by necessity, are less energy intensive than other highly processed materials, offering contemporary architects a means of expression of the spirit of place that is a key aspect of sustainability. Despite these advantages, many traditional earthen dwellings are being abandoned by inhabitants in favour of more highly processed materials because they are perceived to represent progress. Design can play an important role in casting traditional earthen materials in a new light, which is capable of having a profound effect on the use of these materials.

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Is it useless rubble or recyclable building material?

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ABSTRACT: The tradition of re-using existing structures as well as deconstruction, rather than demolition, merits revisiting. These represent the green sustainable practices of recycling existing buildings, and equally important—their materials. To illustrate these processes, building traditions transferred from the Romans to Spain (as part of their Empire), and subsequently to the New World, can be traced. Recycling building debris and rubble has become more imperative due to urban density, diminishing natural raw materials, environmental issues, and economic realities. Essential to the 21st century architectural conservation field is the use of green techniques that significantly reduce the carbon footprint. Retaining a structure in its original site and reusing salvaged building materials (known as embodied energy), reduces consumption and the supplies required for new construction. These are common sense ideas used in the past which represent a viable way to conserve and sustain the natural as well as, the built environment.

1 RECYCLING VERSUS DEMOLITION

One of the most important topics of the Architectural Conservation profession, is recycling or upcycling, a more recent designation. How feasible is it to reuse existing buildings for other purposes? Is deconstruction more feasible than demolition? Can most of the material removed from an existing structure be salvaged and reused; that which is sometimes referred to as debris? What are the origins of these "green" techniques and practices that have been forgotten in the 21st century? Could/should these successful methods be revived and re-integrated?

During the 1st century BC, Roman engineers, as experienced master builders, had also perfected deconstruction or dismantling techniques, due to their acute awareness of the debris disposal problem throughout their Empire. As consummate pragmatists, the Romans had realized that giving new uses to existing structures, as well as re-using their building materials or its resulting rubble accelerated and facilitated new construction or remodeling elsewhere. This practice reduced labor time and offered savings in the acquisition (quarrying and lumbering), transportation, and preparation of materials "...the scavenging of building material was...a thriving business." (Jacks 2008) Reusable construction materials included those extracted from nature and prepared for building (eg. wooden beams and stone blocks), or that had been hand-manufactured (eg. brick and tile). Dismantling and deconstruction, instead of demolition, required the development of systematic procedures by experienced laborers (Barker 2010) such as masons and carpenters, as well as the same equipment required for new construction (scaffolding, wheelbarrows, and tools, amongst others). The materials to be removed and re-used had to be cleaned, conditioned and moved to the new project site. Nevertheless, this was highly economical and considerably reduced production or preparation time. More importantly, it eliminated the problem of remnant rubble and debris, since everything was incorporated into the new project site, including its use as fill material. Building techniques such as pulverizing brick or fragmented clay tile to make a hydraulic additive for mortars (del Cueto 2011), or installing previously used or defective ceramic amphorae within the vaults or walls of the period to lighten the weight or improve the acoustics of the structures (Lancaster 2005), eliminated debris or construction rubble in cities and ports, which proved to be an extremely efficient Roman engineering practice.

2 REAL APPLICATIONS

International examples such as the Liberty Hotel in Boston, originally a prison; Technopolis in Athens, turned from an industrial Gasworks site into a major cultural entertainment complex; Le Murate Monastery in Firenze, transformed into a multi-use neighborhood which includes residential, cultural and healthcare facilities; Gare d'Orsay, a Parisian train station converted into a Museum; as well as the Mercado Colón in Valencia, Spain turned into a successful shopping mall and gastronomic venue, amongst innumerable unique projects world-wide, are notable

benchmarks for the re-purposing of the built environment without increasing the carbon footprint. The Circular Pavilion in Paris, a temporary building "...named for the aspirational circularity of the life cycles of its building components...", not its shape, was built from the ground up with reclaimed building materials. These included 180 historic doors, previously used insulation and light fixtures. "When you find ways to not waste, you find positive energy." explained Nicola Delon, a partner from the designing firm Encore Heureux (Schuler 2016).

In Puerto Rico there is evidence of the practice of recycling or reuse of construction materials since the 16th century. Caparra, the first Spanish settlement on the Island, was moved to the San Juan Islet, at the entrance to the bay, in 1521. At the time, everything that could be reused (beams, bricks, tiles) was taken to the new site, validating the innate importance of this logical practice by the first European settlers of Puerto Rico. In the 1850s, when the building of military barracks required the total demolition of an urban residential neighborhood called Ballajá, the Government of Spain prepared detailed lists which included the "...useful and useless products that have resulted from the demolition..." (The Foundation 1986). Amongst the materials put up for sale at public auction, were remnants of *ausubo* or iron-wood slats, 80 pairs of doors and windows, as well as 18,000 clay tiles, bricks and stones. In order to eliminate demolition debris that was not needed as landfill or for grading purposes, unfit or rotted wood was sold as firewood for kitchen stoves. Approximately 80 years later, any and all possible materials resulting from the collapse of buildings as a consequence of a 1918 earthquake, served to repair structures that had been weakened or were missing segments (Fig. 1).

However, major urban renewal projects of the 1960s and 1970s, such as the demolition of the colonial warehouse sector in La Puntilla as well as the demolition of the San Juan Train Station, were unfortunate events. These buildings could have been successful adaptive re-use projects of significant Old San Juan structures, instead of the new residential and institutional buildings with similar scale and volume that replaced them. It was a waste of the "Embodied Energy of materials and construction... [defined as] The amount of energy required to process and put construction materials in place... [which] is not recoverable" (Booz Allen & Hamilton 1979).

Nonetheless, some rehabilitation and restoration projects in Puerto Rico over the last two



Figure 1. Rubble and debris from the 1918 earthquake in Puerto Rico was recycled in the repair of other structures (Anonymous, 1918. *Puerto Rico Ilustrado* 9:451).

decades have demonstrated the viability of the original Roman process of recycling to prolong the life of significant structures and their building components. Their general goal was to preserve historic buildings by providing them with a feasible contemporary use, and guarantee the preservation of their historic fabric. This was achieved by using compatible techniques which were true to the original design, and through these practices, provide lasting interventions and healthy structures, re-purposing materials in the process. The reconstruction and/or restoration of the semi-flat colonial roofs of the projects for both the Conservation Trust of Puerto Rico headquarters (del Cueto & Reyes 1992–95) and the Conservatory of Music of Puerto Rico headquarters in San Juan was achieved by recycling their historic building materials. Original bricks, hardwood slats and beams from the same building were used to restitute the original form and configuration of the roofs. (Fig. 2) At the 19th century coffee Hacienda Buena Vista in Ponce, age-old structural timbers were reused by removing rotten or damaged segments and replacing them with similar wood sections through the use of traditional construction scarf joints. In more contemporary structures, such as the 1913 concrete-block residence which presently houses the headquarters of the Architects and Landscape Architects Association of Puerto Rico (del Cueto 1991–93), historic pressed tin ceiling panels and hydraulic mosaics cement floor tiles were either refurbished, to fill missing deteriorated areas, restored, and reused, or complemented with new elements when recycled materials were unavailable (Fig. 3).

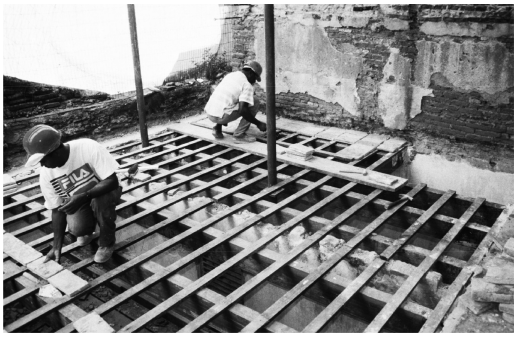


Figure 2. Reconstruction of a 19th century roof with historic recycled hardwood beams, slats and brick from the same building (Restoration project and photo by author, 1992).

Similarly, in projects where there were no recyclable materials from the building itself, original architectural elements that were missing, such as marble floors and hardwood beams, were replaced with materials that had been discarded from other demolished or sometimes deconstructed historic buildings from the same period.



Figure 3. Historic hydraulic mosaic tiles were recycled into the Colegio de Arquitectos project and supplemented with new monochromatic hydraulic tiles (Restoration project and photos by author, 1995).

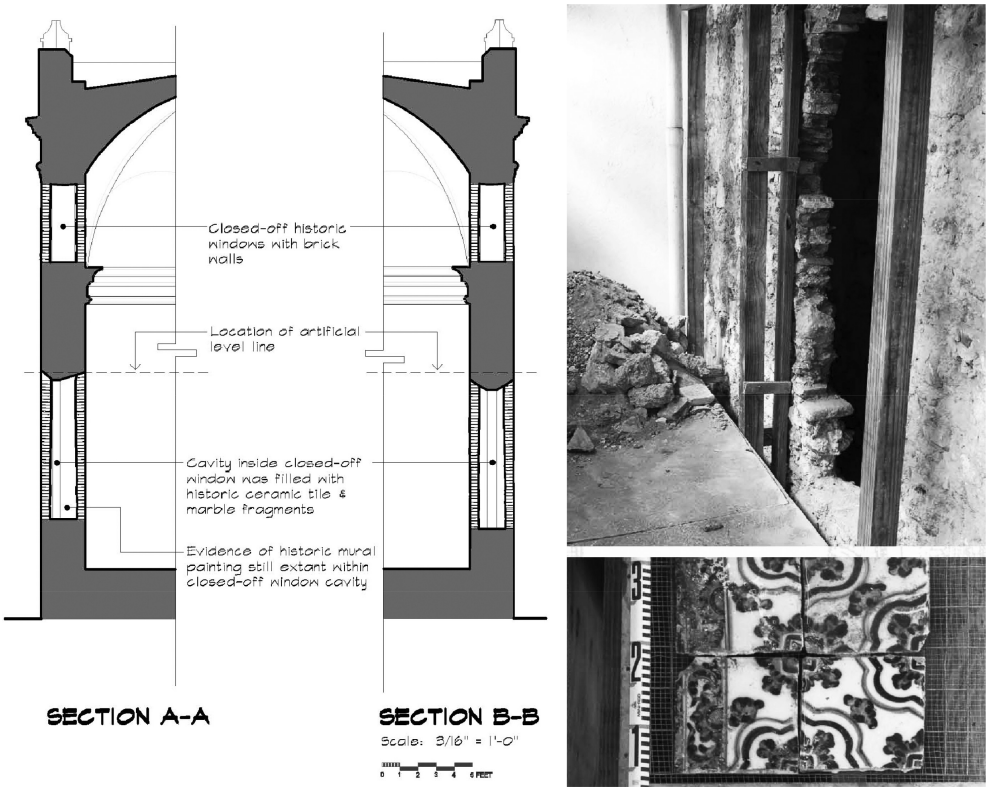


Figure 4. The Roman practice of discarding remodeling debris by using it as fill material within the same building was found during the re-opening of windows in Iglesia de San José (Documentation drawing and photo by author, 2009).

This was the case for the 19th century Fajardo Lighthouse on the northeastern tip of Puerto Rico, where the practice of reusing materials after deconstruction was implemented (del Cueto & Pantel 1988–91).

The Roman tradition or custom of integrating debris within remodeling projects, was corroborated as an early building tradition in Puerto Rico during the conservation project for the 16th century San José Church. When architectural-archaeology investigations re-opened the closed-off windows of a 17th century chapel in the temple, the building debris or rubble that had been removed during the 19th century remodeling of the space was found within these enclosures (Fig. 4). The fill material even included remnants of the then new marble floors. This practice had provided 19th century builders an efficient way of discarding and eliminating what was project debris by inserting it within the closed-off windows of the same space they were remodeling (Pantel & del Cueto 2009).

3 LACK OF INTEREST OR WILLPOWER

As a case in point, of why to recycle rather than tear down, the unbridled demolition of the Puerto Rico Penitentiary, built in 1926, was very difficult to accept. This massive-scale building, constructed of reinforced concrete, was emptied and abandoned in 2004. Although different uses had been proposed to grant a new life to this magnificent example of Puerto Rican architecture, it was summarily demolished in 2014. (Fig. 5) How is it possible in the 21st century to be unable to find new uses for singular, monumental, and irreplaceable buildings like this one? This is especially so when it is considered that "The cement sector alone accounts for 5% of global man-made CO2 emissions", and "That the transport of heavy materials such as sand and cement is energy-intensive"? (Kruse 2004) What was done with the concrete rubble resulting from the demolition of the historic Penitentiary and at what cost? "Recycling of concrete debris can make a contribution to reduce

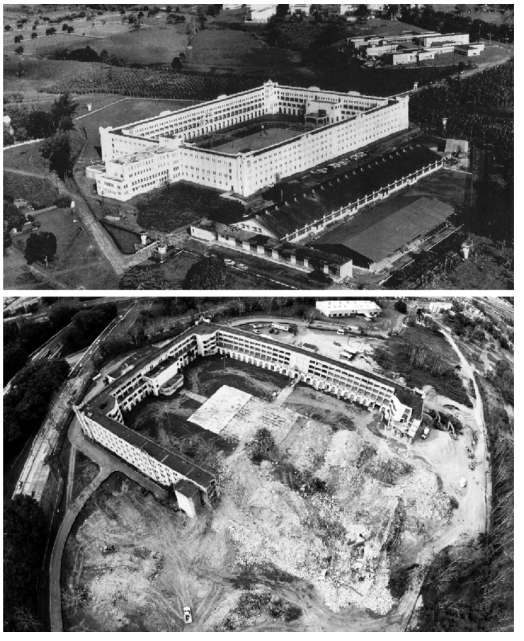


Figure 5. The demolition of the 1926 Puerto Rico Penitentiary in 2014 (Monteagudo, Antonio M. (ed.) 1939. *Album de Oro de Puerto Rico.* La Habana: Artes Gráficas, S.A. and Cardalda, Cristina A. 2014. Save Oso Blanco. www.causes.com, May 24.

the total environmental impact of the building sector...reclaiming aggregates from concrete debris would lead to environmental and economic benefits." (Ganiron 2015) What will replace the main structure which housed the largest inner courtyard in Puerto Rico? Why were the many proposals presented as viable alternatives never considered? Local government representatives, including the Governor himself, justified its demolition due to the building's "negative" connotations as a prison. A lame argument, since numerous historic prisons world-wide have been transformed and re-adapted into successful hotels and shopping complexes. This building was felled due to political incompetence and lack of will. The site now lays empty and without any viable project.

4 THE FUTURE

Replacing vernacular construction techniques with the use of machinery and disproportionate amounts of man-made materials, has eliminated labor-intensive manual tasks which were cost and energy efficient. Likewise, using waste by-products, like flyash, as an aggregate, reduces the need for natural raw materials and recycles waste, making it cost-effective and successful on all fronts. As important reference material, the Materials and Resources section of the LEED-NC for New Construction and Major Renovation, and the LEED-EB for Existing Buildings Reference Guides include procedures to help calculate desirable building reuse percentages, construction waste management strategies, and materials reuse, which can be adapted or used as the basis for the development of standards applicable more directly to interventions, preservation and conservation of historic structures (U.S. Green Building Council 2006).

As an essential technique in the field of architectural conservation, as well as a reality of the 21st century, the recycling, up-cycling or the reuse of both historic buildings and their materials (embodied energy) is of utmost importance. This means that maintaining the original site of a structure and reusing the building as well as its materials is a sustainable practice. It reduces the use of energy and the resources required to manufacture and prepare the materials, as well as those needed to erect a completely new building. "The most sustainable (or "green") building, may be that which already exists. Thus good preservation practice is often synonymous with sustainability." (Grimmer 2011)

These common-sense techniques, used by our ancestors, represent a way of respecting and protecting our natural and built environments. It is a necessary, practical, and economic reality that will serve to guarantee a better quality of life and to a degree, even a successful future.

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Understanding the vernacular heritage to design sustainable habitats in Asni, Morocco

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ABSTRACT: The paper describes the results of the research and the three design workshops developed with the participation of students, teachers and researchers from University of Florence, in Asni, a rural municipality located forty kilometres from Marrakesh at the foot of the Atlas Mountains. The research activities aimed to deepen the relationship between heritage, architectural design and innovation, considering local building culture as key input to develop a new eco-compatible living system. The project of a new sustainable social housing starts from the comprehension of the traditional knowledge system to define new appropriate solutions, from the urban scale to architectural and constructive design, involving the participation of local people in the project through the mediation of local associations. The final objective is to identify sustainable strategies, forms and constructive solutions to meet the needs of the new inhabitants, preserving at the same time the building culture and the cultural landscape.

1 CONTEXT AND BACKGROUND

The rural municipality of Asni, which is located forty kilometres from Marrakesh at the foot of the Atlas Mountains, is organised into 53 small villages (*douar*), traditionally built in earthen and stone masonry.

As well as many rural municipalities of Morocco, Asni is in an accelerated process of transformation of its landscape, mostly caused by a gradual abandonment of the traditional urban and territorial organisation. The outcome is a disordered settlement having no specific relation with the context and its resources, which often results in constructions which present poor environmental, aesthetic and functional performances.

From 2005, the Department of Architecture of the University of Florence has worked in Morocco, carrying out cooperation projects and workshops involving students, teachers and professionals, both Moroccan and Italian (Lotti 2012, Mecca et al. 2009, Mecca et al. 2016). In the framework of the AMA/E Seminar (Architecture, Materials, Environment) we have developed activities, both theoretical and practical, through workshops in situ, to facilitate a better understanding of the local culture and traditional construction systems, while providing interaction with the communities.

The research and the workshops undertaken at Asni originated in collaboration with the Tiwizi and Matter of Act associations: the first works in the area of socio-economic development and for the conservation and valorisation of the landscape and of the cultural heritage; the Moroccan-Swiss association Matter of Act, on the other hand, carries out campaigns and activities aimed at generating awareness and providing training and education regarding environmental issues.

Between 2015 and 2016 three residential workshops took place at Asni, in which approximately fifty students and ten professors and researchers participated, belonging to various disciplines: from technology of materials and building systems, to architectural composition, urban and landscape planning and design, hydraulics and social design (Eccheli & Giorgi 2016). The final objective of the research was that of identifying and experimenting with new architectural concepts able to foster and maintain an equal and sustainable development, capable both of ascribing value to the intangible heritage of humanity, and of building innovative economies and urban structures with an emphasis on low costs and low environmental impact.

2 RESEARCH AND DESIGN METHODOLOGY

Understanding the specificities of the places, as well as the environmental, social and cultural qualities that characterise them, was the first and essential step for identifying hypotheses for intervention on the territory, capable of preserving its identity with an emphasis on environmental, social, cultural and economic sustainability.

The approach to the project originates in assuming traditional knowledge, and through it, the local know-how related to the environment and to

architecture, as an element from where to begin the process of the project: to consider the signs – often worn down by time –, as well as the traces and the transformations of the territory, does not mean fixing them and ascribing to them an excessive dignity, but to use them as elements for defining the framework of the project from the point of view of a new cycle of development which may reflect the identity of the inhabitants and the genius loci.

The methodology adopted on field is that of co-design, or participative design, through the active involvement of all the actors which participate in the project (end-users, stakeholders, team, client). In a context in which identitary references, when facing modernity and globality, are slowly crumbling, this approach permits building a process of appropriation of the project by the communities involved, thus guaranteeing its sustainability and, when possible, its replicability (Rizzo 2009).

The relationship with the local community was structured in several phases. During the initial phase an assessment was carried out, together with the associations, of the aims to be pursued and of the factors capable of favouring or limiting the path to be followed, especially from the environmental and socio-economic points of view. A mapping was also undertaken of projects and activities that are similar to, or connected in some way, to the identified topic.

Thereafter, the ideas generated were discussed with representatives of the institutions involved and with other stakeholders, among which the purchasers of the land that was the object of the second workshop. Further research was carried out, aimed at identifying external stakeholders interested in participating in the project. The proposals presented in the workshops and during the months of further in-depth analysis of the project, carried out in Florence, led to an Exhibition at Asni, in the framework of the Marrakech Biennale, and to the publication of a volume aimed to favour a larger involvement of the local community in the projects.

3 HABITAT, ARCHITECTURE AND BUILDING CULTURE

3.1 *Environmental and socioeconomic context*

Asni is situated in the region of Marrakesh-Tensif-El Haouz, inside the Toubkal National Park, between the plain of El Haouz and the mountains of the High Atlas, and includes altitudes that range from 1070 to 3700 metres above sea-level. The lush valley of Asni (Fig. 1), which follows a riverbed, alternates forests and agricultural fields, and is connected by a main road which links 18 villages located at high altitude, of which Asni is the main town, in terms of infrastructure – it has a large souk, health services and schools – and of geographical position.



Figure 1. Traditional settlement and modern expansions in the Asni valley. Credits: L. Dipasquale.

The economy of the province is based mostly on agriculture and the mineral sector, and to a lesser degree on crafts and tourism. Although Asni is situated in a particularly rich and diversified geographical context, not lacking in resources, in terms of economic and social development the area presents high levels of poverty, and the living conditions for much of the population are harsh.

The region is populated by four Amazigh tribes that embraced Islam during the Arabic surges of the 8th and 11th centuries. The population of the prefecture of Asni (approximately 20,000 people) is experiencing growth, with a 38,67% of the population under 14 years of age, and a very high illiteracy rate that is close to 67%.

The climate of the region is semi-arid, with strong seasonal variations (temperatures between 4 and 47°C) and a relatively low rate of rainfall, situated approximately between 350 and 400 mm per year.

Rain, which is rare but intense, produces evident signs of hydric erosion both on the slopes, and especially in the riverbeds, which drain superficial effluence. Alluvial soil deposits on roads, the presence of temporary solutions for the disposal of excess water near raw earth dwellings and the thriving cultivation of annual and perennial species in the small fields, indicate the presence of a yet unsolved relationship with water, which is thus both a resource and a problem. The mountain slopes are divided up between families and tribes of the villages for pasture and cultivation. The fields are traditionally irrigated by diverting water from streams into canals.

As the situation is today, most of the water used for productive activities in Asni comes from wells dug in the stream bed of the river that crosses the valley, and which descends from the mountains of the High Atlas. With the use of small pumps, these wells feed modest reservoirs placed at a sufficient height, which serve the domestic water usage of the population. Some particularly eroded riverbeds reach small underground aquifers, which are then

partially exploited with rudimentary water intake devices.

3.2 *Habitats morphology*

The *douar*, which is how Berber settlements in the High Atlas are called, house between a dozen and a few hundreds of inhabitants, of Berber origin, traditionally organised as self-governed communities in accordance to the rules and regulations established by the Jemma, or community assembly, which decides upon social and economic questions, and in particularly rules regarding the distribution of property and crop rotation. These small settlements were traditional conceived as autonomous units, which originated from family ties. The *douar* has few basic services: a mosque, a Coranic school (*timzguida*), a threshing floor (*anerar*), occasionally a collective granary (*ighrem*), one or several shops for primary needs, and often a school (Terrasse 2010)

The *douar*'s urban fabric is traditionally compact, and adapts to the morphology of the land, distributing itself over terraced platforms that follow the contour lines of the terrain. The basic unit that forms the urban fabric is the courtyard house, usually of an approximately rectangular shape with a series of spaces distributed around the central patio. The courtyard houses in the valley of Asni were originally distributed only on one storey, yet new storeys have been added in order to house new members of the family (Fig. 2). The rooms, which traditionally house a family nucleus, are organised around the courtyard, often surrounded by a wooden portico. The central open space is envisaged for the carrying out of collective domestic activities, such as the preparation of food and the transformation of agricultural products. In the plains the courtyard tends to be larger, whereas on the slopes it is usually smaller, due to the need to adapt to the terrain.

3.3 *Traditional building systems*

In the small villages scattered throughout the valley of Asni, the earth became architecture: small houses and fortifications are born from the mountain, are sculpted from its stone and its clay. The thick walls of the traditional constructions of Asni and the villages that surround it are made from rammed earth, adobe and stone (Fig. 3). The rammed earth walls are built on a stone base of changing dimensions according to the overall size of the building. This provides insulation from the ground and protection from the humidity produced by capillary action and rain. The base consists on two external wall facing and an interior filling nucleus which is composed of smaller elements and minute material. The elements in barely hewn stone, are organised in irregular rows and set with a mortar made of earth and gravel. Stone is also used for the parts of the buildings that required a more resistant behaviour: corners, lintels, buttresses, some times the entire first floor.

The rammed earth walls are usually between 60 and 80 cm wide. The walls are set with a humid mix of earth, gravel and small stones between a wooden frame that is fixed to the walls with further wooden elements. The earth that is placed in the framework is first ground, then rammed with the use of a heavy wooden maul with the purpose of compacting the clay and liberating it from some of the humidity before the process of desiccation sets in. Interior partition walls and raised sections are usually made of raw bricks placed on the wall using a header bond.

All wall types include reinforcement systems obtained with wooden devices placed inside the walls during the construction phase. These are circular or irregular beams with a maximum diameter of 10 cm, placed along the bearing wall. In some cases the beams can be seen alongside the walls, in others the wooden elements are in pairs, placed one on the inside and one on the outside of the wall and connected between them with additional transversal wooden elements. The resulting spaces between the beams are filled in with mortar or pieces of bricks. These circular reinforcement systems, although rudimentary, in the presence of pressure pushing outward work as an independent

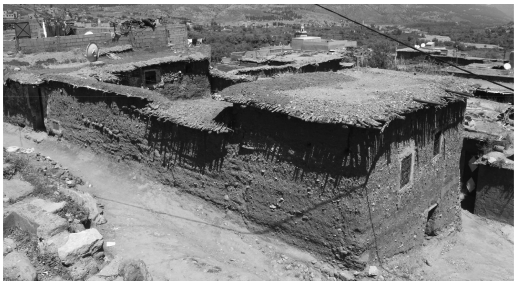


Figure 2. Courtyard house. Credits: L. Dipasquale.



Figure 3. External façade of a building in Asni with walls of stone, rammed earth and adobe. Credits: L. Dipasquale.

chain or hooping device, which contributes to the uniform distribution of loads on the various walls, and thanks to the elastic and tension absorbing features of the wooden sections, increase the lateral stability and the resistance in the joints between the walls (Dipasquale et al. 2016).

Floors and coverings are often made with trunks of local trees: juniper, pine, walnut and poplar. The wooden structure is traditionally covered by a layer of reed matting, which serves the purpose of distributing the load of the earthen screed, about 15 cm thick, and made of a first layer of dry earth and a second layer of humid earth; both traditionally rammed with a special punner. The covering is covered with two additional layers: one of twigs, placed orthogonally to the external wall, and a final one of earth, gravel and lime. The covering protrudes approximately 20–30 cm from the external wall in order to protect the earthen plaster of the wall from the effects of the rain.

Wooden logs are also used for the lintels of the openings and for the columns of the portico.

3.4 *Alteration of the traditional system and current trend*

The typological models and construction methods used in traditional architecture have been deeply altered over the past few decades: the comparison with Western models has derived in hybrid technological and typological solutions without any technical and regulatory control, and which depart from the building wisdom which had generated habitats with undeniable landscape ad cultural qualities. In the Valley of Asni, traditional architecture has lost ground to the overbearing presence of more modern construction materials, such as cement and prefabricated construction blocks, which are used without a proper knowledge of their limits and possibilities of application. It is thus common to observe, spread out throughout the valley, buildings with impossible spans, daring additions, protruding reinforcing bars, cement blocks set with earthen mortar: a wide range of combinations, mostly questionable in terms of safety and insulation performance, and sometimes even dangerous from a structural point of view.

The lack of development plans has also caused serious problems from an environmental point of view, in particular regarding the management of water resources, including the almost total absence of a sewage disposal system and of an adequate management of grey waters, but also concerning garbage disposal, and other essential services (health, education, etc.).

Although the population often wishes to abandon the old earthen houses because they are associated with an impoverished and backward way of life, it is evident that the choice of living in small, badly constructed buildings in reinforced concrete, that are not properly suited for local climate conditions, is mostly the result of a lack of alternatives and of the absence of a modern architectural culture. The blind introduction of extraneous technologies and ways of living, in the name of a progress which has often brought nothing more than new forms of poverty, risks endangering the fragile environmental balance.

4 DESIGNING NEW SUSTAINABLE HABITATS

4.1 *Sustainable principles leading the design of new habitats*

To design new buildings with traditional materials, techniques and styles, yet innovative in terms of application and of performance, and based upon current needs and requirements, means giving life to habitats that are more sustainable from the environmental, social, cultural and economic points of view (Correia et al. 2014).

In continuity with the local traditional housing models, the typological choice is that of the courtyard house. The courtyard is traditionally the space for sharing, socialisation and household labour. The structure of the courtyard house, articulated with intermediate spaces of transition such as loggias and galleries, complies with functional needs, responding to the growing necessity for indoor/outdoor transitional living activities, and with making the house flexible, transformable, and possibly expandable (Aguilar et al. 2014).

A dwelling courtyard outlay leads to more efficient housing design, lowering the cost of cooling since its morphology ensures the natural ventilation of living spaces thanks to the air convention property. The presence of shaded places causes beneficial air movement due to the fact that the heated air in the sunny areas, which is less dense, creates a vacuum that draws cooler air into the dark zones. Lodges and galleries provide valuable shade during the day, while the terraces are inhabited in the evening, when the temperature drops below that of the inside (Dipasquale et al. 2014).

The volumes of different courtyard houses can be wedged and the perimetral walls can be shared between bordered buildings, so that the thermal energy loss by external surfaces is reduced, determining benefits also in the winter season.

An interior private space outdoors finally encourages autonomy and self-sufficiency by the possibility of integration of production areas such as gardens, domestic livestock, and spaces for any type of manual activities that need open space.

This efficient system can be enriched with other passive energy features that we can find in vernacular

buildings, such as choosing rather small and few windows, high ceilings, as well as local and environmentally friendly materials, such as earth and stone.

From an environmental point of view, energy consumption in terms of the life-cycle of a building can be considerably reduced if construction materials come from the immediate surroundings. The capacity for thermal inertia of materials such as earth and stone favour the maintenance of indoor temperatures. Likewise, the good thermo-hygrometric properties of raw earth, in particular its capacity to balance the humidity of interior spaces, and the capacity of earthen plasters to serve as a filter for some noxious agents, including electro-magnetic waves, contribute to enhance the comfort of the interior spaces of the buildings.

From a socio-economic point of view, building with local materials has a strategic value since it favours the integration of local resources, understood both as know-how and procedure competences, and as crafts directly or indirectly linked to the construction. The result is a re-appreciation of manual labour, which thus becomes an opportunity for development with positive effects on the local communities.

4.2 *Design proposals for new habitats*

Well aware of the positive effects of the re-discovery of a local building culture, we approached the new context of Asni with the purpose of putting into action our various competences and committed to obtain design results with a level of innovation and interest such as to generate both short-term and medium-term impacts on the local community.

The need to re-give identity to the place and to find characteristic features in the architecture appeared as an important issue since the first meetings with the members of the associations, as well as he need to study the possible interventions in terms of environmental protection (from the erosion of the ground and water conservation, to the disposal of rubbish) that can be easily put in practice and replicated.

The site where the first workshop took place, in April 2015, is a plot of land destined to social housing where, at the moment of our intervention, the basic urbanization and division into lots had already been carried out. Not being able to modify the layout of the development since it was partially built, the project focused on the re-configuration of the single blocks of buildings and on the development of typological models which are centred on the courtyard house as theoretical model, and local materials for the development of evolved building systems to be adapted to the requirements derived from the master plan and from consultations with the local communities (Fig. 4).

On this occasion, a work group focused the activities related to the project on the sustainable management of water resources for containing erosion, the stabilisation of slopes and water collection. To this purpose a series of terraces were built with the help of weirs which permit slowing down the flow of water for controlling superficial effluence and protecting from hydric erosion, and canalisation and water storage for taking advantage of excess water during floods, as well as Rainwater harvesting techniques for collecting water at the housing level.

The second workshop took place in October, 2015, in an area approximately 2 km away from the centre of Asni. The land was purchased by an association of owners as an investment, with the intention of building houses, a hotel, sports facilities and a school Students came up with three master plans which adapt to the morphology of the terrain through terracing systems and valorise the surrounding landscape. The housing model was devised within large green and farmable areas, thus re-proposing the integration of productive and residential activities. The project envisaged a variety of building typologies, differentiated in terms of users belonging to different socio-economic contexts, however always using local materials.

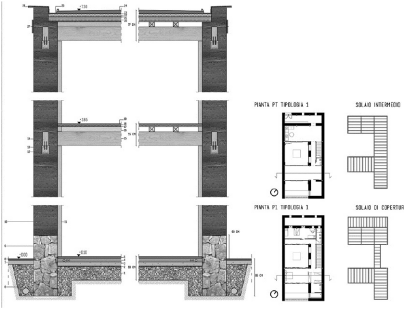


Figure 4. Construction details of a courtyard house, designed after the 1st workshop in Asni. Credits: F. Del Gatto, O. Lotti.



Figure 5. Workday on earth and lime construction techniques Credits: D. Giorgi.

The third workshop took place in September of 2016, and was focused on the rehabilitation of the habitat of the *douar* of Asni, on energy requalification and on the reorganisation of green areas surrounding the headquarters of the Tiwizi association. A topic of special interest requested by the local authorities was research into recovery techniques for existing dwellings. Particular attention was given to mending the urban fabric and to spatial organisation based upon hydric abduction and recovery and disposal of excess water. The recovery of some traditional dwellings is part of a project for a scattered hotel managed by the Tiwizi association.

The workshop offered the opportunity for organising a workday, open to the entire population, on earth and lime construction techniques, with the participation of the Department of Geology of the Cadi Ayyad University of Marrakech. The impact was positive for the local associations and inhabitants, since the interest of both local and foreign experts and universities, contributes to overcoming the negative perception the locals have of these materials and helps generate understanding of their worth and promote their use.

5 CONCLUSIONS

In Morocco, the diffusion of industrial construction materials has brought about a progressive abandonment of traditional techniques, considered as obsolete, and often unjustly seen as a symbol of social and cultural exclusion. The inevitable consequence of this phenomenon is a gradual loss of the know-how regarding building techniques, which today are entrusted to the memory of only a handful of elderly builders; at the same time, the absence of necessary maintenance interventions has resulted in the fact that a large number of buildings are in a situation of irreversible decay. All of this results in the progressive loss of a rich heritage of technical, environmental and socio-cultural knowledge.

The workshops we are carrying out in Asni are a part of a wider project which spans from architecture to landscape conservation and would include programmes for the environmental education for the local populations and support for local associations in terms of communication and in setting up a hospitality system on the model of the scattered hotel.

One of the main results obtained to this day is the fact that, beginning with the Tiwizi association, raw earth is no longer perceived as a poor and unsafe material, but rather as a founding element of the local cultural heritage.

Our ambitious project experience aims at understanding the logic and reasoning of an ancient building tradition and to participate in this process in continuity with it, while designing at the same time a path for project experimentation and innovation that is both expressive and constructive, with the purpose of bettering the quality of new buildings in terms of architecture, welfare, safety and sustainability.

NOTE

In addition to the authors, the workshops were lead by: Oussama Moukmir, engineer, local expert in raw earth and sustainable materials, Maria Grazia Eccheli, Flaviano Lorusso and Adelina Picone, teachers of architectural composition, Graziano Ghinassi, teacher of On Farm Irrigation, Francesco Tioli, expert in 3D survey, Corinne Cauvin Verner, anthropologist, and the tutors: Eleonora Cecconi, Alessandro Cossu, Caterina Lisini, Iole Francario.

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A survey of Danish earthen heritage for sustainable building

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ABSTRACT: Earthen buildings were common in Denmark up until circa 1880, after which the number of such buildings declined. Today earthen buildings are considered as examples of sustainable architecture, nevertheless there are only few contemporary Danish earthen buildings. The first part of this paper investigates heritage uses of earthen building with a view to exploring the factors that led to their decline. To achieve this, the paper will present a literature study and a case study. The second part of this paper comments on the extent to which the earthen heritage techniques have the potential to contribute to future sustainable building.

1 INTRODUCTION

In the early 20th century the National Museum of Denmark began collecting information on vernacular heritage through both surveying buildings and interviewing their residents. In one particular example, Hans Peter Nielsen described how the family farm had been constructed by his grandfather in 1836. He explained that the materials required for half-timbered buildings were cheap and easily accessible—as timber came from the local forest, reed from the bogs, turf for the ridge from the meadows and clay was used for infills of wattle and daub. In 1867 Hans Peter Nielsen's father had taken over the farm and began the work of improving the buildings by replacing infills made of wattle and daub with baked bricks. When Hans Peter Nielsen inherited the farm, he also made a number of improvements including a new brick-built farmhouse. Finally, Hans Peter Nielsen stated that he used cheap building materials just like his grandfather (Skougaard 1985).

This oral account provides us with evidence of several interesting features of earthen heritage. Firstly, it suggests that clay required for building was so easily accessible from a number of locations that its origin was not specified. Secondly, it is known that although clay was a cheap building material, baked bricks were considered better. Finally, this account indicates that wood, reed and clay were common vernacular building materials. It is interesting to note that while wood and straw still are in use, earth is not considered a building material.

Recently, a growing number of research fields with a focus on sustainable architecture has emerged. In this connection, clay is often touted as an example of a very sustainable building material, primarily due to its low energy production methods, thermal properties and possibilities for recycling and natural decomposition. Considering all these advantages of using clay, as well as, its accessibility, one would expect that earthen building would be very popular in Denmark. However, contemporary earthen building techniques are only used by a small group of experimental building owners.

Contemporary building focuses, largely, on energy consumption in the operational phase due to strict building regulations, while other aspects of sustainability often are paid little or no attention. New research demonstrates that the main differences between preindustrial vernacular dwellings and contemporary dwellings are that preindustrial dwellings decompose naturally and generate far less waste than their contemporary counterparts (Eybye 2016). Moreover, heritage rammed earth is praised for its qualities in relation to indoor climate and energy (Risom 1959) and earthen buildings can be designed in accordance with most architectural styles.

Due to the low environmental impact and the architectural possibilities, it seems logical to study heritage uses of earthen building techniques for the purpose of exploring their potential in future building.

2 AIM OF RESEARCH AND METHODOLOGY

This paper investigates the heritage uses of earthen building in order to discuss why this readily available and versatile building material went out of use; and to examine if earthen building techniques

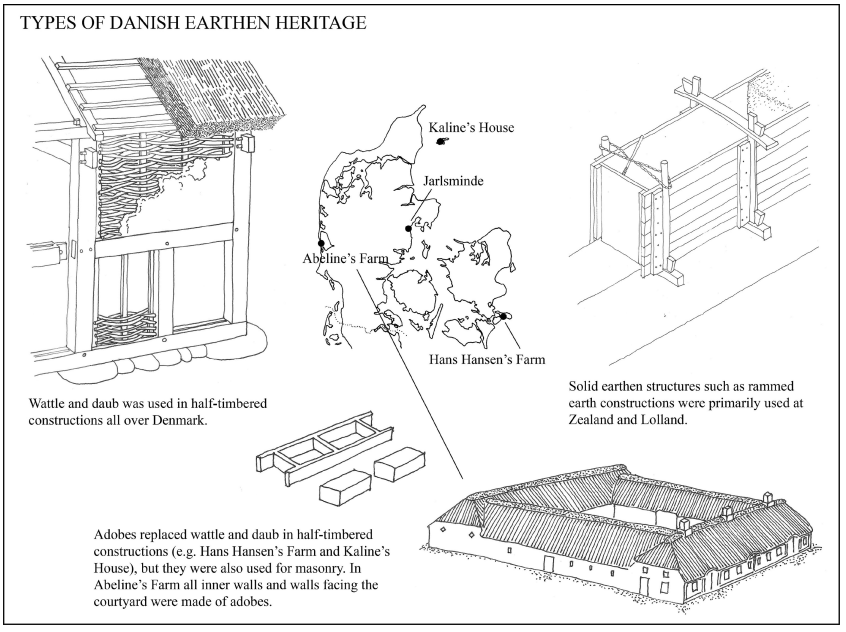


Figure 1. Types of Danish earthen heritage: wattle and daub, adobes and solid earthen structures (Eybye).

can contribute to future sustainable building, i.e. particular easily applicable solutions that can be used in more 'standard' building and not just by few, idealistic building owners.

The first part of the paper examines why the construction of earthen building ceased in the late 19th century, as this knowledge is essential to any discussion on the potential use of earthen heritage principles in future sustainable building. Hence, the paper presents a literature study in order to explore the earthen heritage buildings. The study focuses on three main types of historical earthen building techniques—namely, wattle and daub, adobes and solid earthen structures. In addition, examples of particular earthen heritage buildings are briefly described. For the purpose of illustration, this paper provides a case study of a former farmhouse situated in Stavtrup, Aarhus. Lastly, this section identifies advantages and disadvantages of earthen buildings and offers reasons for the decline of earthen building in the late 19th century Denmark.

The second part of the paper investigates the potential application of earthen heritage building techniques in relation to future sustainable building, via outlining the advantages and disadvantages of earthen heritage buildings. In doing so, this section presents a framework for assessing the sustainability of earthen materials and techniques, based on four evaluation points. This section concludes with a number of suggestions for future sustainable building.

The main sources utilised in this paper are 'Lerhuse' and 'Nordiske Ler-jords-huse' by Sven Risom in which he promoted the use of earthen building due to scarcity of resources during and after World War II and more general literature on Danish architectural heritage. The case study used comprises of the authors' empirical studies, interview with owners along with other sources such as drawings. Assessments of sustainability are, largely, informed by Karina Vissonova's categories of sustainability.

3 A HISTORICAL SURVEY: TYPES OF DANISH EARTHEN HERITAGE

3.1 *Wattle and daub*

Half-timbered houses with infills made of wattle and daub were built from prehistoric time until the 19th century all over the country. In rural areas, the construction of half-timbered houses was a communal task undertaken by the entire village community. Once the timber frame had been erected and roofed, it was time to organise the infills. This was preferably done in May, because mudded earth was less likely to crack at this time of year. Sources indicate that village men provided 'fresh' clay and mudded it with straw and dung, while village women built infills with mud on a framework of hazel branches. After a day or two of drying, the infills were plastered with a thin earthen gruel-like substance made of 'old' clay and, lastly, whitewashed to improve its durability (Risom 1952, Skougaard 1985).

As infills of wattle and daub are fragile, each year they were maintained by female residents. A number of architectural features developed over time aimed at improving lifespan of the infills—including wide eaves, drips and boards leading water away from the facades. Furthermore, it was common practice to stack turfs (so-called 'træk') along walls or to nail mats made of reed on the lower infills for winter protection.

3.2 *Adobes*

Similar to wattle and daub, evidence of the use of adobes is seen across Denmark. Adobes have their origin in the type of bricks that have been used in prestigious building, beginning in the middle of the 12th century. However, a general use of bricks in 'common' building cannot be registered until the late 18th century. Baked or not, building techniques using bricks and adobes are rather similar—for this reason adobes were applied as a cheap and easily accessible substitute.

Reports on rural building traditions were compiled in 1786 in the context of agrarian reforms. These reports state that wattle and daub was still prevalent, but adobes were beginning to replace them due to better durability (Lerche 1987). An example of this is the half-timbered Hans Hansen's Farm on the island of Møn. This farm was relocated from its village plot and reconstructed on a new site outside the village in 1800. Original infills from year 1800 were made of wattle and daub, while later repairs were made of adobes. Another example of the use of adobes is the half-timbered Kaline's House on the island of Læsø. This house is considered to have been built around 1865 and all infills were made of adobes.

Furthermore, a particular type of farms situated in the dunes close to the west coast of Denmark provides us with a clear example of the use of adobes as masonry. These farms were built approximately between the years 1800–1880 and they are (among other things) characterized by brick-building techniques due to harsh climate conditions that made half-timbering less durable in this area. Baking bricks quickly depletes solid fuel resources and hence, adobes were applied instead of bricks wherever possible. In general, inner walls and outer walls less exposed climate (and visitors) were constructed using adobes and plastered and whitewashed to improve durability.

3.3 *Solid earthen structures (rammed earth and cob)*

In 1796 an influential book called 'Kunsten at bygge bequemme og uforbrændelige Huse af stampet Ler' (which can be translated into 'The art of building comfortable and non-flammable solid earthen houses') was published in Denmark. As wood had become a scarce resource, a number of building pioneers—in particular squires and clergymen—promoted these new construction methods. It is estimated that about 4.000 earthen buildings were constructed between the years 1780–1870 with rammed earth as the primary construction techniques, which was particularly popular between the years 1810–1830 (Risom 1959). The vast majority of earthen buildings are found in Northern Zealand and on the island of Lolland. In contrast, there are only a limited number of solid earthen heritage buildings located at Funen and in Jutland respectively. From the sources, it appears that earthen buildings were frequently constructed in the same area—perhaps reflecting an enthusiastic squire or a local master builder familiar with the technique(s).

Generally, buildings constructed using solid earthen techniques include schools, country mansions and dwellings such as the homes of agricultural workers, as well as, stables and barns. While half-timbered buildings are, for the most part, observed in the context of vernacular dwellings, solid earthen buildings appears to have been adopted by well-educated and wealthy members of society for their private dwellings.

For instance, a primary source from 1809 provides us with a squire's contemporary account of the construction of a farm using the rammed earth technique. The squire writes that his farm hands were rather sceptical of this new way of building at first, but they soon realised that the thick walls saved firewood and did not present a fire hazard to the same degree as half-timbered constructions (Risom 1952).

3.4 *Other heritage uses of clay and earth*

In addition to these three overriding types of earthen heritage are a number of other heritage uses of clay. For example, clay was used as pugging in multiple-storey houses to prevent noise and fire, as mortar in masonry of both bricks and adobes and as plaster, for instance to protect infills made of wattle and daub (Eybye 2016, Risom 1952, Risom 1959, Vadstrup 2004).

4 CASE STUDY: JARLSMINDE, AARHUS

4.1 *Introduction to Jarlsminde*

Jarlsminde is a former farmhouse situated in Stavtrup in the southern part of Aarhus. The farm including the farmhouse was built in the early 1820's by Juliane Marie Wedel Jarlsberg, an unmarried daughter of a Norwegian count and envoy. It is speculated that Juliane Wedel Jarlsberg may have become aware of rammed earth construction either during family stays abroad or while living

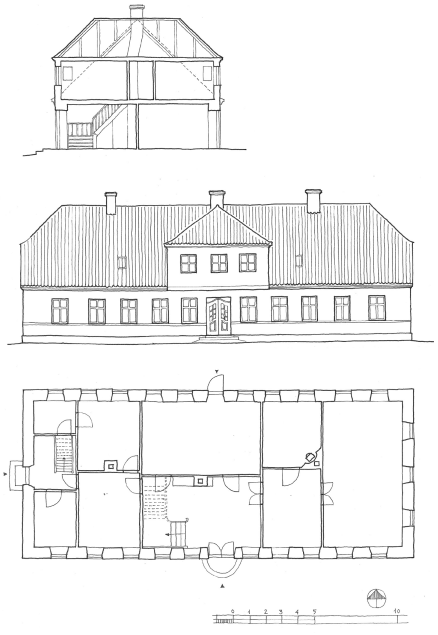


Figure 2. Jarlsminde section, south elevation and plan. Clearly, Juliane Wedel Jarlsberg wanted a neoclassical design for her new house. Original drawings by Tri-Consult A/S (Eybye).

in Northern Zealand (Orduna 2000). The result being that this method of construction was chosen for the building of her new four-winged farm. Subsequent to the building of the farm, a similar rammed earth construction was chosen for the new school in Stavtrup. In 1997, Jarlsminde was listed as a rare example of rammed earth heritage in Jutland; interestingly, it was only at this time that the farmhouse was officially registered as a rammed earth construction.

4.2 *Uses of earth in Jarlsminde*

As previously mentioned, Jarlsminde is a rammed earth construction. Studies of the building show that the walls in the attic are built of adobes. Moreover, the current owners explained that earth is used in the sub-floor construction and as pugging. It is, also, likely, that clay plaster and mortar were applied in the construction phase. The clay used in the rammed earth construction appears to have been sourced from a local clay pit. The house has a facing wall of baked bricks that may be original, but more likely built sometime between 1820's and 1939.

Next to the main house is a smaller house. In terms of interesting features, this building contains a baking oven constructed using bricks and clay mortar—materials able to withstand the high temperatures associated with baking.

4.3 *Interview with Jarlsminde owners*

The topics of the interview can be divided into three themes general knowledge of the house, indoor climate and energy, and maintenance.

The current owners of Jarlsminde (Bente and Einar Rud Pedersen) have lived there since 1996. Einar Rud Pedersen's grandfather bought the house in 1939. The ground floor of Jarlsminde is about 250 square meters and the attic is approximately 200 square meters.

In relation to climate and energy, Bente and Einar Rud Pedersen exclaim that "the house is never really warm, nor really cold." They admit that the house is rather expensive to heat compared to a new house, but most likely cheaper than a contemporary 19th house of the same size. In the winter they use passive energy strategies, as the house is rather big and not all parts need to be room temperature. Moreover, they use slippers during winter, as the floor is cold. The air of house is always fresh, and finally, Einar Rud Pedersen remarks that the acoustics of the house is really good compared to other houses. Due to the rammed earth construction and traditional building materials such as wood, whitewashing etc. they believe the house to be a healthy one.

Continuing on, maintenance is discussed. Bente and Einar Rud Pedersen are very careful to use traditional materials that work well together with existing structures. However, it is noted that such solutions are expensive. They explain that a listed house (such as Jarlsminde) needs constant maintenance; in particular, the windows require a great deal of conservation. Bente Rud Pedersen points out that it is very difficult to find skilful craftsmen familiar with heritage conservation, in particular earthen heritage.

5 EARTH AS A BUILDING MATERIAL: ADVANTAGES AND DISADVANTAGES

The survey of the primary and secondary sources, as well as, the case study demonstrate a number of inherent advantages and disadvantages associated with employing earth as a building material.

The identified advantages of earthen buildings are:

- Clay and (by implication) earth represents a readily available building material, in the majority of Danish regions. This fact is attested by the widespread evidence for wattle and daub infills and adobes.
- The survey and the case study provide us with evidence of the multitude of applications of clay and earth in buildings (e.g. wattle and daub, adobes, solid earthen constructions, plaster, mortar, pugging and sub-floor constructions)

– As a logical consequence of the points outlined above, the techniques applied when processing clay and earth could be described as 'social' or 'egalitarian', as nobody owned or held and rights of these techniques.
– The rammed earth dwelling studied as part of this research possesses qualities in relation to indoor climate and comfort such as acoustics and hygroscopy.

The identified disadvantages of earthen buildings are:

– Earthen building, in particular exterior aspects such as walls constructed using wattle and daub, requires maintenance due to the high level of precipitation characteristic of coastal climates.
– Currently, it is difficult to find craftsmen that are familiar with earthen construction techniques.
– Though rammed earth walls (50–60 cm) are better than walls constructed using wattle and daub (15 cm), they do not provide sufficient insulation in Nordic climate.

5.1 *Potential reasons for earth going out of use*

It is highly likely that the explanation(s) for earthen building declining in use is directly related to the use of bricks—as brick-building was considered prestigious and durable. From the middle of the 19th century, a number of factors aided the promotion of brick-building. The relatively rapid industrialisation of Denmark during this period included the construction of railways and (relatedly) widespread use of coal. The arrival of the railway network made the transportation of coal and building materials easy, so the average person no longer depended on local materials for building. The increasingly easy access to coal solved a number of issues regarding energy, including the problem of providing sufficient solid fuel for brick baking. Furthermore, the so-called ring kiln (or Hoffmann kiln) revolutionised the process of baking bricks—with the rise in the number of brick buildings being indicative of an increased production of cheap bricks. At the same time, a change in agricultural production methods resulted in (even small-scale) farming being more lucrative. As a result, farmers opted for the construction of new buildings using bricks. Starting in the late 1870's, such economic factors led to the decline of rural half-timbered buildings that had been constructed in accordance with local building traditions and the available local resources (Eybye 2016).

Neoclassicism—according to which buildings ought to be plastered and lime-washed—ended around 1850 and eclecticism began. In Denmark, eclecticism found its inspirational sources in medieval brick-building, which led to fostering of masonry and aesthetics of masonry detailing. In addition, the upsurge in the use of bricks for construction at the expense of earthen building techniques may also be considered in terms of a number of badly constructed earthen buildings (primarily cob) which tarnished the perception of solid earthen construction techniques (Risom 1959).

Although it is probable that a plurality of factors played a part in the decline of earthen buildings, but it is an assertion that the socio-economic and technological reasons outlined in this paper reflect the most significant ones.

6 EARTHEN HERITAGE BUILDING TECHNIQUES FOR FUTURE SUSTAINABLE BUILDING

6.1 *Defining sustainability*

Sustainability is an essentially contested concept (Eybye 2016). For this reason, this section of the discussion starts by defining sustainability as it is used in this paper. According to Vissonova (2016), the sustainable design of technical artefacts should be categorized into four groups. The first group comprises of design in which the functional aim is to replace polluting or resource depleting artefacts with sustainable solutions such as wind mills and electric cars; but their material structure is (in itself) unsustainable. The second group contains products with a sustainable function, in which materials or solutions are deliberately chosen and the number of toxic materials are reduced. The third group are designs that can be considered sustainable due to recyclability, decomposition, disassembly and a long lifetime or the reduced use of virgin materials—though their function may not be sustainable (e.g. packaging and wrapping). The final, fourth group comprises of designs that are sustainable both in function as well as structure and are made of clean or reused (local) materials with no adverse environmental effects (Vissonova 2016).

The authors advocate that the principles of Vissonova's four categories can be employed in a wider sense for the purpose of defining sustainability. Consequently, the authors argue on the basis of these four categories that clay and earth represent highly sustainable materials due to the fact that they can be readily recycled and decompose naturally (Eybye 2016, Vadstrup 2013). Furthermore, earthen materials can be designed for disassembly and they are often used in building with the intention of constructing houses, including healthy living spaces and low environmental impact (Guy & Farmer 2001).

6.2 *Earthen heritage building techniques for future sustainable building*

The previous section outlined a number of factors that contributed to the decline of earthen

construction methods, in the middle to the late 19th century—these included maintenance, the availability of affordable bricks and matters related to architecture. The following factors are relevant in any discussion concerning the viability of earthen heritage building techniques in relation to future sustainable building:

- An increasing focus on sustainability has influenced contemporary debates concerning architecture. It seems that sustainability is as revolutionary to current architecture as bricks were to building in the late 19th century. This is likely to be a crucial factor in the promotion of future earthen building.
- The survey presented in this paper demonstrates that clay and earth were used for multiple building purposes, in the past. Techniques such as adobes, rammed earth and clay plaster are projected to be highly relevant for future building. Moreover, it can be asserted that there is a great potential for developing new building techniques and materials based on earthen heritage principles.
- Earthen building techniques can be described as socially sustainable, because they were shared by an entire community. Going forward, ensuring easy access to cheap earthen materials and industrially manufactured products continues this principle of enabling a sizeable majority of people to sustainable and affordable construction materials.
- Increased general access to earthen products has the potential to promote the use of contemporary earthen building techniques in the design of 'standard' domestic building.
- The incorporation of earthen materials in the interior of buildings have definite advantage as they require less maintenance and offer superior hygroscopic and acoustic performance, compared to more modern materials such as concrete or glass.
- Although considered as a traditional technique, it could be suggested that earthen constructions offer the same—if not more—versatility as a number of more modern materials. For instance, earthen materials enable a high degree of design and architectural expressions.

7 CONCLUSIONS

This paper focused on investigating the uses of earthen heritage buildings in Denmark. This topic reflects an area of study that has been, for the most part, under researched. The two objectives of this paper were to discuss the probable reasons for decline of earthen buildings in the late 19th century and to explore how heritage earthen building techniques may contribute to future sustainable building. To achieve these objectives, this paper has presented a literature study of the design, construction and use of earthen building. This paper supported and augmented the primary sources by way of a case study, undertaken by the authors. In addition, this paper presented the most likely scenarios which contributed to the decline of earthen buildings. In doing so, this innovative paper contributes substantially to our knowledge of earthen buildings in Denmark. Lastly, this paper outlines how a number of principles directly associated with earthen heritage building principles can inform future sustainable building.

As this paper represents the authors' initial stage of research, it is suggested that continued study will result in a more comprehensive understanding of the rich heritage of earthen dwellings and their associated techniques in Denmark, as well as, their potential to inform future discussions on achieving sustainable buildings with low environmental impacts.

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Lessons of sustainability from the survey of the Valencian *barraca*

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ABSTRACT: From the conception, constructive evolution and vernacular environment of the Valencian *barraca* (traditional Valencian rural cottage), a series of features may be noticed which are not identified by the current legislation for the creation of strategies for the conservation of rural heritage. In this paper the typology of this building and its habitat from environmental, socio-cultural and socio-economic bases is analysed by verifying the compliance of the 15 parameters which are defined in the Versus Project, an important international research endeavour that aims to obtain knowledge from the study of the principles of sustainability in the vernacular built heritage. According to these parameters, the possession or lack of values of sustainability of this particular type of architecture can be recognised, and consequently, its usefulness as a model from.

1 INTRODUCTION

This research is carried out with the premise that the Valencian *barraca* is considered an example of vernacular architecture, since it is a domestic building, constructed by hand, with no market value when it was built, and built with local materials (Guillaud 2014: 33).

1.1 *Origin, definition and different types*

The Valencian *barraca*, as an architectural typology, symbolises par excellence the traditional housing of Valencian farmers and fishermen.

According to the research carried out by Pastor (2012) and other authors, the origin of the *barraca* goes back to the prehistoric period, and its design is based on the stilt houses over the marshy lands in Valencia and the the fertile, irrigated farmland around the city in Iberian times (Pastor 2012: 182–183). In the eighth century, during the Muslim occupation, the *barraca* is first built on firm ground. Since then, the shape, layout, materials and techniques used for its construction have evolved in order to adapt better to the local weather conditions and to the needs of its inhabitants.

Authors like Gosálvez (1915), Michavila (1918), Max Thede (1993) and Sanchis Guarner (1957) have identified different varieties of *barraca* depending on its location and its function always around a very humble conception, first with a single space with a central fireplace or kitchen, and later on with a side kitchen and a compartmentalised space.

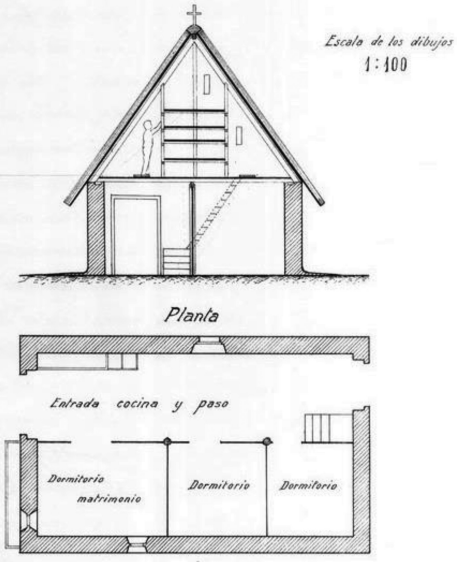


Figure 1. Ground plan, cross and longitudinal sections of a *barraca*. Extracted from Gosálvez, 2015: 21.

1.2 *Constructive evolution: material and techniques used*

The composition of the *barraca* has two essential parts: a base, which is composed of vertical walls, and an upper part, identified by a gable roof. Both parts have changed over time, and according to texts by authors like Gosálvez (1915), Sanchis (1953) and L'Escrivà (1976), up to five different

building stages can be stablished considering the materials and the techniques used.

At the first stage, the materials used are canes and mud, and the process consists of driving bundles of canes, which are tied together with reeds, into the ground. These cane bundles are also interlaced at the ridge, forming a gable roof, and define a single space with a fireplace in the middle. The construction is completed by covering these cane frameworks from the inside and from the outside with a layer of mud (L'Escrivà et al. 1976: 41–48).

At the second stage, driving canes into the ground is substituted by hard branches (elm, black poplar, mulberry, etc.) previously sun-dried. And the mud cover at the roof is replaced by different types of reeds (L'Escrivà et al. 1976: 41–48).

At the third stage a new material is introduced, lime, which is used for the final stages in order to whiten the mud-coated walls. The technique for constructing walls is improved by including a framework made of canes, tied with espartograss ropes (*canyizo*), between timber posts (L'Escrivà 1976: 181). They are finally coated with mud, and covered with material made of different types of reeds, such as dead *borró* (*Scirpus supinus*) leaves, *mansega* (*Cladium mariscus*) and/or *senill* (*Phragmites communis*), in order to increase the durability (L'Escrivà et al. 1976: 48).

At the fourth stage, the introduction of a new material, such as straw, created new possibilities. The mixture of mud and straw turned out to be more stable, and it made it possible for a new wall construction technique to be tried: *fang remugat*/*pared de mano* (cob technique). It's based on the superposition of successive strips of 10 and 20 cm thick of the aforementioned mixture, mixed only by hand, to obtain more solid walls, between 50 and 120 cm high. In order to protect the *barraca* from dampness, the roof is extended to the floor, where a ditch prevents water from overflowing (Pastor 2014: 87–88).

The fifth stage can be considered the most important, because the *barraca* makes a leap forward in the quality of its comfort, security and roominess. Even if at this stage there aren't changes with regard to materials, the technique for building walls makes significant progress: the *gassons* (adobe bricks) technique. As before, this innovation consists of the production of polyhedral pieces of about $40 \times 35 \times 6$ cm with the help of wooden moulds, using the same mud and straw mortar, but with more water and dried in the sun for between 2 and 3 weeks in order to become more consistent (Gosálvez [1915] 1998: 11, De Hoz et al. 2003: 57). The wall is now built on a well trodden base, comprising two adobe bricks lengthwise and one brick across, attaining a height of up to 2.5 m above the floor. The adobe bricks are put together with the same mud and vegetable fibre mixture, which is sometimes improved with lime. Right after, the external walls are protected from the outside by being coated with mud, using a mud and straw mortar and applied by hand or small tools. And finally, a limewash is applied on the wall and annually renewed.



Figure 2. Adobe brick wall. Picture of the authors.

Once this new technique has been tested, other small improvements are tried, like the inclusion of trunks in the wall, driving them into the floor so they support the main beam (*cardosa*), which takes the weight of the roof framework (Pastor 2012: 193–197).

As it has been able to analyse, the creativity and innovation, motivated by the desire to improve living conditions, affect above all the base of the *barraca*, and they deal with the use of local materials, mainly the soil.

The construction of the roof suffers fewer changes. The most significant improvement is the introduction of a structure bracing system of small rectangular framing squares made of sawn timber, which form diagonals within the longitudinal plane, and covers at least the two first and two last bays.

1.3 *Current regulations situation*

The *Ley de Patrimonio Cultural Valenciano* of 1998 (Regulation of Valencian Cultural Heritage) took the first step in recognising the heritage values of the "*barraca*" architectural type, by ascribing the protection of real estate of local relevance to "the traditional *barracas* of the *comarca* (district) of *L'Horta de València*". This regulation also required each local town council within the jurisdiction of which lay each case, to include them in their municipal catalogues of protected assets and spaces.

Fortuitously, the *Plan de Acción Territorial de Ordenación y Dinamización de la Huerta de Valencia* of 2016 (Regional Action and Revitalisation Planning of the Farmland of Valencia, from now on PAT) is being processed at the moment. One of its purposes is to identify and recognise the particular

values of the "*barraca*" architectural type. The result is the *"Catálogo de Bienes y Espacios Rurales Protegidos"* (Catalogue of Protected Assets and Rural Spaces), which contains 29 cases of this vernacular typology.

From analysing the catalogued files, the recognition of the following particular values and their percentage representation overall can be noticed: typological value is identified in 28 of the cases (96%), value of the landscape in 9 (31%), ethnological value in 3 (10%), architectural value in 2 (7%) and value of the woodland in 1 (3.5%).

But there are two significant aspects: the first is that the value of the landscape is present in a third of all of the cases, so it means the habitat is disappearing; and the second is that only two cases possess a value of architectural quality, so it means the *barraca* is much modified from its original conditions.

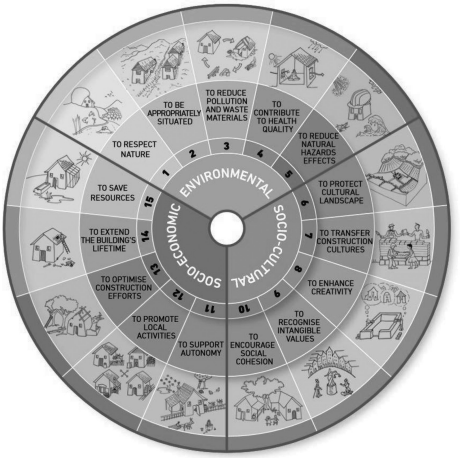


Figure 3. The principles of environmental, socio-cultural and socio-economic sustainability. Extracted from Correia et al., 2014, 27.

2 AIMS AND EXPECTED OUTCOMES

On the one hand, from the definition, evolution and constructive process architectural typology of the Valencian *barraca*, we can infer a set of good practices associated with the vernacular habitat. On the other hand, in the current regulations, it can be observed that these practices are not taken into account at the identification of heritage values. Therefore, we propose that the main aim of the research indexed at this paper be the analysis of this architectural type, from the environmental, socio-cultural and socio-economic principles analysed as typical of vernacular habitats, in the Versus Project.

The outcomes of this paper will allow the acknowledgement or the rejection of the consideration of the value of sustainability of the Valencian *barraca*. We also want to raise awareness of the existence of sustainable designing strategies that can be put into practice these days.

3 METHODOLOGY

The evaluation of this vernacular typology has been structured in three areas of study, within them the Valencian *barraca* has been analysed from five parameters: environmental from the respect to nature, the establishment in the physical environment, the decrease of pollution and other waste, the preservation of health and the minimization of the natural risks; socio-cultural from the protection of the cultural landscape, the transmission of cultures of construction, the promotion of creativity and innovation, the recognition of intangible values and the development of social links and; socio-economic from the development of autonomy, the promotion of local activity, the optimisation of efforts during the constructive process, the extension of the life cycle of buildings and the preservation of energy and resources.

The research submitted in this paper has been principally carried out from bibliographical sources of general topics on vernacular architecture and sustainability, which are specialised in the Valencian *barraca*. This decision was taken after noticing in many, but not all, of the cases, the complexity in gaining access to these properties and being able to describe them from pure visual inspection.

4 OUTCOMES

According to Vellinga (2015), if the sustainability to the environmental aspect results limited, not only do we fail to give a complete outlook of the challenges faced by sustainability, but we also do not learn from them and their usefulness for the context of sustainable contemporary architecture, because the totality of these challenges is not recognised (Correia et al. 2014: 57).

4.1 *Survey of the Valencian* barraca *from environmental sustainability*

Environmental sustainability is considered as understood by Gonzalez (2004): "The capacity of the human intervention in decreasing or avoiding a building's adverse environmental impacts, reacting to every change in the environment understood as the set of conditions in which life is possible, and regarding the whole biological quality (Neila González 2004).

4.1.1 *To respect environmental context and landscape*

The Valencian *barraca*, as a typology, has proved to be a building that respects the environment where it has been built. It has an external image closely related to the surrounding landscape because of the scale, materials, colour and texture that can be extracted from it.

The features of the location and local culture can be seen in the materials and construction techniques. Clay soil, water, canes and reeds are inherent materials of the Valencian farmland, and their use in the construction of the *barraca* with different techniques is not by chance, and provides balance and harmony with the environment, generating an integrated habitat that does not harm the ecosystem.

Also, the natural and/or biological origin of the materials that are used guarantees that once the life cycle of the building has come to an end they will be reintegrated with the environment.

4.1.2 *To be appropriately situated*

The predominant winds in the metropolitan area of Valencia and its surrounding area, with an E-W component, are a key factor in the orientation of the Valencian *barraca*. The application of the *genius loci* of the climate created a solution to the needs of health and hygiene by locating the ventilation openings at the E and W façades. This benefit can also be felt when there is no atmospheric pressure due to the sea breeze, which although of low intensity, is strong enough to allow natural ventilation.

It is also a fact that the position of the long façades implies, mainly in the case of two storey varieties, the existence of a thermal mattress that accumulates heat over the summer and transfers it inside during colder seasons. The longitudinal façade facing N absorbs the heat that is produced inside, thus postponing its transfer to the external environment due to its thermal inertia.

4.1.3 *To reduce pollution and waste materials*

The construction and maintenance of the Valencian *barraca* contributes to the reduction of environmental pollution from two perspectives. Firstly, the lack of manufacturing processes for the production of the materials, because they are used in their natural state (soil from the farmland, water from the irrigation canals, trunks of black poplar wood, elm or mulberry trees, *borró*, *mansega* or *senill* reeds or dead leaves) or slightly manipulated (cane or esparto). Secondly, the local origin of the materials. Both circumstances avoid the consumption of energy and the emission of polluting gases from both the manufacturing process and the transportation from the place of origin that would be necessary.

4.1.4 *To contribute to health quality*

The covering of the Valencian *barraca* is distinguished by the following: natural, not toxic, and air-permeable materials that regulate humidity, such as soil or lime are used; the thermal inertia of the walls facing the N-S axis and the presence or lack of small holes in these walls helps to maintain comfortable humidity conditions for longer; a deciduous arbor shade is created next to the main façade, avoiding the overheating of the inside space during the summer; the openings in the E-W façades allow ventilation to pass through the building; the loft functions on a thermic level as an air chamber, isolating the living area from the outside in the winter, and its holes let ventilation on the chamber during the warm season; the whitewashed internal walls, besides having antibacterial properties, reflect natural light and helps to create a more illuminated environment.

4.1.5 *To mitigate the effects of natural hazards*

Even though the Valencian *barraca* has been able to demonstrate a solid and robust appearance, the roof has turned out to be the most vulnerable part against two different hazards: the effects of wind and the effects of fire. In order to reduce the risks of the effects of wind, diagonal bars are introduced in the design. And in order to prevent fires, the kitchen is brought outside the *barraca*, either onto the street or into the stable.

4.2 *Survey of Valencian* barraca *from socio-cultural sustainability*

Nature and culture are closely linked to the identity of every community. The knowledge of past traditions and habits together with the sharing of experiences constitute a socio-cultural heritage that must not be undervalued, as they can help us to improve our standard of living in the future.

4.2.1 *To protect the cultural landscape*

The Valencian *barraca* has value as part of a cultural landscape, with its own traditions, beliefs, etc. Between any of the versions of the Valencian *barraca* and the socio-cultural environment there is a unique relationship: the existence of a culture based on the farming system of the fertile Valencian fields has created the conditions for the construction of these buildings and, conversely, it is hard to appreciate the values of these buildings when taken removed from their cultural context.

4.2.2 *To transfer construction cultures*

Vernacular architecture displays in its materials and constructive techniques folk wisdom which includes the knowledge and experience of craftsmen and unknown master builders (Guillaud 2014: 53). They know the best option for construction

according to specific parameters of each context. Consequently, each community within a territory is distinguished by these types of architecture.

The success of the evolution and innovation of the construction of the Valencian *barraca*, with regard to materials and structural techniques, is due to the passing on of knowledge from generation to generation.

4.2.3 *To enhance innovative and creative solutions*
From the studies of the construction of *barracas* in Valencian fields done by authors such Michavila, Gonsálvez, Thede and L'Éscrivà, the technical innovation can be noticed, for instance when building load-bearing walls, which is carried out via a technique known as '*pared de mano*' (cob technique) when building with adobe bricks prepared beforehand. This innovation has repercussions for various aspects: firstly, the time taken to build a *barraca* using adobe bricks is less than using the *pared de mano* technique, as in the latter, it is necessary to wait until each layer hardens to avoid the mixture crumbling; secondly, the resistance of a wall made with adobe bricks is greater, as the mixture is dense; thirdly, the flatness of the surfaces and the verticality is better with the adobe brick technique.

4.2.4 *To recognize intangible values*
The intangible cultural values of a community can be recognised through its vernacular architecture.

Different elements can be found at the Valencian *barraca* that show these intangible values. For example, at the highest point of the main façade of some *barracas* a wooden cross can be seen, whose meaning is explained by Gosálvez as follows: "it was used as a distinction between the Christian *barracas* from those belonging to the Moors who lived in the Valencian fertile plains before being expelled" (Gosálvez [1915] 1998: 24). Another example can be found in the space under the roof, specifically in the traces of the horizontal strip frameworks that can still be noticed nowadays. They were lengthways and transversely arranged in two levels, fixed to straight bases supported by crosspieces which form the triangular roof structure. These frameworks reveal a productive activity: silkworm breeding. This activity was at its height in the eighteenth century, when it constituted one of the main incomes of the families, although it disappeared in the nineteenth century. It was considered to be women's work, and it consisted of nurturing the silkworms and then selling the spun silk (Fernández Montes 1996: 606).

4.2.5 *To encourage social cohesion*
Vernacular habitats show the desire of their inhabitants to live together and share in order to improve living conditions and make life easier for the members of the community members. This aptitude can be seen in spaces which have been created for those purposes, such as markets, squares, fountains, communal washing basins, etc. (Guillaud 2014: 54).

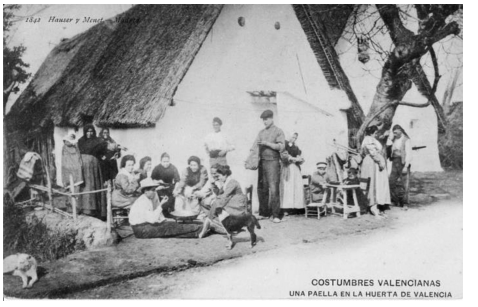


Figure 4. "Paella in the farmland of Valencia" (1906) Anonymous. Source: Digital Library of Valencia.

With regard to the habitat of the Valencian *barraca*, this circumstance is illustrated with different examples: under the arbors of the farmland *barraca* neighbours and families gather and additionally, extension works on the *barraca*, sometimes building a duplication it, also are an indicator of social links, usually family links.

4.3 *Survey of Valencian* barraca *from socio-economic sustainability*

Economic management is extremely important from the process of construction, the performance, maintenance and the impact of the building into local standards of living (Correia et al. 2014a).

4.3.1 *To support autonomy*
Self-sufficiency of small groups was one of the common circumstances in the families that lived in the *barracas*, mainly the ones of the farmland. The fact of living in more remote environments forced the families to be self-sufficient. This peculiarity was clearly shown in the building construction itself, where the stable was planned either at the rear of the *barraca* or in a new *barraca* that was built for this purpose. Animals were bred there, this guaranteeing the annual survival of the family.

The economic efficiency of these small communities lay in the proper work planning, in which field work was combined with the stable maintenance.

4.3.2 *To promote local activities*
The preservation of vernacular architecture and its environment has a direct and indirect positive impact in the local economy. On the one hand, it can be noticed how money spent on restoration or preservation work is returned to the local community. In turn, this has an impact on the craftsmen and the local workers because, thanks to their

experience, they become better acquainted with the materials and most appropriate techniques for each place, rather than indiscriminately using industrial solutions (Vegas et al. 10: 2007). On the other hand, the preservation of vernacular architecture emphasises its intrinsic values and encourages the implementation of local service sector activities such as cultural tourism, so it has also an effect on the local economy. Currently, a subtle trend to reuse the Valencian *barracas* is being noticed. In this sense, a great effort to make is needed in order to make the safeguarding of the values of this heritage easier.

4.3.3 *To optimize construction efforts*

The presence of a specialised trade can be identified, which Gosálvez (1915) describes as "*els barraquers*". This group included the *mestre barraquer* (the *barraca* build master) and the *barraquers* (five workers, two skilled workers and three labourers). The *mestre* was in charge of two jobs: at the start of the works, he rented out the mould for the adobe bricks to the family in question; and after he supervised the works. *Els barraquers* were in charge of building the four walls, the roof structure and the placement of organic fabric. The family also helped: firstly, they prepared the adobe bricks, dried and collected them, protecting them with a layer of wattle and soil; secondly, after the *mestre* had organised the layout, they prepared the levelling and trampling of the foundation trenches; and thirdly, they worked as labourers: bringing materials to the work site at every stage of construction.

4.3.4 *To extend building's lifetime*

Regarding the relation to the ecosystems, Hollings (1973) explained the resilience of the vernacular architecture as "the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes" (Dipasquale et al. 2014: 65). If this is acknowledged it in that sense, it will be possible to adapt buildings to new uses through respectful interventions. In this way, the demands for comfort and quality to meet today's standards will be accomplished, and the life cycle of these specific buildings will be extended. At the same time, the use and enjoyment of this heritage by society will be promoted.

4.3.5 *To save resources*

Geographical isolation and/or the shortage of natural resources have historically necessitated the efficient use of those resources and creativity in achieving more with less.

With regard to construction, aspects such as the use of timber was restricted to the roof structure and the external joinery, whereas inside the building the openings were covered with fabric curtains, since wood was a limited resource. Also, the use of lime was restricted to the whitewashing of the wall faces due to reasons of hygiene, while its use for mortars and plasters was restricted because it was not possible to obtain lime swiftly and it was expensive.

But it was also present in the way people lived. In the Valencian farmland, there were everyday examples of responsible management of resources, such as: the reutilization of the part of the harvest which could not be sold for feeding livestock and pets; or the use of animal excrement as manure for the farming soil.

5 CONCLUSION

This research has proved that the Valencian *barraca* is a model of good practices, as a result of how its construction and resulting habitat are conceived And therefore it is an example of the values of sustainability, based on the environment, socio-cultural and socio-economic principles.

We hope that this research is useful in justifying the recognition of the value of sustainability of this vernacular heritage—something which is not public knowledge. We also hope that the current research identifies strategies for designing sustainable and eco-responsible architecture in the construction of the Valencian *barraca*.

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Restoration of the church of the Immaculate Conception in El Llano, Alajuela, Costa Rica

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ABSTRACT: Since 1889 the Church of the Immaculate Conception in El Llano de Alajuela has been an example of vernacular construction in Costa Rica. The church was built with adobe, tile, wood, stone and brick. It has witnessed the country's religious tradition for about eighty years, being subject to many interventions that tried to give it a modern aspect, such as changing the ceiling and mosaic pavement, the construction of the campanile and the warehouse. In 1980, before the construction of a new temple on the north side, the Church of the Immaculate Conception was abandoned, suffering heavy degradation of the materials in the entire building. In 2012, a group of neighbors began to put pressure on the Center for Heritage Conservation of the Ministry of Culture, to demand the restoration and enhancement of the church. The works lasted four months and were carried out following the traditional construction techniques present in the emblematic building.

1 DESCRIPTION OF THE CHURCH

1.1 *Historical review*

After its foundation in 1782, the city of Alajuela was composed of five main districts. El Llano, at that time, was a small village belonging to the neighborhood called Los Targuaces. Over the years, as the population grew, the idea came of building a church in that place. Thus, a great majority of the neighbors were peasants with few financial resources, carried out money-raising activities to build the new church. They asked German Bishop Thiel-Hoffman, as the highest ecclesiastical authority around 1881, for approval. In August, once obtained the approval of the bishop, the construction work of the building began on a land donated by Eusebio Solano Sibaja, a neighbor of the community.

The church was built as a single-nave building with thick adobe walls and a large teak roof, doors, windows and wooden columns and neoclassical main facade in stone and brick. Construction work was completed in 1889 (Fig. 1).

Originally the building did not have bell-tower. It was not until an intervention realized in the first years of 1900, when this element was added, as well as the altars, the floor of hydraulic tile, the wooden ceiling and the sinks of marble for holy water. Later on, a small warehouse was built with wattle-and-daub on the south side.



Figure 1. The Church of Immaculate Conception before restoration (Hernández Salazar).

1.2 *Constructive characteristics*

It is a church with a Latin cross-plan, although originally it was a single-nave building. Later, other rooms were added. The arms of the church are composed of two sacristies, both communicated with the presbytery through two wooden doors. These rooms also have access from the outside of the church; each one has a small window, built with solid wood. The south arm has also an additional space converted into a small warehouse, with access from the outside,

built possibly after 1910, in wattle-and-daub. It is this added element that interrupts what could have been an absolutely symmetrical construction.

In terms of their formal composition, the east, north and south facades are austere, following the pattern of colonial style constructions built with adobe; however, the west frontage of the church shows a neoclassical architectural style, built with bricks and stone. This facade is composed of three entrances crowned by semicircular arches with small stained glass windows in each tympanum. Each of the arches gives way to the interior of the church, to a diaphanous space that forms the main and unique nave of the building. As part of the decoration, there is a series of cornices and pilasters attached to the wall, topped by two pinnacles, placed at both ends of the upper cornice. Also, the church has a small simply decorated campanile, built later, with a square base and crowned by a dome of wooden structure and metallic sheets, with a modest cross at the top.

The main nave of the church is illuminated by four windows -two on each side- topped with semicircular arches, on which simple multicolored stained glasses as those located in the tympanums of the main frontage, were installed. The church has a tile roof to three waters, on galvanized sheets and wooden roof trusses. Under these pieces is the wooden ceiling, topped with a decorated cornice in the same material. Finally, the church has a presbytery with the high altar built in wood and illuminated by a small window crowned by a semicircular arch and a stained glass window.

The predominant color of the temple is white in the totality of the inner and outer walls, except for the small base that surrounds it to the outside, where light blue color was used, and some elements of the main frontage, as the pilasters and the arches, also in light blue. The use of this color is emphasized to highlight the wooden marquetry inside and outside the building. Finally, for the dome on the campanile a dark reddish color was used as a contrasting element.

2 THE CHURCH BEFORE RESTORATION PROJECT

2.1 *Walls*

Most of the pathologies the church presented were located on the walls of adobe and wattle-and-daub. For approximately twenty years this building was abandoned, lacking adequate maintenance. The pass of time and conditions typical of this Central American region -earthquakes, rainfall and changes in temperature, among others- contributed to its degradation.

The walls presented problems of erosion and loss of material, mainly in the exterior areas



Figure 2. Presence of cracks in north wall (Hernández Salazar).

contiguous to the doors of the sacristy and in the warehouse at the north side. On the other hand, the south wall of the nave presented some efflorescence product of the process of crystallization of the salts coming from the ground, the rain or the irrigation. Another alteration in the walls was the presence of patches caused by dirt particles eroded and carried by rainwater that led to discoloration, loss of coating material or inappropriate coloring on walls or unprotected sections.

Although these pathologies were important, the most dangerous for the stability of the building was the presence of cracks in the walls. Throughout its history, the church endured numerous telluric events, whose mechanical solicitations caused from material detachments in specific areas, to perforations and disintegrations (Fig. 2). These cracks were aggravated by the lack of support of the walls and the presence of excessively long walls. In addition, the weight of the tile roof on a structure of wood simply supported on the adobe walls, without distribution beams, generated concentrated weight on certain sectors of the walls, hence the emergence of vertical cracks. These pathologies were located in the lateral walls of the nave, both in the north and in the south sectors.

Another aspect that affected the stability of the structure was the imperfect union between perpendicular walls, which caused fractures in the corners. This pathology was also found in the meetings between walls. Thus, another conclusion was that in the first instance, the main nave was built and later the arms of the church were added.

2.2 *Wood*

The structure of the ceiling, the ceiling and the carpentry of doors and windows were made in wood. Due to the poor conservation conditions during the two decades prior to its restoration, pathologies could be observed in the wood in many of the most vulnerable areas of the building. Among the

problems encountered in the structure were the presence of biological agents (termites). Two columns of the main nave were affected by this pathology, putting at risk part of the stability of the roof structure, as well as the cornice of the upper part of the campanile and one top chord of the upper truss.

Another problem encountered was rotting, usually as a result of fungal attack. This pathology was detected in the door of the south warehouse and in the bottom chord of the roof truss located on the adobe wall, between the south warehouse and the sacristy. On the other hand, the wood of eaves and carpentries, presented problems of dehydration (whitening) in the exposed outer surface.

Finally, although to a lesser extent, there were problems of breaking of the wood and reeds in the wattle-and-daub walls. Unfortunately, in this case the breaking of the reeds was the result of vandalism, identified only in the south wall of the warehouse.

2.3 *Floor*

The pavement inside the church (nave, sacristy and warehouse) consists of hydraulic tiles. It is a pavement of exceptional quality that has been subject to continuous abrasion, even to blows. Most of the floors were in good condition, but there were some areas with broken pieces, one of them in the south entrance of the main facade and the other under one of the north windows.

The central nave presents two types of pavement with different decorative configuration. The first part is colorful exhibiting geometric shapes in shades of blue, creams and ochres, while the second part—the largest in area as it covers the sacristy and the northern warehouse- has a clearer tonality and geometry based on small blue triangles. Continuous use, high traffic, use of abrasive products for cleaning and lack of maintenance, caused superficial damage. In spite of their high resistance, an important dirt crust and considerable wear of the hydraulic tiles could be observed (Fig. 3).



Figure 3. Pathologies in hydraulic tiles (Hernández Salazar).

2.4 *Roof*

The church has a roof tile; however, given its low maintenance, pieces are missing, displaced and broken. The wind and the seismic movements facilitated the displacement of the tiles, while the atmospheric (thermal) changes and the fixation with very rigid materials caused more fractures and, consequently, leaking inside the building.

2.5 *Arches*

The movements due to telluric events and overloads in specific places of the structure caused cracks in the key (keystone) or arch top of the main frontage. These cracks normally do not alter the functioning, nor are they structural problems; however, they alter the appearance of the building.

2.6 *Carpentries*

The carpentry had problems of insulation and filtration. Among the main causes poor adjustement of the marquetry due to the lack of maintenance, dehydration or rotting of the wood. The doors in general, presented pathologies of filtration, missing elements and decay. On the other hand, although in better state of conservation, some glass pieces of the windows were broken. The locksmiths in general exhibited oxidation, being continually exposed to the weather, humidity and rain. Another problem associated with oxidation is staining, produced by the entrainment of oxidized metal particles, resulting in the appearance of copper colored stains on the walls and wood elements.

3 RESTORATION PROJECT

3.1 *Cracks treatment*

The restoration team verified the fissures of the walls and concluded that the cracks would not affect the stability of the building. The proposed treatment was to remove the lining of the walls around the cracks and close them using a mixture of soil fermented with dry natural fibers (grass), cattle manure and natural binder (cactus water). The mixture was thrown against the cracks into the wall to ensure its complete filling. After the drying time, the operation was repeated if necessary. Finally, a finishing coating was applied.

3.2 *Linings*

In some places, the coating laid in the 1980s was excessively thick and the application of cement mortar to restore disintegrated areas facilitated the loss of material, as well as cracking appearance and lining loss of adhesion.

The work consisted in removing completely the lining until the adobe walls were uncovered and then replace the lining by a new earthen mortar. The preparation of the mixture was carried out according to the traditional process; using finely chopped dry natural fibers (grass) and following the fermentation time originally required by the composition (Fig.4).

After the lining was restored, the final finish was applied using the preparation of the mixture of lime, water and natural binder (cactus) under conditions similar to those of the traditional process.

The color of all earthen walls was white, as traditionally used in this construction.

3.3 *Reinforcing the union between walls*

Although the building did not have significant cracks at the structural level, a problem of collapse and cracking was identified in one of the walls of the sacristy and the south wall of the nave. To solve this problem, a few small areas were worn away in the south wall and in the perpendicular wall of the sacristy.

Two pieces of cedar wood were cured and fixed and four steel rods previously treated with anticorrosive product were inserted as connectors that helped improve the union between the walls and contributed to obtain a joint behavior between the walls (Fig. 5).

Finally, the work finished with coating and lime and the same treatment was given to the rest of the walls of the church.

3.4 *Reconstruction of the wattle-and-daub warehouse*

As a result of the passage of time, the adverse weather conditions and vandalism, the degradation of the wooden columns and beams, as well as the reeds of the framework of the walls, was notorious, making it necessary to replace the walls of the south warehouse. Columns and beams were replaced and a new cane framework was constructed. All the material that was installed in the site was placed following the original construction principles. Moreover, the earthen mixture for the filling of the walls was prepared using the traditional technique, following the same procedure as for the preparation of the lining. In addition, tile sherds were used for the preparation of the walls, placed in each row of mud at angles of forty-five degrees, in alternating arrangement. The walls were left to dry for some time and, finally, the lining and the finishing with lime were made (Fig. 6).

3.5 *Replacement and treatment of wood elements*

Two columns of the main nave were substituted due to the high degree of degradation that they presented, consequence of the termite attack; this pathology put at risk the stability of the structure and its maintenance in the future. Cedar wood was used for the replacements, previously treated



Figure 4. Preparation of the mixture according to the traditional process (Hernández Salazar).



Figure 5. Wood piece with metal connectors to reinforce the union between walls (Hernández Salazar).



Figure 6. Process of reconstruction of the wattle-and-daub warehouse (Hernández Salazar).



Figure 7. Roof intervention (Hernández Salazar).



Figure 8. Process of cleaning of hydraulic tiles (Hernández Salazar).

against moisture and resistant to termite attack. In order to replace the pieces, cuts were made to the wood at the top and bottom of the columns, then the traditional adhesive or "glue" was placed and the new pieces were installed. Finally, to achieve visual integration of the new columns with the original wood of the church, a finish with light varnish was used.

On the other hand, due to the attack of termites, in some wooden structures of the cover a general treatment was applied. The application of the product was carried out by spraying.

3.6 *Roof intervention*

The tile roof had problems with dirt, presence of vegetation, rupture and tile displacement. It was determined to clean all the tiles and remove accumulated dirt of organic or artificial type: debris, nests, and leaves, among others. The procedure was carried out by stages, removing the tiles and cleaning them manually with a brush and water. Subsequently, a product was applied to seal pores and prevent leaks. Finally, the tiles were put back into place and fixed to the structure by means of metal hooks (Fig. 7).

3.7 *Restoration of carpentries*

The continued exposure of wood to adverse weather conditions and lack of maintenance seriously affected the church's carpentries. Firstly, the wood pieces in better condition were removed and were leveled and cleaned for their reinstallation. The pieces highly deteriorated were separated from the carpentries for their replacement with new pieces. All new wood pieces were prepared to replace the missing pieces and the carpentries were rearranged. A mechanical cleaning was performed to remove the dust and sawdust; the adhesive or "glue" was spread and then the new pieces were repositioned in place. In addition, all broken glass



Figure 9. Main nave at the end of the restoration project (Hernández Salazar).

was replaced. The finishing of all the carpentries was done by means of aqueous base paint, applied with brush.

Finally, as part of the work in the carpentries, a metal pickling was carried out using steel wool, to eliminate oxidation. An anticorrosive product layer was then applied.

3.8 *Restoration of pavements*

The cleaning of the hydraulic tiles with presence of dirt scab was performed throughout the building: main nave, sacristy, wine cellar and northwest and southwest hall. Due to the vulnerability of the hydraulic tile to the abrasive products, it was recommended as a first step to carry out manual cleaning using a dry brush to remove the most superficial debris and, subsequently, a wet brushing for the deeper debris (Fig. 8).

The tiles also had some stains and color changes as a result of the passage of time, so the decision was made to maintain the patina. As a final finish, a special natural product for tiles was applied.



Figure 10. The principal frontage of the Church of the Immaculate Conception at the end of the restoration project (Hernández Salazar).



Figure 11. The Church of the Immaculate Conception at the end of the restoration project (Hernández Salazar).

On the other hand, for the exterior pavements -red tiles- manual cleaning with brush and water was carried out. Finally, to treat the areas where the pavement had disappeared, a mixture of lime mortar and natural red dye (ocher) was prepared and applied following the original pavement line.

4 CONCLUSIONS

The restoration of the church of the Immaculate Conception in El Llano de Alajuela was a learning process for a community, an example of love for heritage and a challenge in rescuing the construction techniques of adobe and wattle-and-daub, forgotten in Costa Rica for almost a century.

The purpose of the restoration of the church is to continue using the building to carry out the activities that the community has been developing throughout its history, from important religious celebrations to traditional festivals (Fig. 9).

On the other hand, aware that using this building occasionally is not the ideal and that turning all historical pieces into museum objects is not the only option for heritage buildings, it was proposed to turn this church into a cultural place where different activities can be developed that allow it to generate its own income and facilitate the maintenance and conservation works (Fig.10).

The Church of the Immaculate Conception in El Llano de Alajuela is a witness of the passage of time, an example of traditional construction, a symbol that earthen architecture is possible and valuable, despite the degrading image it has been conferred since many years ago (Fig. 11). The rescue of this building through the example of the struggle of its neighbors reinforces the huge task of Costa Rican citizens for the protection of their already limited heritage, built with the traditional techniques of their ancestors.

NOTE

This article is part of a research project about *"Restauración de la arquitectura de tierra en Costa Rica. Técnicas y tecnología para su intervención en zonas sísmicas"* developed by Ileana Hernández Salazar at Instituto Tecnológico de Costa Rica.

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When the neo-vernacular architecture inspires the contemporary conception

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ABSTRACT: After having its own independence, Algeria has oriented its development towards industrialization, in which the effects were so destructing for the built environment. As result, we notice that the same architectural style was diffused everywhere of the country. That has created a contradiction with the ancestral traditions, this way of construction has intensified the phenomenon of rupture between man and his local environment. André Ravéreau and Fernand Pouillon, two modern designers who worked in Algeria, have innovated in their visions, by privileging the return to local sources as well as traditional architecture, but different from their peers, stemming from the modern movement that favorite concrete. Nowadays, although they introduced new techniques of construction but they made traditional aspects as reference; the contemporary architecture can-not be possible and achievable only through a reinterpretation of modern designer's master works in Algeria. This work was fed by exits on ground, grip of photos, interviews with the persons in charge and the owners.

1 INTRODUCTION

Contrarily to the adherents of the modern movement, the Mediterranean architects Fernand Pouillon and André Ravéreau tried to reconnect with the main principles of Mediterranean vernacular architecture, by being inspired from the past in order to rationalize their works, as well to create their own style of traditional-modern architecture.

These two architects have had many projects/constructions in Algeria. Pouillon's case is more than representative, due to the fact that his achievements can be found almost everywhere around the country, mainly in *the tourism sector* (Bonillo, 2001). Where he has been always inspired by the traditional Algerian architecture incorporating his own language in constructions, innumirating: The Rostomides Hotel in Ghardaïa, the El-Mountazah Hotel in Séraïdi (Annaba) and the Saharian Villas in Ghardaïa.

André Ravéreau was approached by the Algerian Ministry of Information and Culture to become a chief *architect of historical Monuments* (Bertaud du Chazaud & Rarvereau 2007), for the sake of safekeeping a large part of the cultural and architectural heritage of our country. After the independence, he successfully created two workshops in Ghardaïa, which were interested by the local architecture, traditions and climate. According to the principle of "we build a collective approach and a thought resolve".

These two designers had always always favored the respect of the traditional architecture by using local materials such as *stone* (Sayen, 2014), clay and wood. In building any project, they took care of the environment, the landscape and local traditions inherited from the ancestors where we can find the art of the construction appropriate to inhabitant's lifestyle, to the climate and of region.

Their architectural references borrowed as well from the Casbah, M'Zab, *Ottoman and Andalusia* (Bonillo, 2001), which prove that different cultures can be mixed. So, is it not here the ideal opportunity for the contemporaneity of Algeria plural vernacular architecture?

1.1 *Issue*

In this contribution we allude to the impasse in which Algeria's architecture has reached, as long as it continues to imitate foreign models and typologies, extracted from different social and cultural contexts, which have shown their limits and their harmful effects.

Today, the introduction of new techniques of ecological construction refers to traditional aspects in order to build a bridge between Vernacular and Contemporary Architectures. In this pespective which inscribes the necessity of returning to basic 'sources', instead of continuing to import foreign models why doesn't one draw inspiration from our heritage rich in know-how in a purpose of contemporaneity of the vernacular architecture. These links between the gestures of the past and those of today can be restored only through a reinterpretation of modern designer's paradigmatic works, known as the "Algerianists".

1.2 *Objective*

The objective of this study is to understand the behind the success of local traditional architecture and the one of modern designers, who have successfully interpreted its principles, therefore the purpose to seize the lessons that we can draw from this experience, in order to reinterpret and adapt them to meet the needs of the contemporary architecture.

1.3 *Methodology*

We question, two corpuses belonging to two different periods; the original Mozabite constructions and the achievements of the modern designers in the city of Ghardaïa, in order to understand how the latter succeeded in introducing elements of indigenous traditional architecture into their conceptions. For this purpose, we used a collection techniques of qualitative data, on the subject generate information from multiple compelling sources such as: Observations, interviews, as well as the consultation of archived graphic documents.

Our work has been based on a descriptive analysis method, which consists essentially on comparison between two styles of architecture: traditional architecture and neo-traditional. Which will be oriented around the principle of implantation, the spatial organization, the materials and the systems of constructions adapted in both architectural styles?

2 THE M'ZAB VERNACULAR ARCHITECTURE

The importance of traditional architecture is determined by its historical, architectural and social richness. In Algeria, we decline mainly from the medina of Algiers (the Casbah), the Kabyle architecture, Chaouia, and very various Saharians ksour, of which M'zab constitutes our study object.

2.1 *Geographical and morphological context of the town of M'zab*

The M'Zab, as a pentpole located in the North of Algerian Sahara, is situated in the wilaya of Ghardaïa (Fig. 1).

The geomorphologic ensemble in which this region inscribes is a rocky tray, of which the altitude varies between 300 and 800 m (Benyoucef 1986), it is a Cretaceous tray formed by the hard limestone's and which made of the landscape a vast stony stretch of outcrop a rockone of brown and blackish color (Fig. 2).

2.2 *Structure of the town of M'Zab*

Hassan Fathi said: "I understand that the Mozabites have voluntarily expatriated themselves and that they have retained their identity. They have an identity in their architecture. The gesture of the hand follows not only the brain, but also the feeling" (André, 2003).

The city of M'Zabis organized by according sociocultural and religious principles well determined. The agglomeration is structured around the mosque that dominates the city. This one is an important edifice, not only for its religious and social implications, but also for its dimensions. Its minaret, become a symbol dominates the ensemble, which constitutes annexes (Madrasa, Library) gravitatingall around the latter representing the spiritual center of the city (Fig. 3).

In the periphery of the city that the souk is located, for the exchange between locales of Ghardaïa, the foreigners and all the habitats of the M'Zab valley (Fig. 4).

The city is protected by a rampart in which doors are closed, those ones connect the city with the rest of the territory: the palm groves, valley and communication roads.

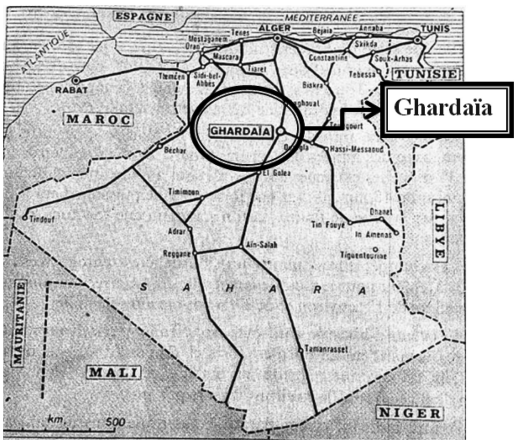


Figure 1. The location of the town of M'Zab (Benyoucef B. 1986).

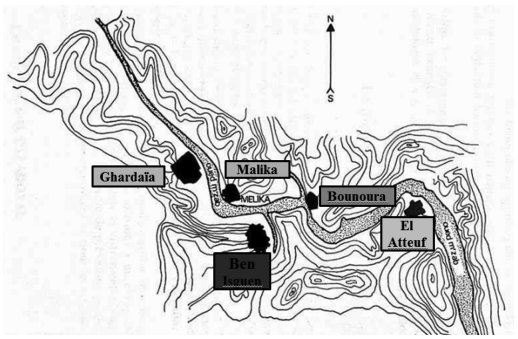


Figure 2. The geomorphological map of the city (Benyoucef B. 1986).



Figure 3. The mosque of the Ghardaïa's ksar (Author 2017).



Figure 4. The market of the Ghardaïa's ksar (Author 2017).

After a very deep study on the M'Zab, André Ravéreau confirms that the Mozabite populations have based its constructive principles on the following formula: "*remove the artificial, there remains only the construction*"(André 2003) which means constructing without the use neither of ornamentation nor of artificial materials even less than ostentatious. This is the secret of the sustainable architecture 'success, which keeps its foundations and principles up to the present day.

2.3 *The vernacular habitat of M'Zab*

The Mozabite habitat was inherited from the plan of the Mediterranean housing environment from the Maghreb and adapted to the Saharan context, as pointed out by Ravéreau: "*Recall that historically, the Mozabite house evolved according to the following process: in the Maghreb, the houses are at two levels. The courtyard, which elsewhere is called 'patio' … is open to the sky, with or without a gallery, as proposed by the Mediterranean physical environment*" (André 2003).

These houses constitute a very dense radial urban fabric, always topped by the minaret of the mosque. The use of pale, pink, ocher, green and blue colors on exterior cladding and terraces gives this valley a unique chromatic appearance. In the M'Zab, there are two types of houses: one that is integrated into the urban fabric of the ksour of the pentpole (urban house) and that of their palm groves (summerhouse) which, concealed within the vegetation, is barely perceptible.

2.3.1 *The organization of an urban type house*

The mozabite dwelling, has been judiciously adapted, both to the climatic and social conditions imposed by the implantation of the Ibadites in this place. (Fig. 5).

Rooms of the house were organized in a way where all the climatic and sociological factors were taken into account (Fig. 6).

All of the house's rooms are organized around the courtyard, surrounded with a gallery arched where open the narrow, lengthened rooms and Multi-purpose ones (bedrooms, storage, kitchen-day,

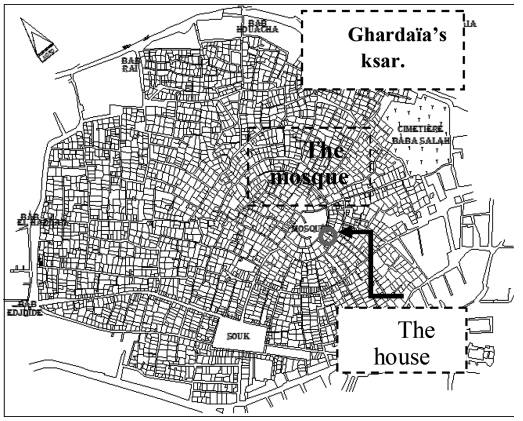


Figure 5. The situation of the house by report to the ksar (P.O.S of the city, 2012).

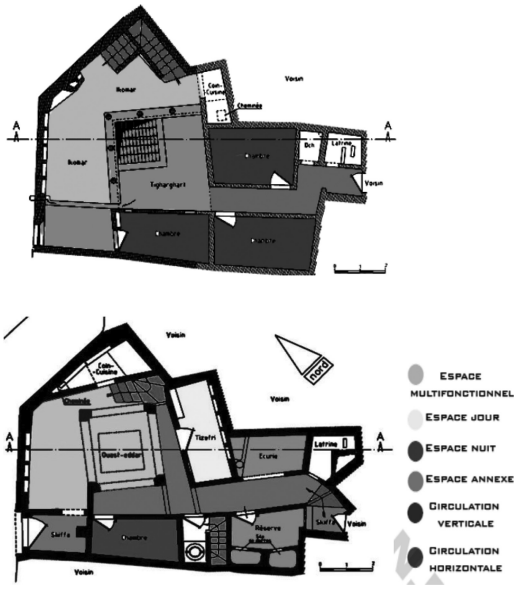


Figure 6. The superposition of the different plans of the house (Mayouf K., Djekidel N. & Zerara R., 2009/2010).

toilets) which complete the occupation on the soil. The pattern repeating on the floor, on the whole lot or the part of the surface. Above, the terrace can still receive a small room arched or closed. The terrace (domestic surface in the full sense) is often fragmented (what contributes to minimize the fissuring), constituting several levels which define specific spaces (sleeping areas, kitchen-dinning, drying, etc.).

2.3.2 *Constructive systems*

Table 1. Materials and constructive system.

Element	Constructive System
Walls:	Constructed of Stony rubbles with a mortarbased on sand and local lime or quick-setting "Timchent".
Structure:	Realized with trunks of palm trees. Wood joist or metallic girder; vaults originally built of stone on a hanger of palm branch.
Cover:	Terrace; on the stone of vaults, we equalize the level by a conglomerate of pebbles, which cohesion is ensured by Timchent, then a layer of clay 5 to 8 cm thick is spread to ensure thermal insulation, and finally a layer of lime mortar.
Finishing Coatings:	The walls are coated with sand and Timchent, and a white-wash with of lime's milk colored blue, pink, ocheretc.

Source: Author 2017.

3 FROM INTERNATIONAL ARCHITECTURE TO NEO-TRADITIONAL ARCHITECTURE

3.1 *André Ravéreau, the return to the roots*

Ravéreau is very influenced by the beauty of M'Zab's architecture and especially by arches and vaults. For this purpose, he created workshops to give people the opportunity to take an interest in local architecture, traditions and climate. The idea is to convey to them a key message: "*When we build collectively that means an approach and a thought is resolved*"(André, 2003).

According to the architect, M'Zab's houses have answered for all the company's needs, because they have managed to find the best solutions that allow them to adapt to the disruptions of the site and the climate, their architecture is not geometric at all, but on the contrary, they have obeyed to constraints of the relief. M'Zab's architecture has inspired Ravéreau extensively in his professional life, where he tried to interpret some referents in his realizations such as: The Post Project, the Ghardaïa City Hotel and the Construction of the Doctor. M Villa, the subject of our study.

3.1.1 *The Villa M*

The villa is located in the M'Zab (Baudouï et Potié, 2003), it was built while taking into account the local climatic and social conditions (Fig. 7). His



Figure 7. Overview on the Villa M. (Author 2017).

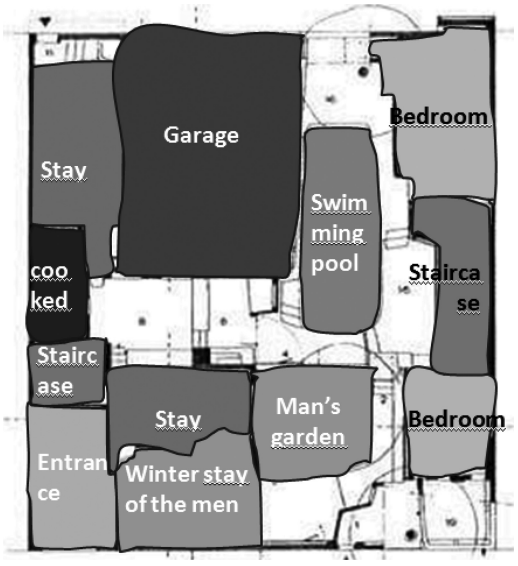


Figure 8. Plan of R.D.C. (Baudouï R. & Potié P. 2003, Interpretation of the author).

conception was inspired by the traditional Mozabite architecture with the adaptation of some principles of modern architecture so conferring him a certain freedom for a possible remodel, if he needs there.

3.1.2 *Concept of quality of life in the design of the villa*

The ground floor plan is designed in a way to provide a pleasant living space during the hottest hours of summer, a prayer room, office, separate entrances *(men's / women's) (Baudouï et Potié, 2003)*, as well as a swimming pool and several gardens.

The architect drew his inspiration from the traditional houses, where he was very fascinated by the role of the patio as a thermal regulator in the organization of the house. In this context, he chooses to integrate it but in another way. It is the superior floors, which were organized around open patios, and terraces that establish so many living spaces answering for Mozabite 'uses. Therefore, *the first floor adopts, in particular, a room of prayer for the women (Baudouï & Potié, 2003)* (Fig. 8).

In the order of respecting the tradition, the access court is located on the central space, followed by the swimming pool. This one is planned in rise, in a way that it can be empty naturally, according to the slope, to irrigate the garden that is below (Baudouï & Potié 2003).

However, contrary to the usual conditions, Ravéreau preferred to create for *each room has its particular terrace for sleeping in summer, the concession for the desert is modern, comfort and intimate* (Baudouï & Potié 2003).

3.1.3 *Technical and construction system*

The architect has built with the local materials available on the site such as: stones, cement blocks, plaster vaults while inventing, improving techniques, and building materials that confront with the contextual conditions of time, such as the tempered ices, plastic materials and reinforced concrete joists. Besides, he designed a system of masked walls to protect the house from sunshine and to provide good ventilation inside the spaces.

3.2 *Fernand pouillon; tradition versus modernity*

This personality, known for his intellectual capacity to face the obstacles of *the modern movement's* (Bonillo 2001) crisis, Fernand Pouillon was always against the autonomous architecture that was presented as one antithesis to the latter. His followers have described his architecture as an architecture as sober as picturesque. By drawing on local culture, Pouillon searched in the historical environment the source of his inspiration and drew up an architectural vocabulary of local impregnation that refers to the vernacular architecture. He especially realized of tourist large sets on the coast and in Oases with characteristic elements of art from the Maghreb, Where he made a reference in Saharan ksour, the Turkish ramparts and the atmosphere of the medina; curves, patio, arches, earthenware covers, enclosed gardens, narrow alleys between blind walls etc. *These are so many elements characterizing his architecture* (Moniteur 1986).

The hotels signed by the architect are not very similar, because he tried to grant to each of them specificities who are appropriate to the natural context of the site and dictated by the typical vocabulary of each region, which makes each project an exceptional work.

3.2.1 *The hotel Les Rostomides*

The hotel is located slightly back from the city center; it is not far from the souk of Ghardaïa. His initial idea was commanded by the desire to display the traditional Mozabite architectural vocabulary. Pouillon, through this project, has honored the principle of the patio in the organization of the hotel. The rooms are distributed in a row on the sides of two patios. The first hosts a garden while the second hosts a swimming pool (Fig. 9).

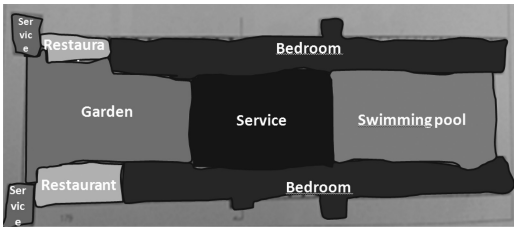


Figure 9. Plan of the hotel (Moniteur. E. 1986, Interpretation of the author).



Figure 10. View on hotel les Rostomides (Author 2017).

3.2.2 *Building materials and technology*

Pouillon has worked to several constructive systems that combine both traditional systems (*such as the stone facades and brick load bearing partitions* (Sayen 2014). And those which have appeared with the emergence of the modern movement architecture (Concrete slabs). The white color used on the facades of the hotel was chosen to ensure integration with the immediate environment (Fig. 10).

4 RESULTS AND DISCUSSIONS

4.1 *Towards a contemporary vernacular architecture*

The study highlighted two different architectural styles; the first refers to the traditional period where companies answered in an intelligent way the conditions and the environmental needs, while the second emerged with the appearance of the new techniques and the modern building materials. Nevertheless, the two architects in question, despite their membership to the modern time, they tried to draw their inspirations from the local traditions, thus creating a style of architecture that engenders a hyphen between tradition and modernity. The objective behind the choice of both styles of architecture is to focus on the lessons that we can pull to participate in the development of an environmentally friendly architecture, and which takes into consideration traditions to answer the current needs. The comparison allows us to understand the relation between both styles, which is

Table 2. Comparison between the two architectural styles.

Element	Style 1 (vernacular)	Style 2 (neo-vernacular)
The environment	Inserts the architectural product in its immediate environment in order to answer all the requirements of the nature	build in harmony with nature
Climate	Searched to discern the best averages for solving climate problems	Appropriate use of the ecological notions (application of the comfort rules, orientation according to the sunshine and the wind).
Society	The arrangement of the construction with the lifestyles of each society therefore man is always inserted into any reflection	They always registered the local and cultural context of the society for which they built.
System and techniques of construction	The use of materials, local techniques available on the site	Promote the return to the local materials thus the combination between materials and local, universal techniques of constructions.

Source: Author, 2017.

summed up in the respect of the environment, climate and social conditions. The insertion of the architectural product in his frame built as well as the use of materials and available premises makes the link between the man and his environment.

Through this study, we managed to determine the motives that generated the success of these two styles of architecture to be able to project her in the development of Algerian contemporary vernacular architecture, which would evolve in the respect for the historical values, the sociocultural, physical conditions. As well as the adaptation of the local materials and the traditional techniques and constructive systems, while adopting the innovations of today.

5 CONCLUSION AND RECOMMENDATIONS

The system adopted by independent Algeria introduced a very strong internationalization of architecture. We imported inappropriate foreigner models that are projected in the Algerian context with a relative concern of adaptation, Contrary to the modern designers that already possesses a big knowledge of the natural environment and the local identity.

These architects managed to master the heterogeneous references of the Mozabite traditional architecture, in a concern to combine the spatial solutions, Formal and constructive most advanced, available in their time with that anchored in the local M'Zab culture. The contemporary Algerian style, Elaborated through the realization the projects of André Ravéreau and Pouillon is confirmed, because they took all the elements of the traditional Maghrebian art: patio, his coatings, the closed garden, the terraces, etc. They especially managed to recreate, on the scale of the projects, this perfect balance between the independence of the private life and its integration in a community that makes, for centuries, the value of the Muslim city. These modern designers 'architecture open therefore widely to the young builders of Algeria, there future road, example to be followed?

In the Maghreb, the modern architecture is subjected to a firm criticism. This architecture not only failed in its technical performances, aesthetic and social performances, but it forgot especially to take in consideration the relation of the architectural object with its physical and social environment. About the reality of the Algerian built frame and the problem of the national cultural identity, how do we intend to solve the current problem of construction? What can we save more of our ancestor's heritage? What will the maghrebian future inherit?

Today, we are in search of sustainable architecture, worried with ecosystems, rather fragile, economic balance and social coherence.

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Characteristics of earthen architecture in Ağlasun

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ABSTRACT: Ağlasun is a rural area in Burdur, on the west Mediterranean Region in Turkey. Most of the buildings in Ağlasun is built with the materials provided from the local resources except the ones effected from the industry of reinforced concrete. The commonly used materials in the vernacular constructions are mud-brick and stone. The specialty that makes the earthen buildings in Ağlasun unique is their respectable structural condition although they are more than 60 years old. Plan layout of the buildings which represents the economic and social life shaped according to the needs of local people. Therefore, this text aims to understand the characteristics of earthen buildings by focusing on the construction technique and plan layout of earthen buildings in Ağlasun and make a contribution to the awareness of the conservation of vernacular earthen architecture in its changing context.

1 INTRODUCTION

Ağlasun is a town surrounded by an intact natural environment in west Mediterranean Region of Turkey. Its location is in the intersection of three big cities; Burdur, Isparta and Antalya. The settlement is near an archeological site named 'Sagalassos' which is an ancient city with a history ground till 8000 BCE (Torun et. al. 2015).

This text is a part of the research project named "Understanding a Historic Rural Landscape in Relation to an Archaeological Site: Ağlasun/Sagalassos". It has been conducted with the collaboration of Middle East Technical University, Ankara, Turkey and Katholieke Universiteit, Leuven, Belgium in 2016.

The main data was collected during the site survey and enhanced with literature survey. Besides, old maps and aerial photos were examined. The site survey includes in-depth interviews with the locals and local masons, visits of specific houses with the direction of the *muhktars* and owner of the houses. In addition to these, several surveys including investigations to better understand the architectural characteristics of Ağlasun houses were done on site. The in-depth interviews were done with three local masons; two of them, Salih Usta and Bekir Usta, are stone masons who are also doing mudbrick work and one of them, Emin Usta, is a mudbrick mason.

Ağlasun has population of 8382 consisting 5 neighborhoods: Bala, Kıraç, Hamam, Sakarca and Kum (Fig. 1). Bala is the first oldest quarter of Ağlasun regarding the literature survey, aerial photos, interviews done with the local people and the fact that it is the closest to Sagalassos. Moreover, the other neighborhoods cannot be so late since all 5 neighborhoods are seen clearly in 1955 aerial photo.

Ağlasun is surrounded by valuable natural environment including forest areas, water resources and broad agricultural lands. The river and its creeks can be experienced from various locations in Ağlasun.

The main income source in Ağlasun is agriculture. Carpet weaving and woodcraft are the other activities that inhabitants carry out for livelihood. Moreover, there are also some external bodies such as Sagalassos Hotel, Sagalasos Archeological

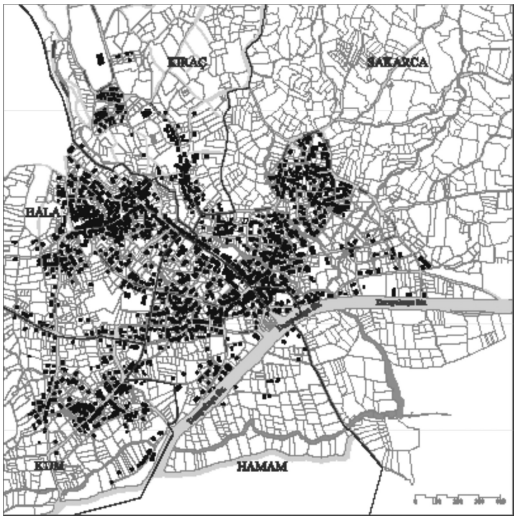


Figure 1. Open-built Up relation in Ağlasun—five neighborhoods of Ağlasun (Bilgin Altınöz et al. 2016).



Figure 2. Façade of a traditional Ağlasun House with spolias (Asrav 2016).

Site and Sırma Water Factory, which provides job opportunities for people of Ağlasun.

Built environment of Ağlasun is integrated with the natural surrounding not only physically but also socially. The close relationships with the nature can be observed in the use of materials, daily social and economic activities, and also place names that the local people has ascribed to their living environment. The main square of the town is named with regard to an old Plane tree: *Çınar* which is standing in the middle of the square. The buildings are constructed with local materials and traditional construction techniques. Though mud is the most used material, stone and wood are also seen frequently. Today, while it is possible to observe numerous traditional buildings, reinforced concrete, unfortunately, is the trendy construction technique embraced by the inhabitants. Especially in Çınar neighborhood, there is a serious change on the main axis of the settlement that the texture of the town completely changes with many new structures.

Buildings constructed by traditional construction technique are usually residential buildings (Fig. 2). According to the interviews made by the local builders; the type of used earth clay which is found in some specific zones of the district, strengthens the durability of the material. Even today, the structural condition of the traditional buildings is quite well.

2 TYPICAL SPACES OF AĞLASUN HOUSES

Traditional Ağlasun houses have a specific plan layout organized according to the inhabitants' daily use of the places. Each place has a local name and specific architectural elements. A typical traditional Ağlasun House may have spaces like "*saçak*", "*dambaç*", "*tahtalık*", "*ambar*", "*girellik*", "*oda*", "*kiler odası*", "*yer evi*", "*kiler/şerbetlik/yunmalık/sobalık*" and "*ahır/depo*". Some of these spaces within a traditional house in Ağlasun are explained below (Fig. 3).

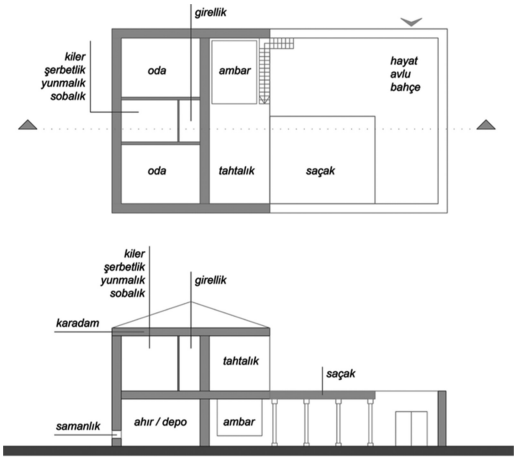


Figure 3. Distribution of spaces in a typical traditional Ağlasun house (Asrav 2016).

2.1 *Saçak*

Saçak which is an elevated open terrace is one of most significant characteristic features of traditional Ağlasun houses. It is an addition to the main house unit, constructed separately yet attached to the main house block. There is always a direct passage from the main house to the *saçak* generally from the *tahtalık* section which is the semi-open hall located in the uppermost floor of a traditional Ağlasun house.

Saçak is constructed as *karadam* or *karaörtü* having the layers of *döver*, *mertek*, *pargı*, *hasır* and *karadam*. The floor is carried by wooden pillars. In most examples, the base of these wooden pillars is made of, reused materials. The semi-open space below *saçak* has a multipurpose use.

Today, most of the *saçaks* are either demolished or changed: constructed with new techniques, mostly with concrete frame and underneath of the *saçak* is closed and used as depot or new volumes are added above the *saçak*.

2.2 *Tahtalık*

It is a semi-open hall in the traditional Ağlasun houses called locally as *tahtalık* used both living and circulation (Fig. 4). It is located on the first floor of the house, reached by the stairs either from the courtyard and/or directly from the street. In general, it has a direct passage to the *saçak* space. On the both sides of the *tahtalık*, there are mudbrick masonry walls having the architectural elements of fireplaces with *yaşmak* and niches on both sides of the fireplaces. The wooden pillars which carry the *tahtalık* has stone bases. A part of the *tahtalık* is used as *ambarüstü*, is an 20–30 cm elevated section than the level of *tahtalık*. In this



Figure 4. *Tahtalık* section of Molla Hüseyin House (*Ağa Evi*), with the typical elemenst; *yaşmak* (fireplace), niches on the both sides, *ambar* (storage units) on the *tahtalık* and *ambar* (storage cells under *tahtalık*) (Asrav 2016).

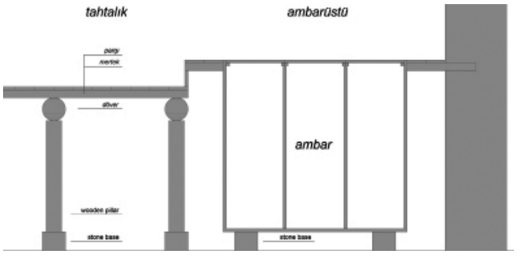


Figure 5. The *tahtalık* section with *ambar*, *ambarüstü* and wooden pillars (Asrav 2016).



Figure 6. Oda (room) of Yarık Hasan House with the characteristic features; fireplace and *yasmak*, niches on both sides, *gusülhane* (bathing section) that are highly ornamented (Asrav 2016).

part, there is *ambar* (granary) often used for storage purposes of cereal products. The *ambar* is located in-between the ground and the first floor. It is reached from *tahtalık* and has small partitions with almost 2 m depth.

The *ambarüstü* part is used to prepare food collectively with neighbors, to cook the meal and, in a good weather, to have the meals. There is also a *tezgah* (wooden bench) in *tahtalık* to put stuff on it and to wash the dishes. Sometimes *sedir*, a sitting platform, is put on one side of the *tahtalık*, especially in the *ambarüstü* part. Our in-depth interviews show that the house owner used to put the carpet and/or sackloth looms of the house in the *tahtalık* and weave carpet and/or sackloth. From the *tahtalık*, there are two entrances leading to *girellik* which functions as a corridor between rooms.

2.3 *Ambar & Ambarüstü*

Ambar is a wooden box located between the ground and the first floors. It is based on stone pillars (Fig. 5). It has small partitions with almost 1 m width and 2 m depth. *Ambarüstü* is the upper part of the *ambar* used as the kitchen and the living room of a traditional Ağlasun house. The bread and the meals are cooked and eaten in this section. The *ambar* and the *ambarüstü* sections are generally seen in a*ğa evleri* (landlord houses) and in the houses of the rich. *Odunluk* is located under the closet used for storing the wood to be buried in the fireplace. Its dimensions is around 100×60 cm. *Sedir* (divan/sofa) is a sitting platform elevated 40 cm from the floor, that can be seen in almost all rooms.

2.4 *Oda*

The *odas* (rooms) are located on both sides of the *kiler*/*şerbetlik*/*yunmalık*/*sobalık*.

Both the floor and the ceilings are covered with wooden planks and ceilings are ornamentated in some cases. Wood is the main material used in all architectural elements in the rooms.

These rooms have various architectural elements with ornamentation. The architectural elements are *gusülhane*, *yüklük*, *ocak*, *yaşmak*, niches, *şerbetlik*, *odunluk* and *sedir*. The *gusülhane* is a bathing cabinet, the yüklük is a closet to put bed *matresses* as well as clothes; *ocak* is a fireplace and *yaşmak* is a wooden facing on top of the fireplace to prevent the fire to go through the room; the niches are located generally on both sides of fireplaces and used to put candles and other things; and *şerbetlik* has small shelves to put food on them (Fig. 6).

2.5 *Girellik*

Located next to *tahtalık, girellik* is the first space before entering to the rooms of the house. It functions as a cellar or a corridor in traditional Ağlasun houses. In general, there are two doors opening to *girellik*. From *girellik*, there are accesses to cellar and/or storage the rooms and to the space called as *kiler*/*şerbetlik*/*yunmalık*/*sobalık* named according to the function that this space takes in the house. In the *girellik*, there are ornamented wooden carved shelves and compartments called as *şerbetlik* which is used to store food (Fig. 7).



Figure 7. Girellik parts from Yarık Hasan House (left) and Molla Hüseyin House (right) (Asrav 2016).

2.6 *Yer evi*

In some traditional houses, especially in *ağa evleri*, there is a single-floor house called as *yer evi* located in-between the ground and the first floors used either as a guest room or a temporary storage area. In the rooms, *yer evi* has also various wooden architectural elements with ornamentation. The floor and the ceilings are wood as in the rooms on the upper floor (Fig. 7).

2.7 *Kiler odası*

It is the cellar space where the food is stored. In these rooms, there can be granary boxes different than the ones in *tahtalık*. In addition to the *ambars*, other architectural elements as fireplace, niches and closets. *Kiler odası* is not seen in ordinary traditional Ağlasun houses, but in the houses of the rich and/or in the *ağa evleri*.

2.8 *Kiler, şerbetlik, yunmalik, sobalik*

The usage of the space behind *girellik* changes according to choose of the house owner. It is often functions as a refrigerator and used to store food due to its low temperature. In this case, it takes the names as *kiler* and/or *şerbetlik* and used to maintain cheese, cottage cheese, dry legumes as chickpea, dried beans and lentil, jam and grape molasses in a cool temperature. This space is also used as bathroom as an alternative to the *gusülhane* in the rooms. When used this way, it is named *yunmalık* and/or *sobalık*. Today, all these various usages coexist in traditional housing.

2.9 *Ahır/depo*

The ground floor of a traditional house is used either as animal barn and/or as a storage area. There are small openings leading to animal barn on the façade in order to throw the straw to the inside of the house from the street. These small openings are called *samanlık*.

According to the spatial characteristics, the traditional Ağlasun houses can be classified into three groups: "*Ağa Evi*" (Big Houses or Mansions); ordinary traditional houses; and "*köy odaları*" (community houses/village houses). These different types of traditional houses can be seen side by side within each cluster and neighborhood. Only in the Ağalar Neighborhood, the majority of the houses are *ağa evleri* that are big in scale with big gardens and/or courtyards around the house.

3 CATEGORIES OF AGLASUN HOUSES

3.1 *Ağa evi*

Ağa Evi is the biggest traditional Ağlasun house owned by important rich families living in Ağlasun. The plan organization of these houses is quite similar to the ordinary traditional houses yet ağa evleri have more characteristic features than the others. They almost have all spaces that a traditional Ağlasun house can have as "*saçak*", "*dambaç*", "*tahtalık*", "*ambar*", "*girellik*", "*oda*", "*kiler odası*", "*yer evi*", "*kiler/şerbetlik/yunmalık/sobalık*" and "*ahır/depo*". There are rich and highly ornamented architectural elements in almost each of these spaces.

3.2 *Ordinary traditional houses*

Ordinary traditional houses are smaller than *Ağa Evi* but maintain an average size when compared to the rest of the traditional buildings. They can be one or two stories. They have the characteristics features of traditional Ağlasun houses. Also, they may have the spaces as "*saçak*", "*dambaç*", "*tahtalık*", "*ambar*", "*girellik*", "*oda*", "*kiler odası*", "*yer evi*", "*şerbetlik/yunmalık/sobalık*" and "*ahır/depo*" (Fig. 3).

3.3 *Köy odaları*

Köy odaları are the community or village houses used as a gathering place and guest house. They used to be used mainly by the elderly of the village. *Köy odaları* are also called *söğüş yeri* as a place to meet on a daily basis as well as in important days such as holidays and celebrations. Besides, *köy odaları* were used as guesthouses for people coming from outside the village. When a guest comes, he can accommodate in this house and neighbors would collectively prepare food for that guest.



Figure 8. Köy Odası, Kıraç District (Kurtuluş 2016).

Köy odaları have one or two rooms in general with common architectural elements as in typical house rooms (Fig. 8). They are *gusülhane, yüklük, ocak, yaşmak, niches, şerbetlik, odunluk and sedir*.

There are still *köy odaları* in Ağlasun (e.g., Tellakların Evi, Saray Street) even they are not functioning any more.

4 CONSTRUCTION TECHNIQUE OF AGLASUN HOUSES

The construction technique of traditional houses in Ağlasun are mostly mud-brick masonry. Stone masonry is second common technique in the settlement. Generally, rubble stone is preferred for the foundation and sub-basement; yet the upper part of the structure varies. In some cases, rubble stone continues along ground floor while the first floor is mud brick or *köğke* (other type of stone). In other cases, the whole structure is stone. There are also stone-made structures of which one façade on the first floor is *bağdadi* Fig. 9).

4.1 *Stone masonry*

Stone is provided from the nature nearby surrounding. There are two types of stones that are used for the construction of the houses. The first one is hard and used as rubble stone or/and rough cut stone that are seen generally in sub-basement and lower parts of the structures (See Figure 10).

The other one is "*Köğke*" which is a soft stone and usually used in the upper levels of the structure.

4.2 *Mud-Brick masonry (Earthen Architecture)*

In reference to an in-depth interview with Emin Üre and Salih Masters; mud-brick making is composed of two stages. First, clayed earth is mixed with water and then, with wheat chaff and it is left for two days in order to come to its proper consistency. Second, it is molded and dried—under sun if possible—for two to three days or one week.

Salih Master mentioned that the appropriate earth clay is red earth taken from Bala, Kum and Hamam district of Ağlasun. Clay in Sakarca is not

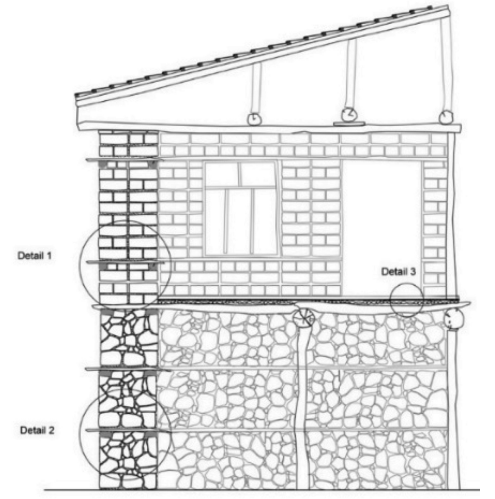


Figure 9. System section of a typical Ağlasun house (Kurtuluş 2016).

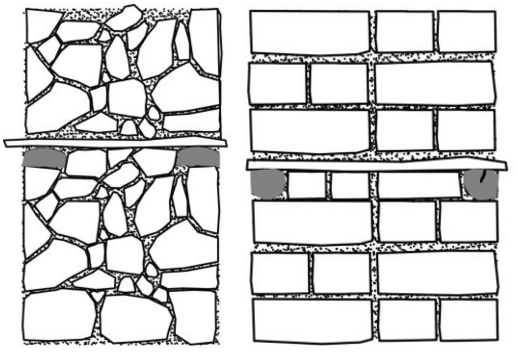


Figure 10. Detail 1: Wall section (Rubble Stone), detail 2: Wall section (Mud Brick) (Kurtuluş 2016).

convenient to make mud-brick because it is dark earth. According to the information given during the interview, width of the walls was 80 cm before, then it was decreased to 50 cm. When putting up a mud-brick wall it is necessary to emplace girder in every 1,5–2 meters to strengthen it against lateral (earthquake) forces.

Merteks and *girders* used in the structure are produced from *Selvi Kavağı* Trees which is seen throughout Ağlasun (Fig. 10)

4.3 *Timber floors*

In Ağlasun houses, floors are carried by large-cross section main beams called as *döver* and big cross-section posts. It is grounded on *dövers* and upper layers are respectively; *mertek* (beams), floor plates,

straw and lastly 15–20 cm damp earth. If it is a slab of *saçak* or flat roof, the soil is get moisture and compressed with "*yuğa*" stone in order to consolidate the slab. If it is a floor of *tahtalık* or an ordinary room wooden floor can be implied on the damp earth and a straw or a carpet can be laid on it (Fig. 11).



Figure 11. Detail 3: Slab section; Yuğa stone to compress on the slab of saçak (Kıraç) (Kurtuluş 2016).



Figure 12. Mubrick masonry + Bağdadi, Bala (Kurtuluş 2016).

4.4 *Timber Frame—Bagdadi*

Bagdadi is an infill type of timber frame construction system which wooden laths are nailed to the surface of the frame providing a base for plaster and paint. This technique is used only for a façade of a building (Fig. 12) or a portion of a façade.

As Ağlasun is a region close to the archeological site of Sagalasos, spolia is frequently encountered on the façade of the structures (Fig. 13).

In these houses, materials that are above mentioned can be observed in various combinations which are, only mud-brick masonry, only stone masonry, mudbrick and stone masonry, and lastly; masonry and *bagdadi* (Fig. 14).



Figure 13. Spolia, bala neighborhood (Asrav 2016).

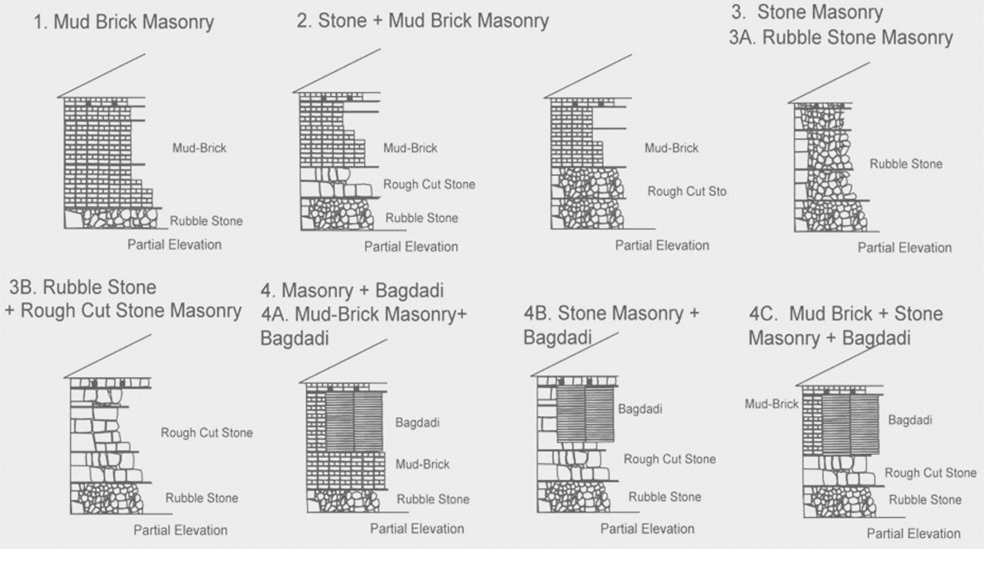


Figure 14. Different variations of construction technique (Kurtuluş 2016).

5 CONCLUSION

Vernacular construction technique of Ağlasun Houses and its components—as they are reflecting the uniqueness and identity of the settlement—are significant values for the Ağlasun. The names of the architectural elements, the use of the spaces, construction technique, regional materials, knowledge of this information are particular features of daily life in Ağlasun. However, these values are disappearing with the effect of unregulated increase of new constructions.

Studies aiming to guide this inevitable change must done in order to conserve these values. As this kind of a study is necessary for most of the rural areas in Turkey.

NOTE

The project called "Understanding a Historic Rural Landscape in Relation with an Archaeological Site: Ağlasun/ Sagalasos" was conducted by G. Bilgin Altınöz, N.Ş. Güçhan and A. Ataöv with the participation of A. Uluç, E.Ç. Asrav, E. Balkanay, İ. Demirdağ, Ö. Yersen, V.B. Kurtuluş in 2016 within the context of the course entitled "Cons 509: The Multidisciplinary Studies in Architectural Conservation" in Conservation of Cultural Heritage, METU.

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The painted facades and the urban landscape of Bisceglie, Italy. Notes of history and restoration

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ABSTRACT: The paper offers some preliminary results of a broader research project that aims at investigating the architectural use of paintworks in the Kingdom of Naples, little studied until now, focusing on the town of Bisceglie as an interesting study case. The work provides an historical outline of the painted facades of the town, based on archival and iconographic researches, survey campaigns and stratigraphic analysis. The results show how the colour and the architecture have developed together to create the urban landscape and points out how the facade paintwork is not only a decorative issue but a more important cultural one, related to the way in which the town wanted to show itself. The work, therefore, aims at being a useful tool for the future restoration activities, to be aware of a complex problem often unknown or, worse, culpably neglected and to deepen some theoretical questions behind the restoration practice.

1 BISCEGLIE: THE STUDY CASE

The theoretical and practical problem of the paintwork restoration has been widely studied in significant contributions by C. Brandi, R. Bonelli, P. Philippot, P. & L. Mora and the more recent works of G. Carbonara, P. Marconi or A. Bellini (Carbonara 1997), just to name a few. Moreover, the historical and scientific researches, carried out through conferences and academic works, supported the drafting of many 'Colour Plans' or 'Guidelines for the restoration' in several towns of central and northern Italy (Muratore 2010) whereas the South has received little attention so far.

The present paper offers some preliminary results of a broader research project that aims at investigating the architectural use of paintworks in the Kingdom of Naples, focusing on the town of Bisceglie as a study case. In fact, among the towns of the so-called Terra di Bari, known to be rich and developed harbour cities since the medieval time, Bisceglie is an interesting study case for the combination of several factors.

The town, for example, has largely preserved its medieval urban layout, which provides some information on the urban landscape between the 11th and the 15th century; moreover many Renaissance and Baroque palaces show the urban development of the modern town.

It is also interesting to note that a large number of buildings has been abandoned in the past century and therefore they are not affected by harmful restorations. This condition provides precious information on the original colours, survived in small traces in the most hidden recesses of the facades, apparently discolored and gray at the present and hardly imaginable as painted in the past. On the other hand, it allows to suggest new restoration methods, more respectful of the cultural heritage. Moreover, a detailed previous research on the buildings of Bisceglie, carried out by local scholars in recent times (Consiglio et al. 2006), has been a great support to the present study since fixed dates have been associated to the architectural transformations of the main buildings, on the base of archival documents. However the specific archival research on paintworks is more complicated, because the painter activity is not ruled by the Town Statutes and does not appear in written contracts, being mainly based on verbal agreements (Tabak 1993). Anyway it is possible to get some information from the statements of expenditures in the private archives: even if rarely preserved and not always available, the research will keep investigating this track.

The present study has been carried out even through a large number of survey campaigns, using both direct and indirect techniques, and stratigraphic analysis to appropriately record, document and survey the fragile remains on the walls. Moreover the samples analysis will provide a detailed chemical characterization of pigments and plaster composition, by means of the most advanced archaeometrical and colourimetric technologies.

2 COLOUR AND URBAN LANDSCAPE

2.1 *The medieval town (11th–15th century)*

In the last quarter of the 15th century, Bisceglie was a small feud of Francesco II Del Balzo, duke of Andria. The aspect of the town must have been

similar to the view of Andria, painted on a big panel realized in the same period and currently exposed in the local Diocesan Museum.

The general impression is the one of a fortified town, where both external walls and internal buildings were made with solid white local stone and had the typical shape of the defensive architecture. The only difference between the defensive and the residential towers is represented by their rooftop, flat and embattled in the former whereas the latter is pitched with red tiles. The same landscape is confirmed by the architectural evidences in the heart of the old town of Bisceglie, where a large number of medieval buildings have survived.

The main architectural type consisted in the so-called Tower house: a residential unit, vertically developed, with few single-light windows (monofora) on the facade, to allow in light and air, up to the pitched roof. The medieval towers, initially surrounded by public open spaces or private gardens, increased in number along the centuries, saturating the urban land and generating blocks (De Fronzo 2009). A rarer type is represented by the Palace (mansion), reserved for rich and important families, with a larger number of rooms but similar defensive shape of the tower.

The masonry of the facade was composed by finely dressed and squared blocks, laid in regular rows, or more irregularly shaped stones, in almost horizontal layers, with a larger use of mortar. To increase the idea of solidity and strength, the base was sometimes rusticated.

The analysis of the walls does not reveal traces of coloured pigments on the stones except for layers of white limewater, cyclically spread on the surface of some of these buildings over the centuries.

In particular, it seems more likely that white limewater layers covered only the less refined masonries, to hide the uneven, rough surface and to protect both the mortar and the stones against the action of rain and wind. The usage of this colouring material is motivated both by its easy and cheap production (by processing the local stones) and by the disinfectant properties of lime, widely used owing to the frequent epidemics. In addition, the white colour was in natural continuity with the white material of the masonry, hidden by the limewater but formally alluded by the same tone, and increased the luminosity in the narrow winding streets.

On the contrary, the most refined buildings showed the lineage of the secular and religious customers, by the high quality of the lapicides work: polished stones, very thin mortar layers between the blocks and highly detailed sculptures. This may suggest a former intention to leave the facades in natural stone even if it is no possible to exclude the use of very thin limewater or patina layers, to protect and make the surface even.

Instead an extensive use of paintworks is attested in the interior of these buildings, as shown by recent researches. (Andriani et al. 2011).

Therefore, despite the development of the architecture from the Norman to the Swabian and Angevin period, Bisceglie appeared as a fortified town throughout the Middle Ages, built in solid white stone, directly shown or alluded by the white limewater colour. The white paintwork was both dependent on the use of the local materials and building techniques and useful to stress the idea of solid constructions against enemy attacks.

In the Del Balzo panel, the only different colour is related to the red tiles of the pitched roofs which should be considered a late introduction in the urban landscape of Bisceglie, since both residential and religious architectures show a large use of thinly and rectangular slices of local stone (chiancarelle) to cover the roofs. Some remains are still evident on a tower in Strada Pastore, while further evidence is found on the roofs of S. Margherita church and attested by some documents for the Romanesque Cathedral (Diocesan Archives of Bisceglie, Fondo S. Matteo, Processi a stampa). Within the framework of the present study, more specific researches are carried out on the introduction of tiles in the town.

2.2 *The spanish viceroyalty period (16th–17th century)*

During the last years of the Aragonese Kingdom of Naples, Apulia was endowed with new fortifications against Ottoman and Venetian invasions, especially after the disastrous Battle of Otranto in 1480 (Mongiello et al. 2009). The updating of the old fortifications in Bisceglie continued even under the Viceroyalty of Naples by building several pentagonal bastions (Dibenedetto & La Notte 1988). It seems that the military need to build stately fortifications by means of resistant square blocks raised in a short time and at low cost, updated the local construction technique. It follows that new quarries of local tuff (a biomicritic limestone with granular consistency and intense yellowish background) were opened for this purpose along the ancient routes to the towns of Ruvo (Scotelloni area) and Corato (la Tufara). This material, known but rarely used in medieval buildings (Valente 1985), was easily processable in comparison with the white stone and particularly suitable for extended masonry in isodomic technique. However, the surface was more delicate and perishable so it needed a protective layer, which led to the use of plaster and paintwork.

In addition to the change of building techniques, the new political status of the town influenced the architectural development. In 1513, in fact, the town got the privilege, known as *Pateat Universis*, to be a state town, enfranchised from the feudal

domination that restrained both the economic and the social development (Consiglio et al. 2006).

The local nobility and new rich merchants moved in from the nearby feudal towns and even from Spain; they started an important urban transformation, building rich patrician palaces in the modern Renaissance style.

The architectural production aimed to celebrate both the prestige of the noble families and the power of the aristocratic town, now under the direct rule of Naples. The new noble house, so-called *casa palaziata*, was the result of the purchase and rearrangement of two or more medieval towers, in order to get a bigger house with many rooms over several floors and, sometimes, even an inner courtyard.

The facades were characterized by the rustication of solid white limestone blocks on the ground floor, using the original medieval structures (Palazzo Ruggeri) or building it on purpose (Palazzo Frisari, Figure 1). Above the stringcourse, the upper levels were in the new yellow limestone masonry, dressed in smooth-faced rustication (Palazzo Cesario) or diamond-shaped rustication (Palazzo Frisari). Sometimes, it was totally smooth, both in yellow limestone (Palazzo Milazzi) or in the white stone of the original medieval structure (Palazzo Lupicini). New large rectangular windows, with frames and sills molded in white limestone, opened onto the facades.

These distinguishing features of the *casa palaziata* remained unchanged for almost two centuries, with few differences in details and decorations. (Giacomobello 2009)

The analysis of the few paintwork remains confirms the use of single-layer plaster, coloured by white limewater, throughout the 16th and 17th century. As a matter of fact, limewater was used both to protect the surface of the newly introduced limestone and to even out the colour of the facade, making it appear as an even masonry work of the same material. Clear examples of this need can be seen on the stringcourses, usually in yellow limestone except for the windows sills, in more resistant white stone. Another interesting clue is offered by the smooth bottom part of the molded window frames, which protrudes from the wall surface, suggesting the use of thin plaster layers to level out the thickness. If this is evident in the few palaces built *ex novo*, it is even more so for the larger number of medieval palimpsest facades, where the old windows and doors walled up needed to be hidden under plaster. The use of limewater, moreover, smoothed and evened out the rough surface of the limestone, which could contain vacuoles and small marine fossils.



Figure 1. Bisceglie, Palazzo Frisari, 1560.

Both the *casa palaziata* in the town and the patrician villas in the countryside, built as summer residence of the aristocracy, show white colour facades and a defensive appearance. Actually, only the sturdiest elements of the facade (portal, windows, quoins) were in real white stone, whereas the wall masonry was in yellow limestone, covered with white limewater layers (Villa Posa, Villa Fenicia). Whitewashing the masonry in white travertine colour, both on real stones and on brick curtain walls, is also attested in Rome during the same period (Tabak 1993).

Therefore, the Viceroyalty town continues to show itself as a white stone citadel, solid and resistant against the enemies, even if the new elegant palaces introduce a more modern element. The extensive use of yellow limestone, started for the military walls and then available to the civil architectures, implied the regular use of plaster and limewater, mostly developed in the future centuries.

2.3 *The bourbon kingdom and the 18th century*

In the first decades of the 18th century the new architectural trends of the Capital reached Bisceglie, even if not immediately. More complex and elaborate architectures were introduced, with a modern interior layout, new elaborate stairs with columns and balustrades and facades defined by architectural orders and no longer rusticated (Cazzato 2008). The existing examples seem to indicate that the new facade design also led to a larger and more complex use of paintwork.

Villa Frisari and Villa Fornari can be considered among the first examples of the new facades, articulated by vertical and horizontal bands underlining the upper part of the basement, the second floor, the window level, the cornice and the corners of the building. Whereas the colour of the bands was white like the white stones of the basement, there are no certainties about the original colour of the bays, red-brick colour only in the last version.

It is possible to get more information on the paintwork from Palazzo Ammazzalorsa, built on the waterfront of the town at the beginning of the cen-

tury, by the Bruni noble family. On the high white stone basement, the limestone facade is divided by pilasters of the same material, with bases and capitals, and topped by a molded cornice. The large painting by J. P. Hackert, depicting The Port of Bisceglie and actually exposed in the Caserta Palace, shows Palazzo Ammazzalorsa as it was around 1788.

The pilasters are coherently in stone colour, as they represent the strong underlying structure, whereas the bays are differently in yellow colour. The duotone became a trend in the Capital since the construction of the Viceregal Palace by Domenico Fontana in local volcanic stone (piperno) and brick curtain walls (clay from Torre Annunziata); it was also used for the facade of both royal and noble houses throughout the 17th and 18th centuries (Mazzoleni 2000). The architectural elements could range from the dark gray colour of *piperno* to the yellow tuff and white tr*avertino*, while the brick could vary from light yellow to light and dark red, as recorded in the documents of the period (Pisani 2003).

The same typological approach was used for Palazzo Ammazzalorsa, even if it is not clear whether the yellow colour of the bays refers to a brick wall (not a local technique) or to the yellow limestone masonry. This material, in fact, was considered less resistant and formally not as suitable to represent the architectural frame as the bricks were in the Neapolitan or the Roman regions, rich in clay.

A clearer evidence of the use of duotone, comes from the analysis of Palazzo Manes (Figure 2). The palace, built in 1776, refers directly to the Neapolitan models both in the interior decoration and the facade design (La Notte 2016). The pigment analysis reveals a uniform yellow ocher colour on the limestone pilasters and frames but even on the white stone elements of the windows. The bays, instead, alluded to a brick curtain wall, painted in red colour and detailed designed by cutting the joints of the bricks on the single-layer plaster of the facade. Lastly, few details under the windows, were painted in green. Incidentally, Palazzo Montecitorio, in Rome, adopted a similar duotone in the 18th century, as shown in a painting by F. Pannini (Tabak 1993).



Figure 2. Bisceglie, Palazzo Manes, 1776.

Moreover, in the same century, many old flat facades were decorated with new pilaster layouts even just by painting vertical bands on the plaster, topped by the cornice of the building slightly protruding in correspondence of them. It is the case of Palazzo Carelli, restored around 1780 with white painted vertical bands and brick-red bays. Another duotone possibility consisted in the use of yellow bands and white limewater bay, as shown in the 18th phase of the Santi Martiri church in Sagina or S. Adoeno.

The research, not only pointed out different paintwork possibilities of the duotone practice, but new discoveries, also, suggest other solutions in the use of the colour during the same period. For example a monochrome facade of white limewater on a single-layer plaster has been adopted by the small Palazzetto Manes on the harbour, by the stately Poor Clares convents of S. Luigi and S. Croce, the convent of S. Domenico and the churches of S. Niccolò and S. Maria del Suffragio, here recovering the old tradition to even out the medieval stones and the yellow tuff by the same limewater colour. A yellow ochre monochrome, instead, characterizes the facade of the Misericordia church and Villa Abrescia. Therefore in contrast with the duotone practice, sometimes, the paintwork was uniformly distributed both on frames and on bays, leaving the facade articulation to the light and shade of the lugs.

Moreover, different colours could be used to emphasize few specific parts of the facade, for example to increase the shadow perception. It is the case of the rural church of S. Maria di Giano, whose perimeter walls were painted in yellow ochre, in a sort of continuum with the natural colours of the countryside and not using the contrast effect of the white. At the corners of the wall, the pinnacles have protruding scrolls, whose shadow effect is emphasized by a dark red colour. In Villa Fiore, furthermore, the yellow colour of the facade niches was used to make the white marble busts stand out, creating a so-called cameo effect.

Under the stable government of the Bourbons, therefore, the town gradually abandoned its old defensive aspect to take on a more elegant and refined look; the new facades with architectural orders implied a greater sophistication in chromatic effects, directly inspired by Naples. G.M. Galanti, in fact, points out in his *Report on Apulia Peucetia* (1791) that the towns on the Apulian coast follow all the most updated trends of the capital.

2.4 *From the 19th to the 20th century*

In the 19th century the town underwent a period of intense urban and architectural transformation (Dibenedetto & La Notte 1988). The rampant bourgeoisie abandoned the small uncomfortable houses in the old town and built new elegant pal-

aces *extra moenia*; even in the countryside, the middle class built lots of new villas in imitation of the aristocracy's lifestyle. The noble families, as well, renovated their urban and rural houses, frequently changing the interior decoration and restyling the facades. From the latter part of the previous century, the architectural production was characterized by a more normed and uniform style, due to the academic teachings of the Institute of Fine Arts of Naples, which promoted the neoclassical and then the neo-Renaissance style, largely inspired by the Roman architecture and widely adopted by the new architects of the kingdom (Chieppa 2006). The usual application of the architectural orders led to a more conscious and widespread practice of the duotone on the facades, consolidating the association of colours imitating stone for architectural elements and colours imitating curtain for masonry funds. The wide distribution of treaties and manuals on construction techniques, contributed to achieve a uniform architectural *koinè* (Mantovano 2003), often prescribing paintwork with limewater, both coloured and in pure white, as well as stucco applications to achieve scratched or rusticated surface effects (Villa Vecchio in Bisceglie). The research carried out in Bisceglie pointed out mainly four different duotone modes, adopted for the facades.

During the first half of the century the widely used mode was the association of white travertine colour for the architectural elements with yellow ochre for the bays (Villa Siciliani, Villa Logoluso, Palazzo Berarducci). Some details, moreover, could be painted differently such as the frieze of the balcony windows, in red colour (Palazzo Consiglio) or in light blue (Villa Minutillo, confirmed by a coeval view of the villa, painted on the interior wall decorations).

The use of yellow bands and white bays, instead, characterized the facade of Palazzo Veneziani Santonio, restyled around 1840 by the family Tafuri.

Differently, yellow frames but light brick-red bays were used for both Villa Abbrescia and Villa Lancellotti in the same period. This combination, even with the variation in white bands, is the most common choice in the second half of the 19th century until the first decades of the next one. This duotone, in fact, was the most theoretically coherent with the facade layout in resistant stone frames and brick curtain walls, promoted by the academic teaching and adopted by the architects and civil engineers of the time, such as the Apulian Luigi Castellucci (Chieppa 2006). Palazzo Milazzi, Villa Bufis, Palazzo Ruggieri but also Villa Nigri and Villa Turco are interesting examples of this mode as the late 19th century phase of many other palaces, according to the stratigraphic analysis.

The last combination was in light brick-red frames and yellow bays, showing that the use of color has lost its original architectural meaning and became just a simple decoration possibility.

Moreover, the stratigraphy indicates a general preference for the brick red colour, even for the monochrome facades, in the second half of the century (the late phase of the Dominican Convent, Palazzo Veneziani and the Misericordia church).

In the 18th century, therefore, the town shows a renewed aspect in neoclassical and neo-Renaissance style. The facades, initially related to the previous paintwork tradition, gradually turn to brick red tones, suggesting the use of materials different from those employed in the local construction technique. Both the facade layout and the colours alluded to the Neapolitan and Roman architectures, losing the close relationship with the local context. The yellow-red duotone will be followed by trials of new colours and materials in the late 19th and early 20h century, according to the Eclectic style and Art Nouveau.

The small feud of Bisceglie, developed in Kingdom of Naples, has become part of the largest Kingdom of Italy now.

3 NOTES ON THE PAINTWORK RESTORATION PRACTICE

During the last thirty years, the restoration of the historical centre of Bisceglie show an alarming alteration of the facade plaster and paintwork, rapidly changing the original appearance of the monuments and irremediably compromising the urban landscape.

Too often the removal of the facade plaster, according to the recent taste for the shown stones, erase the laborious historical effort to transform isolated towers into palaces and often lead to the disappointing discover of scarse traces of the medieval pre-existences, heavily transformed. Sometimes, instead, the old plaster is completely renewed, losing the information about its original composition and technique. Furthermore, when the colour is renewed it is often preferred a white monochrome, more suitable to the recent taste for minimalism. In other cases, incoherent colours are used for different parts of the facade or one single colour is applied both on the architectural elements and the wall bays, flattening the tridimensional articulation. The same happens when a uniform colour hides the old duotone painted layout, drastically changing the perception of the facade that, as a result, appears banal and flat.

Therefore, a detailed historical research on the paintworks and plasters is necessary to take more conscious decisions in the future works, since the facade restoration should not be considered as a merely cosmetic issue but an operation fully integrated with the proper 'architectural restoration' of the entire monument and in close connection with the urban context it belongs to.

The research on Bisceglie points out the historical and urban complexity of the paintwork and therefore it is not possible to offer an easy and valid restoration solution to be applied in all the cases. Actually, the most suitable approach seems to be the so-called Critical Restoration, far from the extremes of both Pure Conservation and Renovation approaches. As a matter of fact, given the necessity to preserve the original material, it seems necessary to balance all the different instances that the monument requires, avoiding preconceived dogmas and accepting the responsibility of a final choice.

Therefore, experts should take into consideration both the well-known historical and aesthetical issues but also the so-called psychological issue, respecting the established image of the monument in the collective memory. The urban issue is equally important, as the present research shows, since the colour is closely related both to the actual urban context and to the preexisting overall. Among such complex historical transformations of the buildings, a final issue needs to be underlined, one that could be defined as a 'didactic issue'. It refers to the important target of the restoration: helping the monument to develop its role of witness of history and civilization (The Venice Charter 1964), in the most perceptible way. Therefore, in the paintwork restoration, the choices should increase the expressive possibilities of the buildings, helping to better show the context of the other architectural elements of the facade layout, deeply connected with the colour, and to communicate the idea of architecture that the building aimed to express.

In this sense, therefore, it is possible to consider 'the restoration of the colour' within the wider field of 'the loss reintegration', where the loss (lacuna) is not only a limited portion of missing plaster or pigments, but the more serious loss of important historical information, carried out by the fragile paintwork which time fades year after year.

4 CONCLUSIONS

The present research discusses the problem of the architectural use of paintwork in the Kingdom of Naples, little studied until now. The synthetic historical analysis, presented in this work, aims at showing how paintwork and architecture developed together to create the urban landscape. The colour, in fact, supported the facades in the double task of architectural identity of the building and urban relationship with the town context. Therefore, is does not only represent a decorative issue but a more important cultural one, also related to the way in which the town wanted to present itself.

These preliminary results of a wider research do not have the ambition create an exhaustive regulatory code for future revival restorations but aims at being a useful tool for the future restoration activities, to be aware of a complex problem often unknown or, worse, culpably neglected. The future scientific analysis on pigments and plasters and the archival research on the original documents will bring new information on the topic: origin of pigments and earths, chemical composition, specialization of workers, demands of clients and transaction costs are just some of the questions that will be possible to answer in the future. This wider research will lead to more interesting results not only for the history of southern Italy's cultural heritage but also for the restoration practice. Moreover, it will help to define a complex and organic 'Colour Project' of the town, to guide the restorations of historic buildings with a more conscious and analytical awareness of the problem and also with a synthetic global control of the urban transformation.

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Set of nine cave houses in La Algueña, Alicante (Spain). Renewal proposal

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ABSTRACT: This work outlines the discovery of a unique set of nine excavated cave houses from the eight-eenth century in the vicinity of La Algueña, a small village in the Vinalopó Medio region in the province of Alicante (Spain). These cave houses are of special interest since they were dug out by Algueña's first settlers and boast all the main features of excavated architecture in this area. Studying these caves has shed light on the sequence of excavation. After comparing them to other excavated cave houses from the same region, part of a previous study, a plan for their renewal and reuse is outlined. With the goal of preserving the region's ex-cavated heritage, this proposal involves transforming the set into hotel complex.

1 INTRODUCTION

Excavated architecture has always been associated with the countries of the Mediterranean basin, since it is here that this habitat has been most developed (Jessen 1955).

Most of the cave houses in the Iberian Peninsula are found in the southeast, with Granada, Murcia and Alicante being the provinces with the highest number of inhabited caves (Urdiales 1987).

In the Alicante province, cave houses have been studied, or at least identified and located, in Alfafara, Crevillente and Rojales as the three main and most referenced sites in the province. However, there are numerous other cave clusters in the Vinalopó Medio region, the existence of which is known almost exclusively by their current inhabitants and immediate 'neighbours'.

The research presented here is part of a broader, on-going project to inventory and catalogue the 1000 or so caves in Vinalopó Medio.

The caves presented in this work are located in the municipality of La Algueña which, at the turn of the eighteenth century, was made up entirely of cave houses. So far in this area alone 140 remaining cave houses have been inventoried.

The focus of this paper is the detailed study of one of the oldest sets of cave houses in the municipality, excavated by its first settlers. The morphological and architectural features of the nine caves in the set are presented and compared to those typical of excavated architecture in the Vinalopó Medio region, as outlined in earlier studies (Martínez et al. 2014), (Martínez, unpubl.). Finally, a plan for their renewal and conservation as habitable spaces is proposed, by way of demonstration that excavated architecture can indeed be recovered and put to use in the present day (Aranda 1988).

2 LOCATION AND ENVIRONMENT

La Algueña is a village in the province of Alicante (Fig. 1) with a total population of 1391 (INE 2016). It is located on an alluvial plain set between three prominent hills. The surrounding landscape is typical of the warm and arid Mediterranean climate, and has significant environmental value

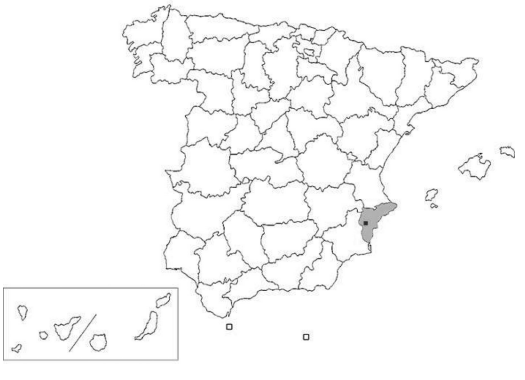


Figure 1. Location of La Algueña, Alicante (Spain).

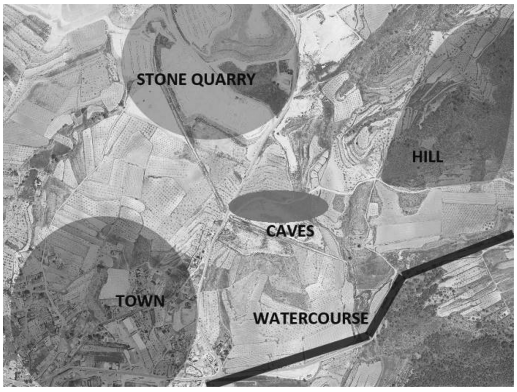


Figure 2. Location and environment of the cave houses (aerial photo from SIGPAC).

thanks to agriculture (table grapes and almonds) and the unique topographical features and Mediterranean flora (rosemary, thyme, and almond, olive and pine trees).

The nine cave houses of this study are set between a watercourse to the southeast, a hill to the northeast and a marble quarry to the north (Fig. 2).

All nine are located on moderately sloping terrain. The geological materials in the study area correspond mainly to the Tertiary period and are made up of conglomerates, sandstone and red clays (AAVV 1984).

3 METHODOLOGY

3.1 *Previous study*

First the general data relating to the typology, orientation, mode of access, grouping, use and characteristics of the external constructed elements (façades, parapets, ceilings, chimneys, finishes, attached constructions, skylights, yards and urbanization) of the cave houses was collected and recorded, together with the corresponding photographs.

A survey of the nine caves was then carried out to establish floor plans, elevations and cross sections of each cave individually and of the set as a whole.

Lastly the caves were inspected for damages and defects, analysing their origins and causes, and making a photo record.

3.2 *Establishing the bases of the renewal proposal*

The following bases were established to guide the proposed renewal of these excavated spaces:

Determine a new function for the excavated spaces, with a public residential use (hotel) being considered ideal, since it would work perfectly with the essence of the original architecture being recovered.

Integration of the immediate natural setting into the proposal.

No modifications to the original floor plan, this being a feature common to all the excavated houses in the area.

Use the same regionally-sourced materials for the finishes as those used traditionally.

Improve living conditions in the excavated spaces, proposing solutions that will bring them up to modern standards and expectations.

4 RESULTS FROM THE PREVIOUS STUDY

The nine caves are irregularly clustered on a terraced hillock. They are accessed via wedges cut into the mound until reaching what is the front façade (Fig. 3). The architectural form is typical of cave houses that are fully excavated, with no attached constructions built onto the front (García et al. 1998).

The cave houses were observed to share the same morphology as that typical of other such dwellings found in the Vinalopó Medio region (Martínez et al. 2014). The climate and soil conditions have given rise to this unique architectural form (Aranda 2003).

The floor plan and distribution of rooms is split into two bays, with three communal spaces (entrance hall-living room-kitchen) running through the length of the cave, generating an open feel with large connecting arches (Fig. 4).

The kitchen is located in the second bay, with an oven and a chimney which, together with the windows on the front façade, allows air to circulate throughout the dwelling, ensuring adequate ventilation. The rest of the rooms lead off from these communal spaces, in some instances forming a third bay and a yard area (Fig. 5). Seven of the caves have a yard excavated into one of the banks lining the "access wedge".

The different stages of the excavation process presented by each of the nine caves allowed us to

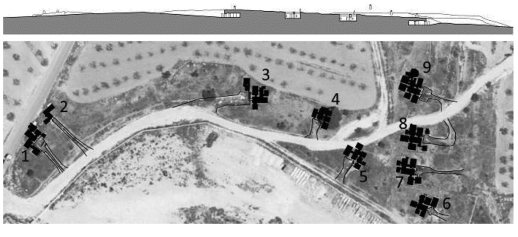


Figure 3. Floor plan and general cross section of the cave houses (Authors).



Figure 4. Interior of cave 9 (Authors).

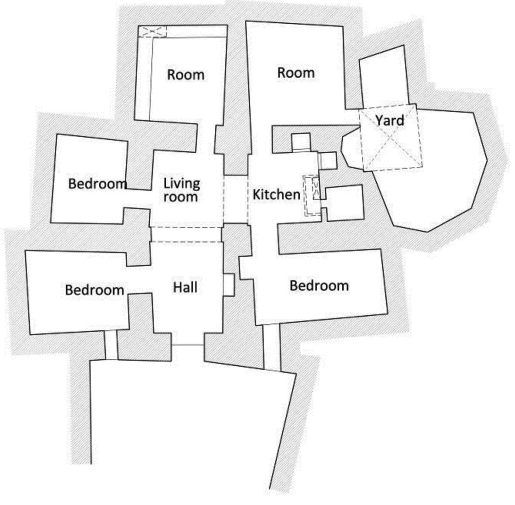


Figure 5. Floor plan of cave 9 (Authors).

confirm our hypothesis as to both the sequence of excavation and the excavation process itself for caves in this region (Fig. 6).

First, a wedge is excavated into the hillock until reaching a depth that allows suitable headroom to begin excavation of the cave house itself.

Once the access wedge and front façade is defined, excavation proper begins by making the main entrance and then excavating out the entrance hall from there. From this first space, excavation continues to the back of the house, forming the central space from which, to the left or the right, the kitchen and vertical shaft of the chimney are dug out. Next, one or two bedrooms are excavated along the outer wall (façade), adding the windows

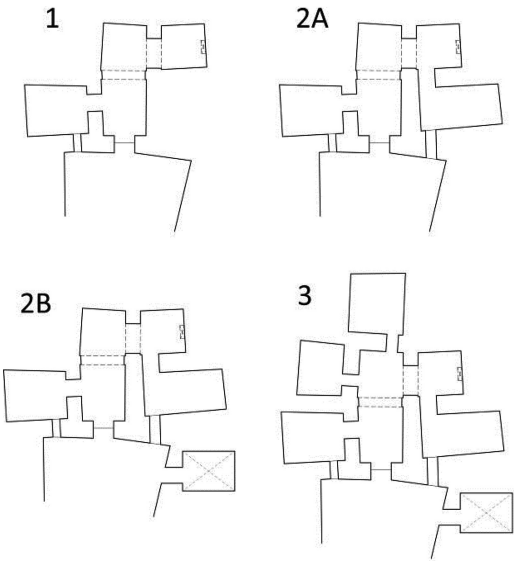


Figure 6. Sequence of excavation (Authors).

from inside out. From this basic floor plan, the cave can be further expanded according to the needs of the occupants, adding rooms in a second and even a third bay.

A study of the typical external built features (Martinez et al. 2014) reveals that none of the caves have an attached façade (Fig. 7). Originally, then, the natural terrain making up the front façade would have been cemented by lime mortar. The parapets above the façade are made from dry-stone walls. All roofing is made up of the natural soil itself without any kind of coating. External chimney shafts are the shape of truncated square pyramids (Fig. 8). One of the caves features a skylight (known regionally as a *lumbrera*) in a third bay room (Fig. 9).

The caves are semi-abandoned, meaning their state of conservation is suboptimal. The most common damages are indicative of damp, cracks and material degradation.

Among the types of damp observed, that deriving from rainwater seepage is the most frequent. Specifically, given that the layer of earth that forms the roof of the vault is well-cemented and therefore completely waterproof, any leaks through the ceiling are the result of mechanical fissures.

In some of the caves, rising damp (by capillary action) has occasionally been observed.

In excavated architecture, damp caused by condensation is more likely to be caused by high humidity levels rather than by low wall temperatures. No damp of this kind has been observed in these caves, mainly because of their open plan



Figure 7. Façade and parapet (Authors).



Figure 8. Chimney (inside and outside) and oven (Authors).



Figure 9. Skylight (inside and outside) (Authors).

layout and consequent good ventilation, which is key to avoiding condensation build-up.

The cracks detected in the cave houses are mechanical fissures, found most frequently in the low-rise vaults.

There is considerable material degradation in all nine caves, due to an obvious lack of maintenance, further exacerbated by water, wind and sun damage.

Soil erosion and disintegration has been substantial in the façades, also causing the collapse of the parapets and chimneys. A collapsed chimney has knock-on effects for the state of conservation inside the cave, with water running in through the shaft.

Crumbling of the enclosures and internal partitions is also common. This kind of decomposition is caused by the water getting in and sweeping away the base of the walls.

Where there is damp inside the caves, the adherence of the claddings to the structures themselves is lost and they have become detached.

Finally, much of the original exterior carpentry and textiles draped in the doorways between the different rooms has been lost.

5 RENEWAL PROPOSAL

The proposed renewal is born of a strong desire to preserve the region's excavated heritage. The proposed plan is therefore very respectful of the characteristics typical of this kind of architecture. It also honours local traditions in construction and the surrounding landscape.

Both the position of the cave houses and their relationship with the immediate natural setting will be maintained. Each cave house will become an independent space within the hotel complex. The reception and restaurant facilities will be located in the two caves closest to the main vehicular access, while the remaining seven, a little further from this access road, will be turned into suites with room for two to four guests (Fig. 10).

The immediate natural setting of the cave houses will be harnessed and showcased through the incorporation of outdoor recreational spaces into the complex, also planting native vegetation. The existing almond tree plantations will be retained, and the dry-stone walls, here known as *ribazos*, restored, serving the primary function of containing the terraced fields. The proposed footpaths and rest areas have been dictated by the land topography.

The rehabilitation of the outdoor spaces of each cave house (access wedges and excavated yards) will turn them into semi-private outdoor rooms.

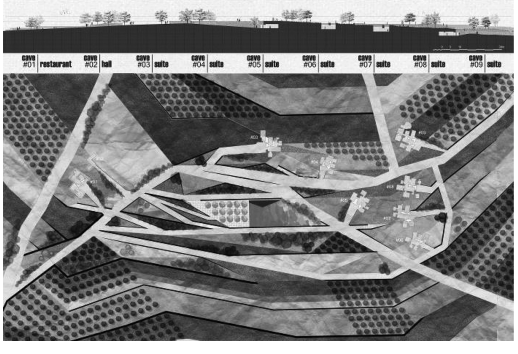


Figure 10. Overall plan of the proposed hotel (Authors).

In this paper a detailed outline of the proposed renewal of cave number 9 is presented, which would become a suite for four people. This cave house will have two separate bedrooms, each with their own en-suite bathroom, along with the communal spaces of the kitchen and living and dining rooms, and a semi-private outdoor space.

The design of the suite is closely tied to the original morphology and configuration of the caves in the area, as already described. In this way the original essence of the spaces will be maintained, even while they are given a new lease of life (Fig. 11). The vertebral axis of the cave house will be maintained, used as an entrance hall-living room-dining room. The chimney will stay where it is, as the focal point of the ensemble, with the dining table extending out directly from the chimney breast, forming a unique design feature.

The kitchen will be moved to one of the former first-bay bedrooms, opening onto the entrance hall and the dining room. Slight modifications to the doorways to the other rooms will create two separate bedrooms with en-suite bathrooms.

The final layout allows both bedrooms to be naturally ventilated, either via the front façade or the yard.

The redesign introduces an innovative twist on the traditional use of materials for the different interior finishes (natural stone and ceramic floors, carpentry, textiles, whitewashes, etc.).

A continuous microcement flooring will connect all of the rooms, preserving the cave's "back to nature" feel, while smoothing over the geometrical irregularities of the floor. Large geometric pieces of marble and limestone from regional quarries will be used as "carpets", taking centre stage in the rooms. The walls and the ceilings will be left with the texture and roughness of the natural earth, and coated with lime mortar and a whitewash finish. Woodwork elements will be introduced to the façade, as well as wooden slat door panels for the doorways so as to allow an adequate through-flow of air. This will optimise ventilation much in the same way as the textiles that were traditionally hung would have (Fig. 12).

The thermal stability inside caves is one of the key features of excavated architecture. Studies carried out in the region have shown that the maximum temperature range inside a cave house during the month of December is 8.1ºC, with an average inside temperature of 19.4 ºC and a relative humidity of around 50% (Martínez et al. 2014). These conditions are the result of the ground's high thermal inertia and the good ventilation the excavated space provided by the chimney. For guests to be comfortable, the space need only been heated by a source of internal heat gain which, in this proposal, is again provided by the chimney. The use of conventional external energy sources or air conditioning units will not be necessary, keeping energy demand and expenditure low.

Nevertheless, to meet public health standards, improvements are needed, to the bath—and bedrooms in particular. Both of these rooms tend to have high steam and humidity levels, making them prone to outbreaks of mould and bacteria growth. To counter this effect, the proposal contemplates the use of eco-active porcelain stoneware tiles (widely available), which actively interact with the environment to purify and clear the air of pollutants, as well as boasting antibacterial properties. This material is compatible with excavated architecture, and will improve living conditions in the caves without having to install additional air purification or ventilation systems.

In our design, the bathroom floor flows uninterrupted into the excavated bathtub and up the walls.

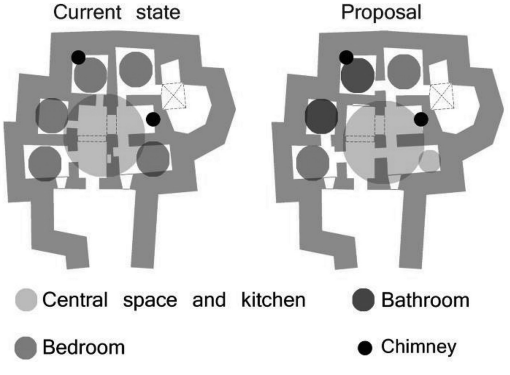


Figure 11. Scheme of the remodelled cave house (Authors).

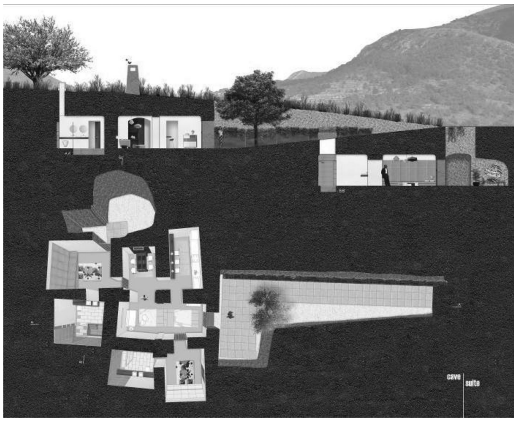


Figure 12. Floor plan and cross-section of the suite (Authors).

With these same public health standards in mind, the original skylight or *lumbrera* in one of the new bathrooms will be retained; besides improving ventilation, it will give a pretty overhead lighting directly over the bathtub.

Outside the cave house, the proposal includes the use of natural stone for planters that will line the access wedge. To smooth out irregularities of form, a perimeter of gravel will surround the square paving of the private outdoor spaces (accesses and yard).

6 CONCLUSIONS

The nine cave houses in this set have been studied and documented, recording their main features and characteristics.

They have been surveyed, and floor plans, elevations and cross-sections have been drawn up for each.

By analysing the geological, morphological and architectural features of the nine caves, it has been established that they are typical of the immediate area, including in terms of the way they are grouped and accessed. These characteristics are also shown to be similar to those observed in the other caves found in the wider Vinalopó Medio region.

The general state of conservation of the excavated cave houses and their structural elements has been inspected in detail. On the basis of a preliminary survey of damages and defects, it was concluded that their renewal is possible, suggesting measures for their repair and improvement. Lastly a proposal for the future use of these caves has been outlined, one that is respectful of their essential nature, while enabling their on-going conservation.

The proposed renewal would give rise to a set of excavated cave houses that have minimal environmental impact and which are completely in harmony with their natural setting.

It remains as future work to develop the proposal, at both the constructive solutions and the installation design.

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The influence of rice cultivation in the architecture of Sueca's village (Valencia, Spain)

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ABSTRACT: In the context of the Albufera Natural Park, more specifically in the territory surrounded by the municipality of Sueca (Valencia, Spain), is placed this investigation, which is focused in the study of different architectural typologies that revolve around rice cultivation. This protected area of 90 km^2 is divided into numerous smallholdings watered by irrigation canals of Arab origin, which contain more than 350 constructions. These structures are classified according to their function within the agrarian activity: residential architecture, hydraulic architecture and industrial architecture.

1 THE ARCHITECTURE RELATED TO RICE

The architecture that revolves around rice cultivation has been the basis of the development of many villages, being a leader in a period of splendour, not only in the economic field, but also in the cultural and demographic. However, the passing of the years, the specialization of the activity and the creation of farming communities has made that it has suffered consequences. The centralization of the production resulted in the loss of the functional basis of these buildings, in many cases suffering the abandonment and the subsequent start of deterioration, and, in other cases, the complete disappearance. Moreover, the weather conditions in which they are exposed, along with the poor quality of construction, accelerate much more the deterioration of these buildings.

2 OBJETIVES

The documentation about these type of constructions is scarce. This is not first-rate architecture with great ornamental or typological qualities. It is not a work of planning neither of great architects. This architecture should be read as a whole, as a unit, where the elements cannot be explained on its own.

The architectural ensemble can be understood from each of its elements, their relation and the role they play. If the elements are in danger of extinction, the whole will be unable to survive. Having in mind that this architectural ensemble is already involved in the decontextualization process of the deterioration of their elements, the main objective of this analysis is to produce a detailed sample of a large majority of these houses, to place on record what remains at present, making a comparison of the different typologies in order to obtain some compositional, structural and functional conclusions. Likewise, studying in which kind of situation (use or disuse) they are and identifying the repeated distortions of typologies with poorly accurate interventions.

3 THE PYSHICAL ENVIRONMENT

3.1 *Geographical context. characteristics.*

The Valencian Albufera Nature Park is located in the south of the capital between the Turia River, in the north, and the Júcar River in the south. It is also delimited by the sea in the east. It is formed by 21,120 hectares located in the plain of Valencia, in a territory placed below sea level, where water streams are produced from one river to another, and from the sea, making possible the presence of a type of land with specific qualities.

But what is known as a nature park is a group of ecosystems that coexist within the same territory and which enable the growth of a wide variety of flora and fauna. These are: *albufera*, a lagoon of freshwater; *marjal*, where the rice is cultivated; and the *restinga*, where is placed the coastal band that separates the other two elements from the sea water.

The Mediterranean climate's parameters are slightly modified in the specific area of the Albufera due to the high humidity level, which is maintained on an average of 70% throughout the

year. The average temperature is about 18°C, ranging from 11°C in winter to 25.5°C in summer. The dominant winds are those that come from the sea and cool the atmosphere of the park, followed by west winds which provide hot days in summer and are mostly present from November to March.

3.2 *Activities*

In the Albufera Nature Park are mixed different types of resources' exploitation that distinguish it from the rest of nature parks.

The fishing since the Muslim period has been the basis of the economic sustenance for its population until the decrease of the water quality reduced the exploitable species.

On the same way as the fishing, the hunting is currently practiced in Sueca, Cullera and Silla, where this activity is regulated by a local regime. Each season eight hunt trips are organized on Saturdays, between the end of November and the middle of January.

Rice, together with orange trees and vegetables, are the main types of crops made in this area, although rice is the most relevant and popular.

4 SUECA

Sueca is located 25 km in the south of Valencia, in the middle of the Valencia plain, bordering Cullera, Riola, Polinyà del Xúquer, Fortaleny and Llaurí in the south, separated from them by the Jucar River; to the west with Albalat de la Ribera and Sollana; to the north it is limited by the Albufera lagoon, whereas in the east is limited by the Mediterranean sea.

The Sueca landscape is defined by the different ecosystems which form the nature park, where the characteristics of the marsh can be observed. There is 8,500 hectares for cultivation, 6,500 ha of which are destined to rice cultivation, while the remaining are for citrus and vegetables growing. Therefore, its topography is flat and practically located at the same height as the sea level. Only the Muntanyeta dels Sants exceeds 25 meters height 0, and from there we can obtain an excellent view, as we can see in the Figure 1.

From the fifteenth century, the history of Sueca is linked to its rural character, to the countryside and especially to the water, which is what will mark its ups and downs. At the beginning of the sixteenth century the rice cultivation began to be developed, but it was not until the Bourbons period when the rice fields took the hegemony of the crops, starting the struggle and the constant desire of the peasantry to gain fertile ground to Albufera lagoon. The population rose from 460 inhabitants in 1600 to almost 18,000 in the twentieth century.

4.1 *The rice cultivation*

Traditional cultivation covered a full year. Just when the harvest finished in October, the first step to start again was to flood the land for two months. In the meantime, in order to prepare the crop, the farmer, using mud banks, enclosed an area separated from the rest of the field, which is called *planter*. It began with the *fangueo*, a technique where a horse pull of a wheel which seems like a kind of cage and move the ground until turning it into fine mud. In doing so, in March the quarry was prepared for the mixing, which consisted in dropping the cereal seeds evenly throughout the area.

By May the rice had grown from 30 to 40 cm in the quarry and it was time to pick it up to transplant it into the big field. The field, previously *fangueado* (treated with the *fangueo* technique), received rice thickets of 30 to 40 cm diameters—called sheaves—which were placed evenly all over the area. The rice had all the summer to grow, until September, when the harvest get close and with it the hardest work for the farmer as well.

The sheaves were transported in dryers to start with the threshing of the rice. Once the rice was separated from the straw, it was necessary to let it dry, so, to achieve this, the rice were scattered in the dryer.



Figure 1. Overview from the Muntanyeta dels Sants. Photograph taken by TFM, "*L'arquitectura de l'arròs*" (Carme Masó).

Finally, they were piled up in the granaries and some even in the rooms of farmer's houses. In the mill, the brown bark was finally separated from the grain and after this it was ready to be sold.

4.2 *The irrigation system*

The human being has needed to look for stability in the technique, a guarantee that let him have harvests year after year. A hydraulic system is a network of water channels that are based on the geographical principle of gravity, causing the water to flow from the highest to the lowest parts. In the case of the rice fields of the Albufera Nature Park, located on a plain and near the coast, a system of mega scale has been constructed, that means great dimensions of continuous irrigation, thanks to the presence of the main Valencia's rivers.

4.3 *The road network*

The network of roads, with a hierarchical order, has made possible the access of farmers to their fields for hundreds of years. Within the paths we can find:

- Asphalted roads. They are the ones of greater width and go from the top to bottom of the area, but their number is limited.
- Dirt roads. They are narrower and their length vary. They are the most numerous.
- Flood Road. They become flooded when the water is conducted to the fields.
- Sides of the road to enter into particular houses.

5 ARCHITECTURE

5.1 *Residential architecture*

Residential architecture is the result of the settlement of the mankind in a certain place, and in the specific case of rural architecture is deeply linked to the land. However, it must be taken into account that rice production works differently from other types of crops, especially because the constant presence of the farmer in the cropland in not a necessity. That was not the case in the 1960s, when rice was the economic base of many more families, and the transportation facilities of the town or village to the property field were not so favourable. But a matter of a physical nature made difficult to establish housing in the countryside in the past as well as in the present, caused by the discomfort of dwelling in marshy places where the humidity and abundance of insects are much present.

The Sueca's farmer grouped into population centres, but had the necessity to rely on buildings



Figure 2. Examples of houses. Photograph taken by TFM, "*L'arquitectura de l'arròs*" (Carme Masó).



Figure 3. Examples of small houses. Photograph taken by TFM, "*L'arquitectura de l'arròs*" (Carme Masó).

that could allow him to stay in periods of high activity and also house the essential tools for cultivation, which were much smaller and rudimentary that those used nowadays.

Therefore, the residential architecture belong to a scattered structure as a result of the division of land, where each owner was as close as possible to his field, using the minimum part of land they could.

5.1.1 *Houses*

The houses are residences for the gentlemen, located in farms, with dwellings for the staff, livestock rooms and warehouses, tools, raw materials and harvests. There are sets formed by several units, where the house is situated at one end and the rest are annexed to it by one of the sides, while those that have an unrelated agrarian function are placed apart.

The house is usually compact, ground floor plus one or plus two, with multiple windows and balconies and decorated with either sculptural or pictorial ornaments, but without losing its rural character. On the ground floor is usually located the kitchen, the dining room, the service rooms, a patio and spaces for the animals. Through a narrow staircase we arrive to the noble floor, where the rooms are situated.

5.1.2 *D'apeo houses*

The huts, also known as shelters *d'apeo*, are the homes designed to meet the needs of the small farmer, such as being able to keep the car, tools to work the land, products, the horse and, sometimes, in times of planting or mowing, even the family. All this solved in a minimum and cheap surface affordable for them. This is the main reason for why the constructions and material systems are simple and low cost.

These constructions have usually only one interior corridor and a single floor to make his structure simple, but gaining storage space with the incorporation of a loft with wooden beams.

Table 1. Results obtained from the characteristics of houses.

Results	49 elements
Function/Status	51% in use and in good condition
	22.5% ruined elements
	20.4% in use/pathologies
	3% new elements
Composition	55.1% complex typology
	38.8% compact typology
	6.1% elemental typology
Constructive system	57.3% can't be recognized easily
	22.4% mixed solutions
	4% ceramic brick
	2% metal/concrete
Rooftop system	67.5% mixed solutions
	28.5% sloping roof
	4% flat cover
Rooftop material	49.1% mixed solutions
	36.7% ceramic tile
	14.2% concrete
Color	69.4% white finish
	26.6% colored
	4% uncoated

5.2 *Hydraulic architecture*

The hydraulic architecture is that one which provides mechanisms to make possible the arrival of water at all points of the rice area, where can be found: *canos* and engines. In the case of this typology of architecture, it is worth noting a common characteristic that all elements share: its good condition and the fact that it is an active architecture due to its important functional role. The owner is the Water Trade Union, which ensures its proper functioning.

5.2.1 *Canos*

A *cano* or *canet* -also known in other regions as a siphon-, it is a method of conducting water that facilitates the passage of a slope or a ground obstacle, especially roads, path and railway lines, to allow its extension to other irrigation spaces. The *canos* are usually located on a ditch or canal, because their system consists of a U-shaped channel generally placed underground. Nowadays, they are normally prefabricated cylindrical pieces, but originally they were made of copper or ceramic material.

5.2.2 *Engines*

The engines have been favoured by the electricity network facilities of nowadays. On one hand, its functioning has become easier but, on the other hand, for this reason, the most of the chimneys of the ceramic brick factory have disappeared.

The engine is a machine that produce movement from a source of energy. It is used in this particular case to pump the water and make it reach the highest points of the fields.

5.3 *Common details*

In addition to the basic characteristics taken into account in the inventory, there are other types of aspects that many of the buildings of the research have in common and which are briefly described below.

- Space near the hut. The space gained to the cultivated land has a rectangular or squared floor, in some cases just with the surface enough to access to the house, and in others, to keep the machinery.
- Access door. It is usually located off-centre of the front of the building.
- Interior attics. Made with wooden beams and used as a storehouse.
- Small fireplaces. They allowed farmers to light a fire indoors in moments of low temperatures or high humidity.
- Porches and benches. As any Mediterranean architecture, rice architecture takes advantage of the warm climatology to live the outside life with the incorporation of the porches.
- Trees placement. The farmer used to seek shade in their fields planting trees and other plants.
- Ornamentation. There have been found ornaments which in some cases represent a sign of complicity in the culture of Valencia.

Table 2. Results obtained from the characteristics of *d'apeo* houses.

Results	237 elements
Function/Status	41.6% in use and in good condition
	47.6% in use/pathologies
	10.8% ruined elements
Composition	72.5% elemental typology
	26.2% compact typology
	1.3% complex typology
Constructive system	61.2% can't be recognized easily
	25% ceramic brick
	10.3% mixed solutions
	3.5% concrete
Rooftop system	70.2% sloping roof
	20.6% flat cover
	9.2% mixed solutions
Rooftop material	55.2% ceramic tile
	35.3% mixed solutions
	9.5% metal/concrete
Color	46% white finish
	49.7% colored
	4.3% uncoated

Table 3. Results obtained from the characteristics of *canos*.

Results	20 elements
Function/Status	70% in use and in good condition
	25% in use/pathologies
	5% new elements
Composition	95% elemental typology
	5% compact typology
Constructive system	70% can't be recognized easily
	20% ceramic brick
	10.3% mixed solutions
	5% concrete
Rooftop system	55% flat cover
	45% sloping roof
Rooftop material	55% painted cover
	35% ceramic tile
	10% metal/concrete
Color	50% white finish
	45% plaster finish
	4.3% uncoated

– Ventilation openings. Formation of a triangle with three ceramic tiles or with the placement at the forehead of the same tile leaving the holes without coating.
– Attachments for installations. For all water tanks, light generators or any other type of appliance that for its value can be attractive to thieves.



Figure 4. Examples of *canos*. Photograph taken by TFM, "*L'arquitectura de l'arròs*" (Carme Masó).



Figure 5. Examples of engines. Photograph taken by TFM, "*L'arquitectura de l'arròs*" (Carme Masó).

– Black and red colour in wall and covers to get more permeability.

5.4 *Distortions*

There are several actions that were thought as solutions to problems detected by the owners of the houses, which have actually distorted the traditional character of the built elements in a very specific manner. The following is a brief description of some of these aspects.

– Change of door. Replacing the original wood with aluminium.
– Moisture solutions. Cement-based coatings.
– Change of materiality in covers.
– Marshy roads. Areas that have been affected by these circumstances, has resulted in the abandonment and subsequent downfall of buildings.

Table 4. Results obtained from the characteristics of *canos*.

Results	237 elements
Function/Status	48.8% in use/pathologies
	29.3% in use and in good condition
	12.2% new elements
	9.7% ruined elements
Composition	75% compact typology
	25% elemental typology
Constructive system	68.3% can't be recognized easily
	26.8% ceramic brick
	4.9% concrete
Rooftop system	55% mixed solutions
	42.5% sloping roof
	2.5% flat cover
Rooftop material	52.5% ceramic tile
	30% mixed solutions
	17.5% metal/concrete
Color	80% white finish
	12.5% colored
	7.5% plaster finish

6 CONCLUSION

The municipality of Sueca is an example of an active witness of our ancestors' life, and the architecture in it is also a sign of their way of life. The rice fields are for this locality the thread of their history as a village, sometimes full of splendour, with periods of economic bonanza, but also with unfortunate situations, like the coming of deadly diseases. This provided labour force from other localities, some of them closer than others, and it has been the livelihood of many families for a long time.

It is clear that today the connection between population and the rice production is not as strong as when it was the economic base of the people. The advance in the industrial processes with the incorporation of powerful machinery has caused the loss of thousands of jobs linked to the crop.

It would not be reasonable to imagine a future where this architecture regained its active role within the village's economy. For this reason, this inventory has the intention to leave documentary evidences of what in 2016 a visitor could find if he moves through the municipality of Sueca, keeping in mind that lot of things would have been different if he had done it years ago, and it would not be the same if he would do it in future years.

However, the municipalities must generate other focuses that encourage the movement of its citizens towards this scope. With the reuse of some of its elements for activities in line with the needs demanded by today's society, together with an active awareness of the importance of maintaining the roots of a people, it would allow the transmission of the culture of rice architecture generation after generation.

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In situ monitoring and characterisation of earthen envelopes: A review

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ABSTRACT: The aim of this paper is to compile studies which involve monitoring comfort and characterising thermal properties of actual earthen structures, at full-scale and/or sample unit levels, thus showing the current state-of-the-art in the field. Firstly, a table is presented, giving details on its author/s, journals, set-up, climate type, followed standards and the apparatus that were used to take interior measurements. Then, the use of standards like ISO 9869 and ASHRAE 55 is discussed, giving details on uncertainties and on analysis methods for in situ measurements that can be applied to earth constructions. To finish, a selection of apparatus is proposed, considering accuracy and other properties. It seems clear that further research is needed to thermally characterise earth constructions both at wall and room levels, using accurate equipment and following proper standards, whilst testing several structures with similar features under the same climatological circumstances.

1 INTRODUCTION

One of the most influential procedures to prevent climate change is to motivate research on materials that lessen the impact on the environment during its life cycle. Research groups like SERT (Sustainable Energy Research Team) of the University of Bath have demonstrated that the amount of CO2 emissions and Embodied Energy of rammed earth is much smaller than in other materials that are commonly used nowadays (Hammond & Jones 2011). This information should be enough to prove the sustainable characteristics of earth, but there are other properties to which we must pay attention to succeed. Furthermore, data would probably vary if the climatic context changes.

The purpose of the ongoing research is to study the hygrothermal properties of earthen structures in the Dry-Mediterranean climate, Bsk-Csa according to the Köppen-Geiger classification, and then improve them by using natural elements that are present in the immediate vicinity. The goal is to optimise envelopes' thermal behaviour to comply with current standards. Although there are studies which have recently corroborated that earth has a great hygrothermal potential, further research on these properties is necessary combining measurements at both wall and room levels (Woloszyn et al. 2015). Several studies have stressed the potential of monitoring and simulating tools (Taylor et al. 2008; Ip & Miller 2009; Allinson & Hall 2010; Heathcote 2010; Freney et al. 2013, Woloszyn et al. 2015).

The aim of this paper is to compile studies where earthen structures were monitored, whilst paying attention to other research where a proper standard is used. This way, we will end up with a proposition of appropriate tools and methods that could be applied to monitor and characterise the thermal behaviour of earthen constructions.

2 METHODOLOGY

As a starting point, a wide variety of relevant methods and papers that do not necessarily include the study of earth constructions have been read. Table 1 shows specific research on monitoring and characterising earthen envelopes, whilst tests which have been carried out in lab conditions have been left out as they do not consider dynamic-state conditions.

The table is organised chronologically, beginning with the most recent paper on the matter, and considering relevant information which is essential to carry out a proper test: set-up—sample units or actual buildings-; climate type as per Koppen-Geiger; followed standards; and, finally, the apparatus that have been used to measure interior values, including exterior superficial sensors. Information on the authors' and publications' names is also given. On the other hand, Table 2

Table 1. Research on thermal monitoring and characterising earthen envelopes.

Paper	Author/s	Publication-Year	Set-up	Climate*	Followed standard	Described apparatus for interior measures
Energy evaluation of rammed earth walls using long term in-situ measurements.	Soudani et al.	*Solar Energy* 141 2017	In Situ 2 years	Cfb warm humid	~~ND~~**	CS215 Campbell (°C/RH) CS616 (water content) EL-USB-2 (°C / RH)
Adaptation of rammed earth to modern construction systems: comparative study of thermal behavior under summer conditions.	Serrano et al.	*Applied Energy* 175 2016	Sample units Summer 2015	Csa Mediterranean	EN ISO 6964:1996 EN ISO 13786:2001	ELEKTRONIK EE21 (DL) Pt100 DIN B (°C)
Arquitecturas en transición en el Alto Atlas de Marruecos, valle del Mgoun.	Vacas	MFP Univ. Seville 2015	In situ Spring 2015	BWh Desert	ASHRAE 55	PCE–HT71 (DL+°C/RH)
Effect of wall construction materials over indoor air quality in humid and hot climate.	Nematchoua et al.	*Journal of Building Eng*. 3 2015	In situ. Several in 2012	Aw Equat.	ASHRAE 55 EN ISO 7730:2006	CO200 Extech (CO2) CA1226 (DL+°C/air velocity)
Thermal performance summary of four rammed earth walls in Canadian climates.	MacDougall et al.	*1st ICREC Conference* Australia 2015	In situ Winter 2012	Dfb, Dfc Snow humid	~~ND~~**	Honeywell HIH400 (RH) 54 thermocoup. (°C)
General methodology applied to monitoring a building to assess its energy performance.	Felices et al.	*3rd ICCBR Congress* UPM Madrid 2015	In situ Summer 2014	Csa Mediterranean	ASHRAE 55 EN ISO 7726 EN ISO 7730:2006	OPUS 208 (DL) 12 K thermocouples (°C)
Mesure du comportement hygrothermique du pise.	Chabriac	PhD ENTPE 2014	In situ 3 years	Csa Mediterranean	EN ISO 10456:2007	CR1000 (DL) CS215 Campbell SHT75 (°C/RH) EL-USB-2 (°C / RH) 107Betatherm (°C) CS616 (water content)
Thermal comfort of global model earthship in various European climates.	Freney et al.	*13th IBPSA Conference* 2013	In situ 1 year	BSk dry	ASHRAE guideline 14 ASHRAE 55	~~ND~~**
The thermal performance of earth buildings.	Heathcote	*Informes de la Construcción Vol. 63* 2010	Sample units 4 months	Cfa warm humid	ASHRAE 55	DS19121G (DL+°C/RH)
Hygrothermal analysis of a stabilised rammed earth test building in the UK.	Allinson & Hall	*Energy and Buildings Vol. 42* 2010	Sample unit 10 months	Cfb warm humid	EN ISO 8301:1991 EN ISO 10051:1996	Tinytag Ultra 2 (°C/ RH) Hilton B480 (HFM W/m^2)
Comportamento térmico de construçoes em alvenaria de adobe: ensaios experimentais sobre três células de teste á escala 1:4.	Meneses et al.	*7th Congreso de Tierra en Cuenca de Campos* 2010	Sample units at Lab. 1 month		EN ISO 6946:2007	ICP (DL) PT100 DIN 1/10 (°C)

Thermal behavior of an earth-sheltered autonomous building—The Brighton Earthship.	Ip & Miller	*Renewable Energy* *Vol34* 2009	In situ 1 year	Cfb warm humid	~~ND~~**	~~ND~~**	Betatherm 10K3A11A (°C) CRX10 Campbell (DL) Thermal Inst Model A (HFM W/m2)
Energy use and thermal comfort in a rammed earth office building.	Taylor et al.	*Energy and Buildings* *Vol40* 2008	In situ 2 months	Cfb warm humid	ASHRAE 55		

* Köppen-Geiger climate classification (Kottek et al, 2006) **~~ND~~ = Not described

RH = Relative Humidity
HFM = Heat Flux Meter
DL = Data Logger

shows related research which have specified the importance of following standards like ISO 9869-1:2014 and projects to which the authors of this paper have had access and/or have participated (REFAVIV project, 2013–2016).

2.1 *Set-up description*

Most of the research that can be found on thermal transmittance and thermal resistance values—U and R respectively—of earth before the year 2000 are tests that were carried out in lab conditions using methods like the hot-box (ISO 8990:1994). It is a very useful test to determine the steady-state thermal transmission properties of any material, but it is very difficult to take actual samples from already built earth constructions if not through destructive testing. Moreover, several researchers have demonstrated that estimations based on nominal design data do not match with in situ determinations (Heathcote 2010; Asdrubali et al. 2014; Ficco et al. 2015; REFAVIV Project 2013–2016). This is majorly due to properties like thermal inertia, which, in the case of earth structures, is very high.

The basic difference in the set-up is between in situ tests and those that have been executed on sample self-built units. The former usually take into consideration an actual occupancy (Taylor et al. 2008, Ip & Miller 2009, Freney et al. 2013, Chabriac 2014, Nematchoua et al. 2015, Vacas 2015) whilst the latter monitor room sample units (Heathcote 2010, Meneses et al. 2010, Allinson & Hall 2010, Serrano et al. 2016).

None of the experiments in Tables 1 & 2 is carried out both ways: monitoring and comparing occupied rooms whilst studying walls with similar features in the same climatological context.

2.2 *Climate*

The Köppen-Geiger climate classification, taken from the updated version by Kottek et al. 2006, has been used. Taking a closer look at a map of the Iberian Peninsula and its evolution through periods 1961–1990, 1971–2000 and 1981–2010, we can identify that Csa climate type, Mediterranean, is transforming into BSk climate type, Dry.

There is only one research that monitors an earthen building in BSk, and more specifically in an Earthship built in Taos, New Mexico (Freney et al. 2013), so further research of the behaviour of earth constructions in this climate would be interesting. On the other hand, there are a couple of experiments in the Csa climate, but Chabriac is the only researcher that considers in situ conditions. However, we cannot forget the fact that climate is changing, and in a few years' time Csa will probably

Table 2. Related research which gives essential information on apparatus and standards.

Paper/Study	Author/s	Publication-Year	Set-up	Climate*	Followed standard	Described apparatus for interior measures
IIB Module 4M19 Coursework task BE1: Heat transfer characteristics of building envelope.	CAMBEEP University of Cambridge	Present	In situ/ sample units	Cfb warm humid	EN ISO 9869-1:2014	10 T thermocouples (°C) DT80 + CEM20 (DLs) 2 HFP01 Hukse-flux (HFM W/m2) 2 pyranometers
REFAVIV Project.	Oteiza et al. IETcc-CSIC	2013–2016	In situ/ sample units	Csa Medit.	ASHRAE 55	HFP01 Hukseflux (HFM W/m2) EL-USB-2+-LCD (DL + °C / RH) EL-USB-2+ (°C) Wöhler CDL210 (CO2 +°C / RH)
U-value in situ measurement for energy diagnosis of existing buildings.	Ficco et al.	*Energy and Buildings 104* 2015	In situ	~~ND~~**	EN ISO 9869-1:2014 EN ISO 13786:2007	Several types of HFMs, sensors and DLs.
Evaluating in situ thermal transmittance of green buildings masonries—A case study.	Asdrubali et al.	*Case Studies in Construction Materials 1* 2014	In Situ 3 years	Cfb warm humid	EN ISO 9869-1:2014	Resistance Temperature Detectors Pt1000 (°C) HFM (W/m2)

* Köppen-Geiger climate classification (Kottek et al, 2006)
**~~ND~~ = Not described

RH = Relative Humidity
HFM = Heat Flux Meter
DL = Data Logger

be BSk. We can conclude that there is few research on earthen structures in climates A(Tropical), B (Dry), D (Continental) and E (Cold).

2.3 *Followed standard*

In opposition to the hot-box experiment, executed in steady-state conditions, we should consider dynamic-state conditions to characterise earthen walls in occupied buildings. ISO 9869-1:2014 describes this type of test, specifying a high accuracy for apparatus and HFMs (Heat Flux Meters) are used. Most of the papers presented in Table 2 use this standard, whilst in the case of earthen structures (Tab. 1) no research has been found that follows such standard. ASHRAE 55 seems to have been generally accepted, whilst other ISO standards are used alternatively.

In the next section, we will explain the possibility of following ISO 9869-1:2014. Several papers in Table 2 show the use of this standard to evaluate the U-value of several buildings (Asdrubali et al. 2014, Ficco et al. 2015). However, none of them were earthen structures. An exercise found at the Cambridge Building Energy & Environment Portal (CAMBEEP) of the University of Cambridge involves the use of ISO 9869 to look into the heat transfer characteristics of buildings (IIB Module 4M19 Coursework task BE1).

2.4 *Apparatus*

Tables 1 & 2 also show the equipment that has been used in each case to measure interior conditions. As it is mentioned before, tests range from monitoring comfort inside buildings to thermally characterising structures. If we pay attention to the latter, very few of them use HFMs (Taylor et al. 2008, Allinson & Hall 2010, Asdrubali et al. 2014), while none of them appear to be executed in an inhabited earthen structure following a proper standard.

Furthermore, flux tests that act in accordance with the International Standard ISO 9869 are short-term tests which involve dynamic-state conditions with high levels of uncertainty. Thus, it seems essential to use accurate sensors, and that is why the standard specifies an accuracy of ± 0.1°C,

value that is met by few studies on earthen structures (Taylor et al. 2008, Meneses et al. 2010). There are also researches where the sensors were already inside walls (Chabriac 2014, Soudani 2017). This last feature would guarantee perfect conditions for the sensors, but it involves coordination between the owners of projects of earthen dwellings and researchers, and this is not always possible.

3 DISCUSSION

In this section, we will explain a possible way of monitoring and characterising the thermal properties of earthen structures using proper standards and in situ methods.

3.1 *Thermal characterisation of earthen structures*

Instructions on ISO 9869-1:2014 could be followed due to several factors:

- Thermal inertia and/or storage effects. Most of the earthen structures present this features.
- The short period you need to take measurements (3–15 days, every 30 mins – 1 h).
- Not necessary destructive testing. Still, sensors inside walls would prove to be useful (Meneses et al. 2010, Chabriac 2014, Serrano et al. 2016).
- Specified accuracy of apparatus. In the case of temperature sensors, an accuracy of ± 0.1°C is required, whilst sensors typically used have an accuracy of > ± 0.3°C.

To analyse data, there are two methods that may be used abided by this International Standard: the 'average method', and the 'storage effects method'.

3.1.1 *The average method*

$$R = \frac{\sum_{j=1}^{n}\left(Ts_{ij} - Ts_{ej}\right)}{\sum_{j=1}^{n} q_j} \quad (1)$$

$$\Lambda = \frac{1}{R} \quad (2)$$

$$U = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n}\left(T_{ij} - T_{ej}\right)} \quad (3)$$

where R(m²K/W) = thermal resistance between surfaces; Λ (W/m²K) = thermal conductance between surfaces; U(W/m²K) = thermal transmittance between ambient temperatures; index j enumerates individual measurements; q_j(W/m2) = density of heat flow rate; Ts_{ij}(°K) = interior surface temperature; Ts_{ej}dx(°K) = exterior surface temperature; T_{ij}(°K) = interior ambient temperature; T_{ej}(°K) = exterior ambient temperature.

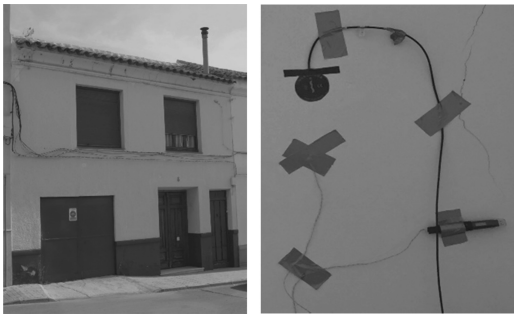


Figure 1a. Ongoing flux test in an earth construction in Campo de Criptana (Ciudad Real, Spain), January 2017.
Figure 1b. HFM and interior surface sensor with Data Logger.

As we are taking in situ measurements, surface resistances are already considered. We can then say:

$$R_T = \frac{1}{U} \quad (4)$$

3.1.2 *Storage effects*

ISO 9869-1 includes a section which considers the heat storage effects in structures. It involves the calculation of the internal and external mass factors (F_i and F_e respectively) so we can then make an adjustment to the measured flux at each data point. As earth constructions are commonly single layer structures with no insulation, the standard gives two simple formulae to calculate F_i and F_e:

$$F_i = \frac{C}{3} \quad (5)$$

$$F_e = \frac{C}{6} \quad (6)$$

where C is the product of the specific heat capacity, density and thickness of the element.

No correction is made to the data taken during the first 24 h, but thereafter we replace $\sum qj$ in equations (1) and (3) by:

$$\sum q_j - \frac{\left(F_i \partial \mathrm{T}_i + F_e \partial \mathrm{T}_e\right)}{\Delta t} \quad (7)$$

where Δt (seconds) is the interval between readings; $\partial \mathrm{T}_i$ and $\partial \mathrm{T}_e$ are, respectively, the interior and exte-

rior differences between averaged temperatures (24 h prior to reading *j* vs first 24 h of the analysis period).

3.1.3 *Uncertainty*

ISO 9869-1:2014 warns that uncertainty can become very large when particular operative conditions occur. This standard calculates an uncertainty band from 14% (quadrature sum of errors) up to 28% (arithmetic sum of errors).

Ficco et al. (2015) study the use of several HFMs under different measuring conditions and envelope components whilst using several methods to find out the U-value. One of these methods is in situ, and they strongly recommend to carry out U-value uncertainty estimations using the uncertainty propagation law (ISO/IEC Uncertainty of measurement Guide 98-1,3). In their case and comparing several commercial HFMs, they estimated an uncertainty band between 8% and 50%. Thus, it depends on the operative conditions of each test and it seems essential to estimate the uncertainty band to end up with results that are close to reality.

3.2 *Monitoring comfort*

ASHRAE 55 is the standard that has been used in most cases to evaluate thermal comfort inside a construction. Overall, it is used to dimension HVAC (Heating, Ventilation and Air Conditioning) and the energy demands of a building. In the case of earth constructions, usually built decades or even centuries ago, this standard was never considered. We will verify the adaptability of these structures to the standard by following the next instructions:

- Temperature, air speed and absolute humidity must be measured.
- Height of sensors: 1,1m for standing occupants, 0.6 m for seated occupants.
- Periods: Tests should last for at least one year if we want to consider weather variations during all seasons. Temperature and humidity should be recorded every 15 min and air speed every 3.
- Survey occupants at least once every season.
- Accuracy of sensors: as we are carrying out long-term tests, accuracy is not so important as when characterising thermal properties.

3.3 *Recommended instrumentation*

To sum up, I will summarise the recommended apparatus that could be used to carry out both tests.

To monitor comfort in earthen dwellings following ASHRAE 55 we must measure interior and exterior ambient temperatures and RH, whilst also recording CO2 levels and air speed. We will not repair in specific features as most of the sensors that can be bought could be used to carry out this test.

On the other hand, to characterise the thermal properties of earthen structures following ISO 9869 we must pay attention to some features. We should use probes (superficial and ambient, interior and exterior), data loggers, and HFMs. It is strongly recommended to use a weather station to measure exterior conditions, although data could be taken from nearby national weather stations. Pyranometers can be avoided if there is no direct solar radiation, so North orientation is advisable.

When speaking about probes, we can use RTDs (resistance temperature detector) like Pt100/1000, accuracy class 1/10DIN, which basically is $< \pm 0.05$ºC in average ambient temperatures (Meneses et al. 2010; Asdrubali et al. 2014; Ficco et al. 2015). We could also use thermistors like Betatherm 10K3A1IA (Taylor et al. 2008), which are cheaper but usually have less stability and poor linearity, resulting in bigger errors. HFMs, on the other hand, depend on several factors. Ficco et al. (2015) have demonstrated that the dimensions of the plate do not influence significantly the in-situ U-value. The company "Hukseflux", which offers measurement solutions and recommends the use of ISO 9869, states that the main sources of uncertainty are location of sensors, exposure to solar radiation (preferably avoided), air gaps between sensor and wall and also the accuracy of the temperature difference. They also suggest at least 2 measurement locations per wall. To conclude, the most important characteristic to have in mind when choosing data loggers is that they must be able to record measurements from high-accuracy probes like the ones described before. It is important to mention that probes that measure water content and RH should be used if we want to study hygrothermal properties.

4 CONCLUSIONS

In this paper, thirteen research items related with the thermal monitorisation and characterisation of earthen structures have been identified (Tab. 1), while an extra four have been used to discuss a possible future modus operandi (Tab. 2). The following conclusions have been drawn:

- Exploring the differences between in situ measurements and nominal data, and between actual occupied structures, sample units and lab probes seems necessary to characterise the thermal properties of the earthen structures in a zone.
- The Köppen-Geiger classification has been used to identify climate for each study. There is very few researches of earth constructions present in climate types A (tropical), B (dry), D (continental) and E (cold). Ongoing tests in the community of Castilla-La Mancha will provide more

information about the behaviour of earthen structures in the dry climate (type B).
– To define the in situ thermal characteristics of earthen structures (short-term test), accuracy and uncertainty seem to be essential, so following a standard that considers them, like ISO 9869, would be advisable. To monitor comfort, (long-term test) accuracy is not so important.
– Very few of the presented studies include short-term tests using Heat Flux Meters (HFMs), as they are usually focused on room measurements.
– No research paper has been found where monitoring comfort and thermal characterisation is executed on several earthen dwellings that present the same climatological circumstances and similar characteristics. Further research in this direction would probably give us a better understanding of the thermal behaviour of earth.

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Study of the situation of traditional constructive techniques and materials in Spain

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ABSTRACT: Constructive solutions in traditional architecture are born of the materials available locally which were used to achieve the best possible technical and architectural adaptation to the local climate. Given the importance of traditional materials and systems and their effect in the conservation and restoration of traditional architectural heritage it was decided that a specific section should be dedicated to the recovery of traditional constructive techniques within the Spanish National Plan for Traditional Architecture, drawn up by the Spanish Cultural Heritage Institute (IPCE). The main objectives were to create a database on the current situation of available traditional materials, the production and use and the survival of specific trades linked to production and execution, encouraging their use in these traditional architecture restoration processes. This text aims to present the methodology and the results obtained in the study in 2013 and 2014.

1 INTRODUCTION

As is known, traditional architecture for the most part uses locally available materials, making good use of local materials in the design of suitable constructive solutions. Thus, a double symbiosis occurs between building and landscape. Buildings drawing on the surrounding landscape for construction with materials linked to local geology and agriculture, shaped by the climate and rivers, are also buildings which blend into and are an essential part of the landscape, adapted to the rivers and climate. This wealth of constructive materials and techniques linked to local diversity has progressively diminished with the introduction of industrial materials and global production. The conservation of traditional architecture calls for the understanding, valorization, and eventually the recovery and/or enhancement of traditional constructive materials and systems and their conservation in restored buildings (Dollfus 1956, Oliver 1997, VV.AA. 1990).

Given the importance of the issue and its impact on the conservation and restoration of traditional architectural heritage, it was decided that within the Spanish National Plan for Traditional Architecture a specific section should be dedicated to the recovery of traditional constructive techniques for the restoration of traditional architecture. The main objectives aimed to create a database on the traditional materials currently available, their extraction, production, and use in construction, as well as the survival of specific trades using and promoting these in the restoration processes of traditional architecture. The use of these materials and associated constructive techniques allows architecture and traditional techniques, to be conserved thanks to their current use, with major benefits for local culture and economy.

2 OBJECTIVES

The general objectives of the project "Documentation and research for the knowledge of the current situation of traditional constructive systems, as well as the extraction, use, and implementation of traditional materials in Spain" are:

- The creation of a database of the existing productive structures for the execution of different traditional techniques and any other centers experimenting with traditional constructive materials and systems.
- Geographical distribution of these processes.
- Basic characteristics of traditional constructive materials and systems reflected in fiches and graphic and audiovisual material.
- Study of basic materials of traditional architecture which are now protected and the impossibility of using these in the restoration of buildings. Assessing how to ensure that regulations allow for their use, at least in rehabilitations.
- Study of the situation of the trades of extraction, transformation, and execution relating to traditional architecture, as well as of educational centers where these trades are taught and researched.
- Knowledge of the regulation of the artisan sector in Spanish autonomous communities in relation to traditional construction trades.

– Reflection and future proposals on the adaptation of protection measures based on the results obtained, as well as a proposal for suitable promotion of the recovery of traditional constructive materials and techniques.

3 METHODOLOGY

The methodology for this project is based on qualitative research which uses several sources of information for data collection. The documentation obtained is subsequently analyzed in order to draw final conclusions.

There are many information sources: specific bibliography; official sources from all levels of the administration; professional associations related to the topic; ethnographic museums; experts and researchers in the field; citizens' associations interested in the subject; all sorts of webpages and internet resources, all duly selected.

The work consists of four major tasks: the creation and compilation of a database on the different agents of traditional construction; the geographical mapping of constructive materials and techniques and their current situation and activity; graphic and audiovisual documentation (photographs, videos and internet links) of traditional constructive materials, processes and techniques; and cross-referencing of information, regulations, analysis and reflections in order to draw conclusions on the current condition of traditional constructive materials and techniques in the different parts of Spain.

4 WORK PROCESS

4.1 *Creation of the database*

Research is firstly tackled through the creation of a database for the different agents linked to the study and located through the sources mentioned.

Information is classified based on the type of activity developed, establishing four categories:

– Extraction: agents dedicated to obtaining raw materials used in traditional architecture (250 recorded).
– Transformation of raw material: activities that involve transforming raw material into products of traditional construction (657 recorded).
– Execution: any activities which involve building using traditional systems and techniques (136 recorded).
– Research/Teaching/Dissemination: all sorts of institutions and associations dedicated to the study and research of traditional constructive techniques, as well as those dedicated to promoting knowledge on the subject through courses and practical workshops, publications, etc. (147 recorded).

The information required is different for each category, and adapts to specific individual characteristics.

It should be noted that the "transformation" database does not include trades such as carpenter, nor does the "execution" database include trades such as general building, as it is understood that with the right instructions practically any carpenter or builder can carry out traditional jobs. This aims to identify trades requiring more specific training, and adding them to the list.

The greatest amount of data possible is collected through the numerous sources of information, so that the comprehensive study presented aims to be homogeneous throughout Spain. However, from the start it became clear that given the scope of the work it was impossible to consider this database as a closed tool, no matter how extensive. It should therefore be seen as a dynamic tool which can and must continue to grow in the subsequent revisions of the National Plan for Traditional Architecture.

The aim of compiling this information, apart from providing the number of agents who still keep traditional constructive forms alive, is that access should be freely available to teachers and specialists.

4.2 *Geographical distribution of processes*

The different mappings are created from the information collected from different mediums and compiled in the database, and from other specific sources of information including the Geological and Mining Institute of Spain, European Forensic Genetics Network of Excellence, specific bibliography, expert opinions, etc.

Thus the areas with different types of raw materials (up to fifteen in this case) are mapped, and the information relating to the places with active extraction, featured in the database, are superimposed. In addition, the localized agents dedicated to the different trades for the transformation of raw materials and use in traditional construction work, research, teaching, and dissemination are added. The aim is to be able to study and cross-reference data from the different mappings to analyze the situation of the geographical distribution of the different activities.

Mapping is also proposed for traditional constructive systems, equally drawn up by consulting extensive bibliography and experts in the field. This part of the study focuses particularly on some specific traditional techniques, partly at greater risk of disappearance, and sixteen different systems were selected. It is considered important to know the field of application of a traditional constructive solution both to study the relation-

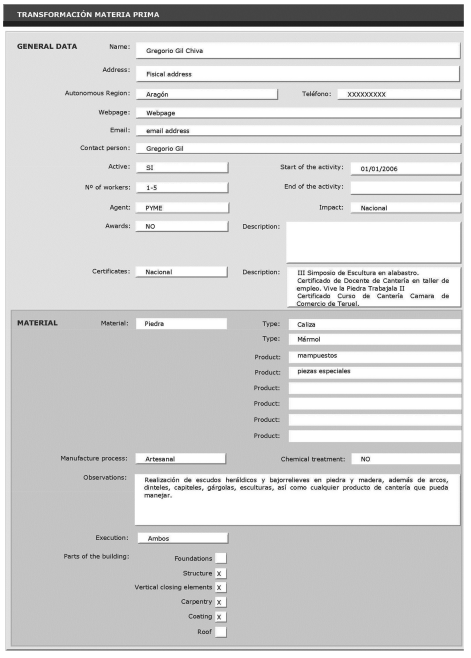


Figure 1. Example of fiche for agent for the transformation of prime material.

ship with its environment in terms of the materials used and its response to the bioclimatic setting, and to recognize the field of action in which the use of a specific technique is truly traditional. Thus, the area of work is recognized in instances where action is needed to recover a technique at risk of disappearing. The techniques suited to use in the rehabilitation of traditional constructions in each area are also documented.

4.3 *Graphic and audiovisual material*

In addition to the mappings, fiches explain the different extraction, production, and construction processes linked to traditional architecture and document these visually, selecting nineteen cases. These are simple documents explaining the manufacturing process of the constructive element or solution primarily for teaching and dissemination purposes.

Following the same line of documentation for teaching and dissemination of knowledge associated to the construction of traditional architecture a search was carried out for videographic documentary information on matters relating to traditional construction processes, confirming the value of tools such as YouTube in the diffusion of knowledge. In terms of tasks documenting traditional activities the great work and effort of Eugenio Monesma, who has produced a series of videos on traditional construction, is laudable.

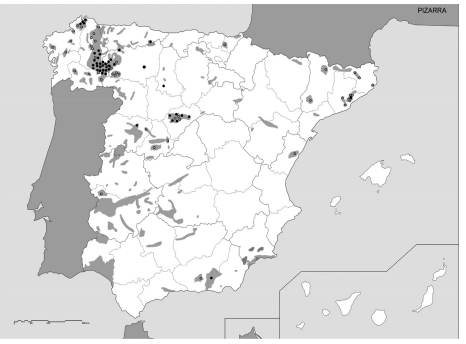


Figure 2. Mapping for points of extraction of slate superimposed on areas where this is found.

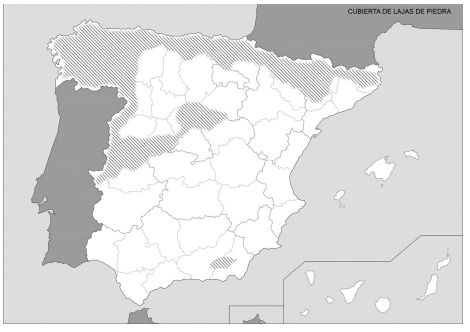


Figure 3. Areas where stone roof tiles are used in traditional architecture.

Both fiches and videos are an efficient form of documenting traditional construction systems, as well as a way of conserving and transmitting this cultural heritage.

4.4 *Study of materials of traditional architecture*

Following the study of the current situation of the most used materials in traditional architecture, an analysis of use and regulations is proposed, providing a brief synthesis of each situation. The materials studied are:

- Wood: protected species or species at risk of extinction, forest management (Wood shortage, PEFC certification, due diligence system) and proposals.
- Stonework and metals (grouped together as they are both extracted through mining): mining in Spain, commercialization of the product and conclusions.
- Earth: compressed earth blocks (CEBs), adobe and rammed earth, and proposal.
- Reed: production of reed, use and regularization of the material and proposal.



Figure 4. Example of fiche explaining slate roofing.

– Plant covers: Spartina Patens (Salt marsh hay), Rye
– Seagrass: situation and protection.

4.5 *State of regulations*

The study of regulations affecting the extraction of traditional materials is examined in the previous section. There are no specific national regulations for traditional architecture. In terms of the current regulations applicable to architecture it is worth noting the rigidity of some of these, designed mostly for new constructions using contemporary materials and techniques conflicting with many aspects of traditional architecture.

The Spanish Technical Building Code (Código Técnico de la Edificacion or CTE) modified in Law 8/2013, of 26 June 2013, for urban rehabilitation, regeneration and renovation has facilitated building rehabilitation by permitting interventions on vernacular architecture that are respectful with the original construction, without the obligation to reach current standards. This is very difficult with traditional construction systems and should always be done with the agreement of owners and/or users, clearly indicating any possible limitations of use deriving from non compliance with regulations. However, this is not simple and requires complex arguments and calculations for this type of solution, as insufficient research has been done on quantitative values in issues such as insulation, and even occasionally, resistance.

Given that at present many of the buildings linked to traditional construction are regarded as part of traditional crafts, a study of the relevant regulations, with variations in each autonomous community, is proposed, undertaking a comparative study of regional regulations.

5 REFLECTIONS

Following the work of "documentation and research for knowledge of the situation of traditional constructive systems, as well as the extraction, use, and implementation of traditional materials in Spain", the first obvious reflection is the impossibility of concluding that a study of these characteristics is complete rather than an ongoing subject of study. Thus, what is reflected is the situation at the time of study and similar work should later be carried out in order to assess the evolution of the state of the art.

Once data compilation is complete, both in terms of agents to be incorporated into the database and the state of the art, geographical distribution of activities, etc., an analytical and reflection phase can be proposed to offer a more global vision of the state of aspects affecting Spanish traditional architecture.

5.1 *On agents relating to traditional construction*

In terms of the agents in charge of the extraction of raw materials it should be noted that they are inevitably on the path to mechanization. As it is practically impossible at present to find anyone who continues to extract materials using preindustrial processes, it has been decided that the database should include companies dedicated to the extraction of raw materials used in traditional construction, specifying on the fiche whether the actual material extraction task is traditional, industrial or semi-industrial. This was considered the best option given that otherwise an important information item for the study would be lost, that of the extraction of the material subsequently used in traditional architecture with traditional constructive techniques. In any case, these details are considered to be less important as access to most of the materials used in traditional architecture is simple and direct.

The difficulty in locating master artisans whose trades are directly connected to the use of materials for traditional constructive techniques shows how far many of these trades are currently at risk of disappearing. The aging population and the progressive depopulation of rural areas are not determining factors, but do have direct bearing in the matter. Some of the master artisans contacted are no longer active, and with the shortage of apprentices willing to continue the trade, they find no young people with interested in keeping the tradition alive. In addition, while agents from other categories show an interest in making themselves known, many of the master artisans are reluctant to figure in any sort of database, partly because they work locally and assume that their possible clients are already aware of their existence and know how to locate them easily. As a source of information, the internet greatly simplifies the task of locating medium-sized and large companies, but this is not usually the case with local artisans, often older or completely unaware of this means of promotion.

There are also companies which offer this type of artisan service but actually subcontract local artisans for the job. In addition, it is not uncommon for these local artisans to do this on the side.

As regards the contacts of the section on teaching and research, companies that have R&D departments as well as other research structures have been identified. However, at the time the work was carried out it was observed that research on materials in traditional architecture is limited. There are more records of teaching, and promotion to be found in associations, provincial and local ethnographic museums, workshops, vocational schools, etc.

At this point it is important to note that while there are associations dedicated to the knowledge and diffusion of traditional architecture, much of the information provided in this respect comes from associations or companies with greater links to bioconstruction or sustainable architecture than to traditional architecture in itself. This type of agent was incorporated into the study as it is true that all their paths cross at certain times. However, it should be clarified that at no point can they be considered synonymous. In many cases, bio-construction and sustainable architecture derive knowledge from traditional architecture, although almost always filtered through the academic knowledge of professional architects, quantity surveyors, or engineers, with an interest in exploring new applications for traditional constructive materials and techniques. This is a path in which some elements of traditional construction coexist, albeit with an interest in using them in ways which are non-localized and different from the original ones, causing the loss of the direct connection between place and architecture, a basic characteristic of traditional architecture.

5.2 *On geographical distribution*

The superimposition of places of extraction and points for the transformation of raw materials over places where these materials are available, as well as the comparison of mappings of constructive systems, highlight a well-known fact of traditional architecture processes: proximity between the source of material and the construction. This study confirms that the constructive techniques used traditionally in different parts of Spain employ materials available locally and do not constantly resort to other more distant sources (Figs. 2–3).

5.3 *On access to traditional materials*

The general conclusion is that access to materials used in traditional architecture in Spain does not present problems, although as mentioned above, traditional methods are no longer used for extraction. The various necessary materials are readily available to the different professionals to a greater or lesser degree. In the case of materials requiring special permits for extraction, it is proposed that warehouses should be set up where these materials can be stored and accessed directly for use in traditional construction, simplifying the process for artisans or builders.

5.4 *On regulations*

The obligation to comply with current requirements in structural stability, safety, and comfort in buildings is undeniable, as both the current standard of living and the expectations for the future require it. However, a path should be opened which contemplates the specific case of traditional architecture. This would ensure that traditional techniques and systems were covered by the current legal framework, not just for restoration but perhaps also for small-scale new constructions. Otherwise, traditional constructions will be built using "modern" materials, tarnishing the image of this architecture and causing the loss of a highly valuable heritage commodity.

The path opened by the CTE not to completely attain regulatory requirements only applies to cases of rehabilitation so that it is almost impossible to build new traditional constructions using completely traditional constructive materials and systems as in most cases these solutions do not comply with current regulations. Thus, the construction of this type of traditional buildings is practically limited to its use as a museum element.

The regulatory efforts of the different craft laws are very laudable, but these actions are unequal throughout the national territory, fragmented efforts, so that while in some cases the management achieved in terms of craft is excellent, in others it is not useful enough. It is important to note that the laws relating to craftsmanship include all sorts of craftwork, and it has been observed that in actual fact the number of artisans relating to traditional construction work included in these laws, especially in available databases, is much lower than that of artisans from other types of crafts. In this regard, it is also very important to successfully incorporate more artisans into this system for recognition, protection and dissemination.

6 CONCLUSIONS AND PROPOSALS

After the work carried out it can be stated that the current condition of Spanish traditional architecture is delicate. This is not so much due to problems in accessing materials for construction, mostly readily available, but rather to the survival of trades linked to them. The aging population who still live in, and therefore maintain, this type of architecture is linked to the progressive disappearance of traditional construction trades. In addition, the

mistaken perception of this architecture and materials as "old" or incapable of meeting current comfort standards has led to their replacement by modern solutions and materials. Constructions like contention walls, enclosing walls, yards, lavoirs, as well as obviously homes. etc., are still necessary to the population and when built with "modern" materials lose much of their original interest and value, as well as entailing the loss of local cultural identity.

The conservation of traditional architecture should incorporate the understanding, valorization and ultimately the recovery and/or enhancement of traditional materials and techniques and their conservation in the restored building.

Given the above, all the studies aimed at in-depth research of traditional construction are considered crucial, both in ethnological and constructive terms, and also in terms of technical knowledge of these solutions and materials to make it easier and more feasible for all specialists to justify the adoption of these solutions. Initiatives aimed at improving the technical characteristics of these traditional solutions and materials are also extremely important. Thus, it is possible for this form of construction to continue to evolve, adapting to current times and requirements as much as possible without losing their character.

It is also vital to promote training at all levels, from childhood to university and from a general education aimed at promoting knowledge, and therefore respect and appreciation, to specific teaching aimed at agents of construction or the specific disciplines involved in this field. Thus, it is necessary to encourage the vocational schools so that construction trades conserving traditional skills may transmit them to future generations.

However, it is not enough for training on traditional architecture, materials, and techniques to be carried out in workshops, specific training courses or specialized masters, but it should be made compulsory for the curricula of any professions which finally interact with this architectural heritage.

Moreover, the diffusion for the general public and general education, guarantee greater awareness of particular aspects in society. The production of materials of interest for the general public (documentaries, television series, radio programs, newspaper articles, social networks, awards …) can reach wide sectors of the population creating a cultural base conducive to the conservation and restoration of traditional architecture thanks to increasing awareness. In this regard, the use of new technologies, social networks and communication tools could be a simple and efficient way to reach the public.

It is also necessary to carry out carefully considered promotion aimed at technicians or specially involved public in the process through specific manuals for the knowledge of traditional architecture, its materials, constructive techniques and objectives, and restoration and rehabilitation processes and techniques.

Another field of action of great importance for the conservation of traditional heritage is protective regulation. At a general legal level there is greater or lesser coverage through the Law on Spanish National Heritage and the individual heritage laws of the Autonomous Communities. At a more specific level, catalogs and inventories of protected goods are particularly important. The danger of these instruments is that they may prioritize protected buildings over many similar ones without protection, so a wide berth is advised in catalogs and inventories to allow general control of urban and rural traditional heritage. It is important to carry out complete and appropriate studies with sufficient specific knowledge prior to drafting the catalogs and regulations for local protection.

At a local level, municipal regulations establish the rules to be followed at a local level both in new construction and in conservation or restoration. These regulations should specifically recommend the use of traditional constructive materials and techniques in restorations of traditional heritage and extend these to entire buildings, not just facades.

At present this work can be consulted on the IPCE webpage (http://www.mecd.gob.es/planes-nacionales/planes/arquitectura-tradicional.html), and is being expanded and transferred to a webpage titled *Red Nacional de Maestros de la Construcción Tradicional* in collaboration with Alejandro García Hermida, organized by INTBAU with the support of The Richard H. Driehaus Architecture Competition and the Rafael Manzano Prize for New Traditional Architecture.

NOTE

The information presented here is part of the project "Documentation and research for the knowledge of the current situation of traditional constructive systems, as well as the extraction, use, and implementation of traditional materials in Spain" (Ref no. 2/1116C0548 EF), a commission from the Spanish Cultural Heritage Institute (IPCE) within the framework of the National Plan for Traditional Architecture.

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Vernacular housing and transformations at the Cordillera de Sama (Bolivia)

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ABSTRACT: In the last decades, the traditional type of domestic architecture of the Cordillera de Sama Biological Reserve (hereinafter CSBR) is undergoing transformation processes and habitat improvements occasionally developed by government policies with NGOs' support. In many cases, these actions have led to the implementation of a necessary toilet or latrine, but there have also been inappropriate transformations or replacements to the local tradition, built with exogenous materials and systems. The main objective of the work here presented is to perform a critical analysis of the traditional architecture of the CSBR and to assess its capacity to respond to the contemporary needs of Sama inhabitants. It also examines whether or not the loss of this traditional habitat (including the impact of its transformations) can lead to the irreparable loss of cultural identity and heritage values in the area of the CSBR.

1 THE SAMA BIOLOGICAL RESERVE (CSBR)

1.1 *Geographical features*

The CSBR is located in the south of Bolivia, at the west end of the Department of Tarija, located 21° (degrees) south latitude and occupies an area of 108,500 hectares. The Sama Mountain Range extends from north to south and has an altitude range from 1,900 to 4,700 MASL and a topography characterized by steep slopes, plateaus and high Andean lagoons, forming the watershed of Tajzara (Figs. 1 and 2).

The climate varies according to the altitude from temperate to cold and has a rainfall from 300 to 1,250 mm per year, with precipitations at the upper areas being scarcer than at the lowlands (PMRBCS 2004).



Figure 1. View of a traditional house in ruins and Tajzara watershed at the CSBR high Andean plateau.



Figure 2. Anthropization of the CSBR landscape with *pirca* enclosures and houses.

1.2 *Landscape and environmental analysis*

The CSBR is part of two different physiographic regions: the high Andean Plateau (Altiplano) and the Interandean Valles. Two different ecoregions can be found at the former: the semi-Wet Puna and the Prepuna. Its noticeable slopes and the existence of wetlands due to the high Andean lagoons, provide this location with a dramatic landscape, making it home to important species. The latter is home to the Interandean dry forests and the Tucuman-Bolivian forest (the lowlands).

In recent years, there has been a decrease in the water level of the wetlands. Climatological phenomena such as "global warming" or, especially, the one known as "El niño", are having severe effects in this area of the planet.

Thus, there is an increase in the temperature of the tropical Pacific waters, which affects the wind circulation, reducing rainfall to 10% of what is considered as normal and causing a remarkable rise in

temperature. Although it is a cyclical process, its consequences are becoming increasingly harmful. Regarding to the CSBR, "El niño" has brought a severe drought to the plateau causing environmental damage and severe losses in agricultural and livestock production, dragging communities to an already growing situation of economic, environmental, social and political vulnerability. A higher rate of rural exodus/depopulation and the loss of traditional ways of life are the consequences.

1.3 *Population and living conditions*

The CSBR affects either directly or indirectly 51 communities with a total population of 13,121 inhabitants and a population density of 10 hab/km^2 (PMRBCS 2004).

The high plateau area, which features a more marked indigenous character, has the highest levels of poverty in the Department, with almost an 80% of population affected, while showing the lowest Human Development Index.

Access to education and health services is low due to issues such as dispersion of population, the small size of some communities and the long distances they sometimes have to cover. Other cultural aspects must be taken into account such as the preference for alternative medicine or the little concern about girls' literacy. Only the populated settlements and houses around them have a water distribution service in the high plateau, and just a small number of communities benefit from electricity service (PMRBCS 2004).

1.4 *Productive activities*

Livestock is the main income-generating activity of the peasant family, exploiting several by-products such as wool, fibers or leather. The grazing system in the Tajzara basin is extensive, occupying 65% of the land, and it is developed according to the traditional system, in open field.

On the other hand, the agricultural activity is oriented mainly to self-consumption. The soil characteristics and the availability of water allow a varied production, although only 20% of the land is used for planting crops. The remaining 15% of the land consists of useless rocky and sandy areas.

In addition, this soil is becoming less productive due to adverse weather conditions, shallow depth, overexploitation of resources and overgrazing (PMRBCS 2004).

1.5 *Legal protection*

The CSBR was created in 1991 in order to preserve a representative sample of the puna biome, the wetlands of Sama and some species of flora and fauna. In 2000 it was named a Ramsar Site (Wetland of International Importance) due to the relevance of its lagoons. The protection level covers sites of historical and cultural interest (pre-Columbian roads, cave paintings, etc.) and prohibits the occupation of land in the Reserve by settlements or endowments, mining concessions, hunting or commercial or sport fishing and logging.

2 HABITAT AND ARCHITECTURE

2.1 *Settlements and housing*

Most of the settlements are located in the lowlands or close to rivers, ravines and lagoons, areas where subsistence crops can be grown. These settlements have a more or less consolidated nucleus of compact character, where buildings of collective use are located. Numerous habitational units of dispersed character belong to the community but some of them are abandoned and ruins today (Lopez-Osorio et al. 2015).

As the height increases, the rural and cattle-raising character of the communities also increases, the size of the settlements decreases and there is a greater isolation among the buildings (which can be grouped up by family bonds).

The house is conceived as a conjugation of interior and exterior spaces (Fig. 3) and accommodates everything the family needs for its daily life. In terms of location, several factors are taken into account such as the proximity to roads and natural sources of water, the slope of the land (preferably the plains or the skirts of the hills), the proper use of sunlight, the protection from the wind and the panoramic view on the ground to control the livestock, grazing or agricultural activities.

It is in the high plateau area where a greater number of intact examples of traditional architecture remain. This is the reason why this work focuses on this area.



Figure 3. Housing include exogenous materials while the traditional layout around a courtyard remains.

2.2 *House layout*

The domestic space is constituted by a set of independent volumes of rectangular plant arranged orthogonally around a courtyard that is delimited in its most exposed fronts with half-height dry stone walls (*pirca*).

The courtyard is where activities in which all members of the household participate are carried out and acts as a distributing space (Figs. 4 and 5) between the different modules (usually from two to four). The main rooms are the bedroom-dining room and the kitchen, an eminently feminine space. Accessory modules, generally smaller, are usually added, such as warehouses or pantries. In case the family expands, the flexibility of the set allows the appearance of a fourth bedroom module. This house layout is a legacy of the pre-Inca *Andean cancha*, which has endured to nowadays, becoming a common pattern both in dispersed buildings in rural areas and in consolidated settlements, where geometry is more precise and compact.

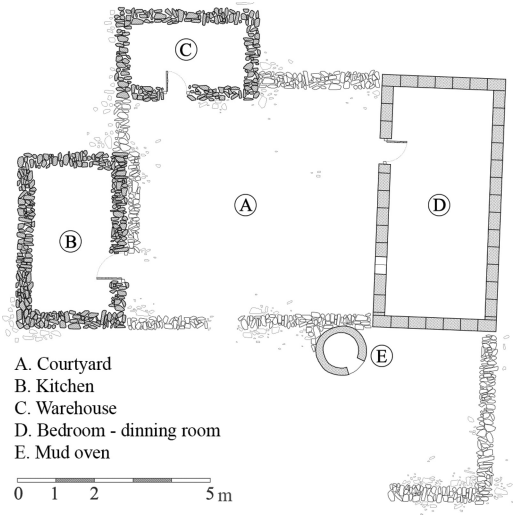


Figure 4. Example of traditional housing floor plan. In this case, one module (D) is built with adobe.

2.3 *Traditional construction technique*

As in any other vernacular architecture, the construction techniques and materials used are the outcome of human adaptation to a set of natural conditions. In this way, in the semi-humid puna, where the availability of mud and straw is more frequent, walls are made of large adobe bricks (approx. 45 × 30 × 12 cm) laid to stretcher bond. These are arranged along stone foundations and baseboards that prevent the adobe from capillarity and erosion by surface runoff.

As we go deeper into the slopes of the western area (drier and rockier than at the watershed) the construction with stone masonry plays a greater role, extending from the baseboards to the entire walls.

Thus, heavy and hard stone (*piedra hina*) is laid at the base, followed by a softer and lighter stone (*piedra laja*) of slaty appearance used for the upper layers and the eave.

The foundation is made by a bed of small size stones in order to favor a proper settlement of the wall. Both adobe and stone are laid on clay and sand mortar beds and the walls are generally not rendered. Stone benches are attached to the façade or the interior of the modules, offering basic furniture to the room. Also, mud ovens are usually disposed in the courtyard.

When it comes to formation of hollows, usually scarce and small, cactus (*cardón*) wood which is very light and resistant, has been traditionally used for lintels and carpentry, but it has fallen into disuse since it was declared a protected species, motivating its substitution by wood of similar characteristics such as pine or caven (*churqui*). Wood doesn't grow naturally in the upper part of the CSBR, and that is why it has to be brought from other sites.

Housing modules are normally sheltered by gable roofs, although shed roofs are not uncommon at all, and they use simple structural systems. In the first case, a main beam is arranged as a ridge board, resting on the gables and holding sloping logs supported, in turn, by the walls (Fig. 6). When the building is composed by a shed roof, the log beams are upholded by two walls of different heights.

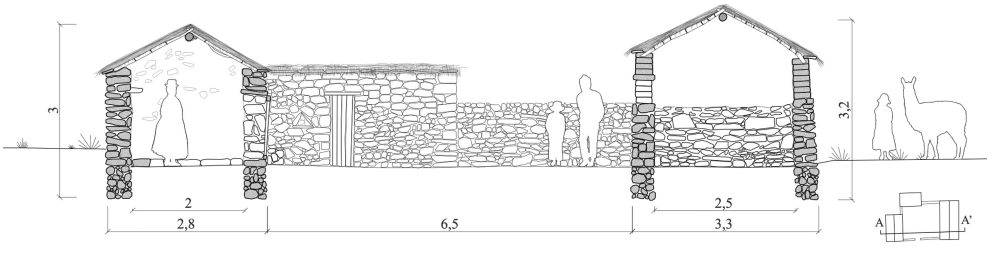


Figure 5. Traditional house sectional elevation (measured in meters).

In both cases, a layer of reeds or *churqui* branches is arranged on the supporting structure in order to receive a mud and straw mortar (*tortado*), which extends to form an eave over stone slabs on top the walls (Fig. 7). In the gable roofs, a protection of woven straw (*guaya*) is placed over the mortar. Once again, the availability of material predetermines the constructive solution adopted, so that, as we move away from the wet areas and the straw is scarce, we find a smaller number of roofs finished with *guaya* and more *tortado* shed roofs.

Particular attention should be paid to rectangular or circular enclosed fields which are built with dry stacked stones (*pirca*) so aligned that cavities are left to reduce the thrust of the wind and to prevent the structure from collapsing. These enclosures are linked to the domestic set and are used for farming, to protect the crops from wild animals, or as shelter for livestock.

In bigger settlements, such as Copacabana, there are shed roofed houses concluded with traditional ceramic roof tile (*teja chapaca*) on mud mortar bed, which is seen as an evolution and improvement of the *tortado* covering. This tile was produced in the nearby city of Tarija, outside the CSBR, requiring transportation. In these settlements, it is more common to render the buildings with mortar. Nevertheless, lime mortar rendering was frequent in the past but this tradition has been lost due to the absence of this material in the area and the need of importation.

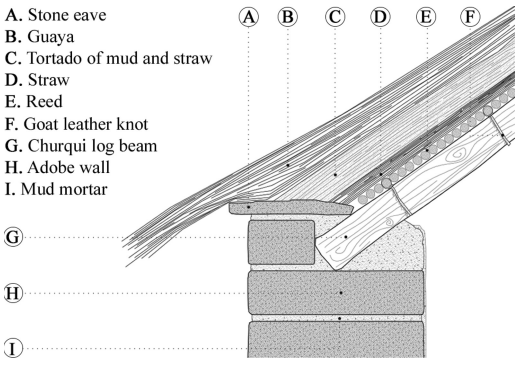


Figure 6. Traditional house constructive detail. Joint between adobe wall and *guaya* roof.

2.4 *Transformation processes*

Beyond the addition of a toilet or latrine, the volumetric and programmatic characteristics of the house have varied little over time, but the high maintenance requirements of the traditional techniques, the scarce of material (especially of straw) and the deterioration of the constructive knowledge, have led to the inclusion of exogenous materials.

One of the first transformations that is introduced is the addition of a polyethylene sheet between the mud and straw layers of *tortado* in order to improve its waterproofing properties. However, it is very common to completely replace the *tortado* roof by a corrugated sheet, made either of metal (*calamina*) or fiberglass, and to finish its perimeter with a small parapet of stone or cement mortar, in order to protect it from high winds. This solution implies a considerably lower thermal inertia than the traditional solution which may be relevant in an area with such an adverse weather.

On the other hand, remodeling the roof with conventional ceramic tile (on cement mortar bed) is becoming increasingly common. The large temperature changes experienced here are not always consistent with such a rigid solution, what may entail breakages.

Occasionally, walls are rendered with cement mortar and painted, intending an improvement of their consolidation and aesthetics. Nevertheless, this

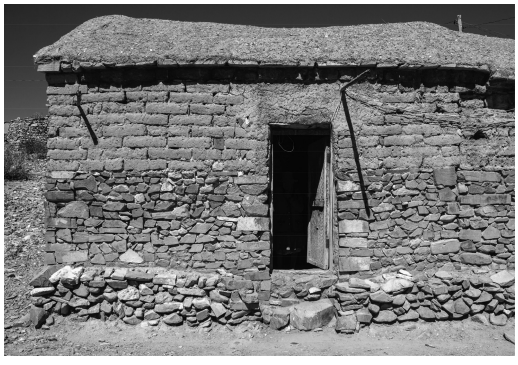


Figure 7. Traditional house built with adobe and stone. Note the *tortado* roof and the stone bench.



Figure 8. Comparison between traditional *guaya* roof (left) and transformed metal sheet roof (right).

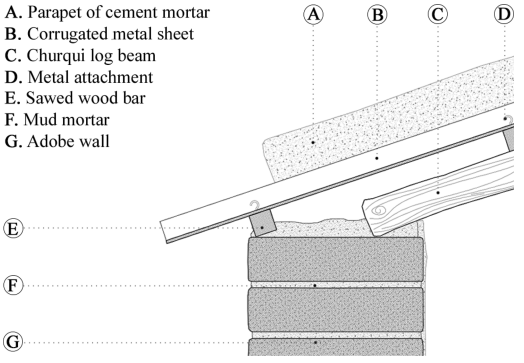


Figure 9. Transformed house detail. Joint between adobe wall and corrugated metal sheet roof solution.

can lead to hygrometric incompatibilities between materials.

Also, the incorporation of manufactured products such as sawed wood to roof structures and metal or wood carpentries is significant.

2.5 *Replacement processes*

Nowadays, there is a proliferation of new housing, usually self-built, which reflects an inertia from the traditional type.

This fact makes the use of systems and materials totally foreign to the local tradition. It is important to point out that these measures are sometimes provided and performed by government policies and some NGOs initiatives.

The result is determined by each program characteristics. Hence, in cases when it only consists on the donation of materials, there is an analogous use of the new elements and constructive materials to the traditional techniques, as well as a very similar house layout. In other circumstances, there are preset configurations, more rigid and decontextualized, which suppress the courtyard and ignore the traditional layout of the habitable spaces (Fig. 10).

These are usually composed by concrete slabs over stone paving as foundations and a concrete wainscot along which burnt clay hollow bricks are laid to stretcher bond, on cement mortar bed and not rendered. When the roof solved with ceramic tile (laid on cement mortar bed), its structure is generally made of sawed wood beams that rest directly on the walls. In case that the roof solution is composed of corrugated metal sheet (Fig. 11), these beams can be replaced by small lattice girders (30×15 cm).

The walls are usually braced by a concrete edge ring beam that is used sometimes as lintel when it comes to hollows formation.



Figure 10. Replacement house developed by government initiative, built with exogenous materials.

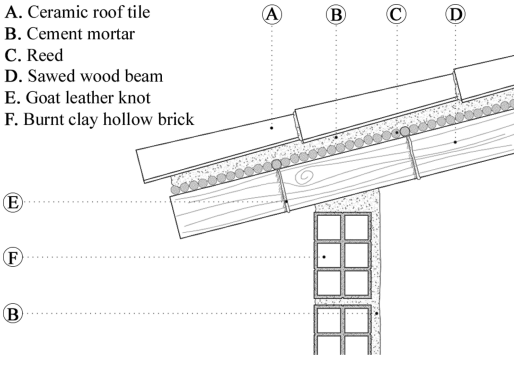


Figure 11. Replacement house detail. Joint between wall made of burnt clay bricks and ceramic tile roof.



Figure 12. Traditional house next to a recently built school in Copacabana (Credits: Authors).

3 CONCLUSIONS

Housing, as a space of affective, symbolic and historical relationships, is a witness of the communities that inhabit them. The analysis of the different typologies here studied reveal a turning point in

the local construction tradition that is leading to an irreparable loss of architectural and landscape heritage.

The reasons are diverse. On the one hand, climatic phenomena are accelerating a significant desertification, an environmental disaster due to the desiccation of the wetlands and the loss of protected species. The lack of food, the scarce of some basic building materials (such as mud and straw) and, above all, a worsening of the agricultural and livestock productive potential are the consequences. This pushes the rural population to the abandonment of these settlements; especially young people who, dissatisfied with these precarious living conditions, try to take advantage of the opportunities that cities may offer, seeking for a more prosperous future. The result is a population that is increasingly aged and not as happy as it once was to deal with the frequent maintenance requirements of traditional techniques and materials, which, coupled with the increasing periods of absence, consolidate the use of exogenous materials more durable than local ones.

On the other hand, the use of these new materials is associated with modernity and is a symbol of social and economic status. Hence, the community is willing to get them from the institutions. This replacement is promoted by government policies and some associations that believe that these measures will lead to social progress and, sometimes, to an improvement in sanitary conditions, especially, in relation to the Chagas disease, an epidemy caused by the bite of an insect named *vinchuca* (triatoma infestans), who dwells in the cracks of the walls and the straw of the roof.

The population, which is aware of the construction techniques required by local materials, applies them in an analogous way to the new ones, turning out to unsatisfactory results in some cases. The thermal inertia of the construction is decreased, and hygrometric incompatibilities can lead to the appearance of condensations or accumulations of water. The breakage of ceramic tiles is also frequent due to the large changes in temperature or the lifting of calamine roofs caused by the wind.

However, the consequences over intangible values are more worrisome. The abandonment of these ways of life means the extinction of endemic knowledges and traditional crafts of the High Andean region that are part of the local culture and of a landscape that is bounded to the social imaginary. It is important to emphasize the architecture as a valuable heritage element and to evaluate up to what point it should be protected as an essential factor in this ecosystem and as a basis for collective identity.

The necessary progress should not ignore a knowledge collected over centuries, but it should benefit from it and merge with it. In the long term, local solutions are usually the most efficient and sustainable in the broadest sense of the word. But there is no architecture without inhabitants. They are the ultimate guarantors of a heritage that will only survive if the original work methods do so. There have been some attempts to promote tourist activity in the CSBR in order to provide the population with new ways of earning a living. It is crucial to considerate whether or not the development experienced by these communities under the influence of global dynamics is compatible with the vernacular architecture preservation in terms of sustainability.

NOTE

This paper shows part of the investigation enclosed in the project "Habitat and architecture at the Sama mountain range: preservation and participation", promoted by the association Lógicas Locales and developed at the "VI Convocatoria del Programa de Voluntariado Internacional en Cooperación para el desarrollo de la Universidad de Málaga", and counted on the support of the local NGO Protección del Medio Ambiente Tarija (PROMETA).

All images belong to the authors.

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Built heritage as catalysts of environmental sustainability: A pragmatic paradigm for Anthropocene

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ABSTRACT: Addressing the fundamental causes of anthropogenic global warming is inextricably linked with achieving the criteria for environmental sustainability. To this effect, mitigating global GreenHouse Gas (GHG) emission has procured primal significance and dominated global debates. Sadly, despite the global coalesce and plenitude of scientific perspectives, only a mixed success has been achieved so far on the GHG emission mitigation from the building sector which produces arguably one-third of the global emissions. This is owing to a couple of reasons and sometimes, fundamental misconceptions. Against this background, this paper argues that reinventing traditional building materials and traditional design construct holds a huge potential in the carbon emission mitigation in the building sector. Therefore, this paper examines and measures the energy consumption and carbon emission rates of built cultural heritage in comparison to modern buildings under the same energy supply and climate conditions using a parametric computer based comparative simulation procedure using REVIT Architecture with green studio plug in.

1 INTRODUCTION

In the most succinct words, industrialization came with its pros and cons. Ever since the advent of industrialization, the greenhouse gas (GHG) concentration in the anthroposphere has increased by 70% (IPCC 2007) and the earth has been pushed to a post-Holocene era called the Anthropocene. Within this context, Anthropocene refers to the current era in which there is enormous increase in the GHG concentration in the anthroposphere and humans have become the global geophysical force and causes of perturbation in geophysical equilibrium. (Steffen et al. 2007). Appraisal of contemporary research however, have demonstrated that the building sector alone is responsible for consumption of 40% of the global energy and therefore the sector is responsible for one-third of the global (GHG) emission, both in developed and developing countries (Zhang & Cooke 2012, Olukoya & Kurt 2016, Power & Zulauf 2011, Gunnell et al. 2009). To reduce the energy consumption and carbon emission rates therefore, the building sector has been at the center of global discourse. Sadly, despite the global attention and coalitions, only a mixed success has been recorded so far in the context of GHG abatement and energy consumption (IPCC 2014, OECD & IEA 2015). This is due to a couple of reasons and perhaps, fundamental misconceptions. Against this background, this paper aims to address one of the commonplace misconceptions which states the built heritage are incompatible with progress and holds no valuable lessons in the context of GHG abatement and energy consumption. The paper argues that built heritages have proved for several millennia, to be energy efficient and have lower carbon footprints (Opaluwa et al. 2012, Power 2008, Chiras 2000) and thus, they are worthy templates of emulation in the context of environmental sustainability and earth consciousness. According to this paper however, built heritage is defined as buildings which are built from traditional materials such as adobe, straw bale, wood, stones and by local artisan using traditional know-how. To achieve main objective of this research therefore, the paper makes a case of residential typology of built heritage in Louroujina village in North Cyprus. The aim is to compare the energy consumption and carbon emission rate between the built heritage typologies and the modern buildings in the same climatic conditions and energy supply. This is an attempt to show that built heritage are more energy efficient and have lower carbon footprint and thus hold valuable lessons in the discourse of GHG abatement.

1.1 *The correlation between GHG emissions, climate impacts and environmental sustainability*

Traditionally, environmental sustainability entails the ecosystem integrity, carrying capacity and

Table 1. Climate change indicators and the effects on the tenets of environmental sustainability.

Climate indicator	Associated risk	Impacts on environmental sustainability
Temperature change	Extreme events, heat. Waves, glacial melting	Biodiversity extinctions. Perturbed carbon circle and lower carbon sinking. Change in soil PH value.
Sea Rise	Coastal flooding. Sea water incursion.	Degradation of land surface nutrients. Removal of plants and green spaces. Exposure of soil carbon
Wind	Wind driven rain. Wind transported sand. Wind gust and change in direction	Destruction of trees, biodiversity destruction, Deposits of dust on leaves which distorts photosynthesis
Desertification	Drought. Heat waves. Drop in water table	Inadequate water for survival of green spaces Lowered carrying capacity through lowered natural resources Distorted eco-system balance
Atmospheric moisture change	Flooding Intense rainfall Change in water table level Change in soil chemistry	Change in soil composition Change in water table level which alters the eco system balance
Climate and pollution	Heavy metals in the soil and atmosphere	Change in soil composition and chemistry Change in the carbon circle

biodiversity conservation. The natural environment which is the natural capital must be maintained as a source of economic inputs and as a sink for greenhouse gases. Therefore, harmful emissions must not be emitted faster it they can be assimilated by the environment (Kahn 1995). Hence, mitigating emissions from the building sector plays an irreducible role in addressing the issue of climate change and its effects on environmental sustainability. Table 1 discusses the indicator of climate change and its effects on the criteria of environmental sustainability.

2 CASE STUDY

To attain the empirical aims of the paper, the research was conducted using Louroujina Village in North Cyprus. Cyprus is the third largest island in the Mediterranean Sea (Antoniadou 2007). Louroujina is situated in the south of central lowlands of Mesaoria in the Northern part of Cyprus. Geographically, the village is at longitude 350 00' 42'' North and latitude 330 27' 51''East with altitude of 236 m (Kurt et al. 2013). The building materials of the traditional structures in Louroujina have evolved through the different eras of civilization, ranging from adobe, stones to wood. Most built heritage available in Louroujina village today are built using this mixed manner material (stone and adobe units and stone). Although, some of these buildings are built completely using adobe.

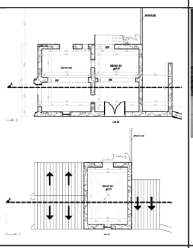
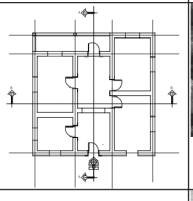
2.1 *Built heritage typologies in Louroujina*

According to the TÜBITAK project 112M417 which was conducted in Louroujina (2012–2015), the village has four typologies of residential traditional buildings (Kurt & Mesda 2014). The classification is based on the space morphology and the façade typologies. With regards to these dual characteristics, four typologies of traditional building are identified in Louroujina village, namely; (1) Dichoro plan typology; (2) Columned porch typology; (3) Two storey town house typology; (4) Center hall plan typology.

3 METHOD

This paper is organized in two phases. Phase one involves the collection of secondary data via existing scientific perspectives. The primary data source was mainly through field survey. Meaning that field survey was conducted and four buildings were identified, measured and drawn using AutoCAD. The criterion for identification of the building was based on the typology which is informed by the building material, façade characteristics and plan configuration (Ibid). Subsequently, the buildings were coded according to the typologies (built heritage/modern building) and the Geographical Information System (GIS) number. A descriptive table was prepared and the description (Table 2) was guided by the criteria of identification afore mentioned and the period the buildings were built.

Table 2. The buildings attribute description.

Traditional and Modern building	Building Architectural Feature			Fenestration/Air movement		Building Envelop
Typology	**Orientation**	**Plan Scheme**	**Facade**	**Window/Door Type**	**Ventilation**	**Wall**
GIS 440, 442	**South – East (SE)**			Wooden Shutters	Axial Corridor	Stone+ Adobe
Period Built	**Window Size/Orientation**					**Roof**
Venetian Period 1489-1570	800x1200mm/ South East					Clay tiles
GIS 474	**South – East (SE)**			Wooden shutters	Axial Corridor	Adobe
Period Built	**Window Size/Orientation**					**Roof**
Lusignan Period 1192-1489	700x1200mm / South – East					Clay tiles
GIS 72	South – East (SE)			Wooden Shutters	Cross Ventilation	Stone+ Adobe
Period Built	**Window Size/Orientation**					**Roof**
Lusignan Period 1192-1489	1000x1200mm/ South – East					Clay tiles
GIS 181	North – West (NW)			Glass/ aluminum	Axial Corridor	Hollow sandcrete blocks/ Concrete
Period Built	**Window Size/Orientation**					**Roof**
Post British Period After 1960	1200x1200mm South- East					Corrugated aluminum roof

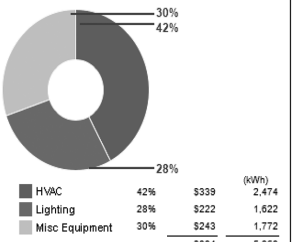
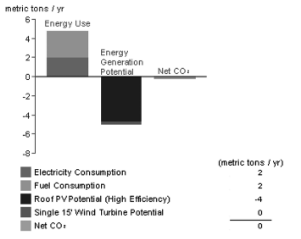
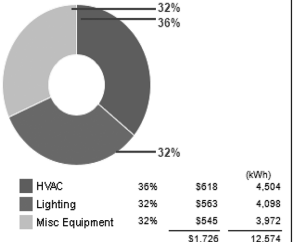
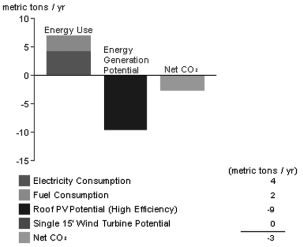
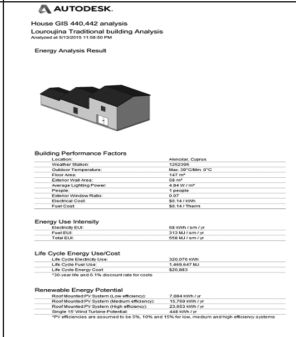
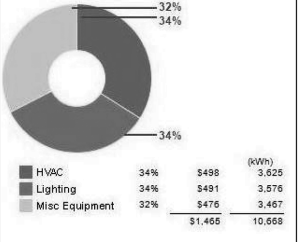
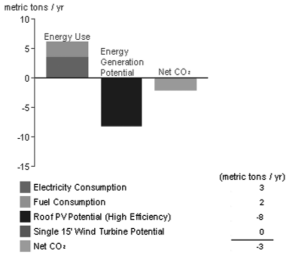
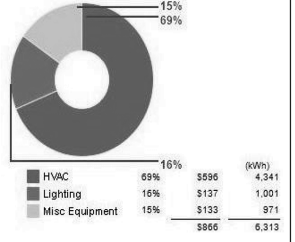
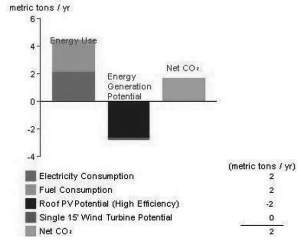
As a next step, a parametric computer based simulation was conducted using Autodesk Revit Architecture software with green studio plug in. The software measures the energy consumption and carbon emission rate of each building under parametric conditions. As caveat however, the dichoro typology was not simulated in this research due to the convectional total size (4 m^2) which is argued to have a trivial impact in the environment. Hence, a total of four buildings (three traditional building and one modern building) used for the simulation procedure. These buildings are as follows (1). GIS No. 474 - Central hall typology; (2). GIS No. 72 - Columned porch typology; (3). GIS No. 440,442 - Two storey town house typology; (4) GIS No. 181 - modern building. The parameters for the simulation include; construction materials for the building envelop, the building orientation, sizes and orientation of the openings (doors and windows). Concerning the data analysis, a quantitative comparative analysis approach was adopted. Comparison was made with the results achieved from the simulation of the built heritage against the modern building. This approach consisted of establishing a correlation between the parameters included in the simulation procedure (construction material for the building envelop orientation of the building, sizes and orientation of the openings) and the result achieved. Also, the comparative analysis allowed the establishment of the correlation between the energy consumption and carbon emission rate.

4 DISCUSSION

4.1 *Energy consumption—Built heritage versus modern building*

From the data presented, it can be concluded that, heritage buildings are more energy efficient irrespective of the prevailing weather condition (Table 3 and Fig. 1). It is noteworthy however, that

Table 3. Data presentation (simulation procedure).

	GIS Number	Building simulation parameter	Energy consumption (Electricity)	Yearly carbon emission
Built Heritage	GIS 474			
	GIS 72			
	GIS 440,442			
Modern building	GIS 181			

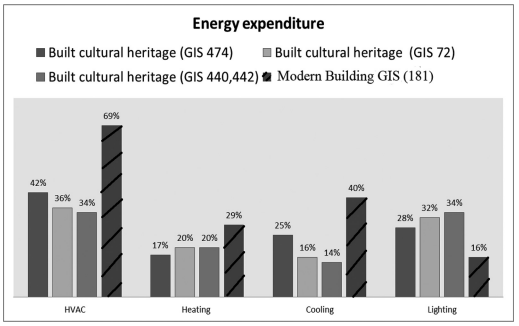


Figure 1. Energy consumption in built heritage and modern building.

Figure 1 has an additional column—HVAC—to illustrate the sum total of the energy expended and it also includes the heating and cooling column to illustrate the precise consumption in winter and in summer respectively. In that vein, the data illustrates that built heritage uses lesser artificial heating procedure and require lesser cooling in winter. The presented data also shows that the built heritage offers more comfortable interior spaces, both in winter and summer. This is further discussed according the to the following;

4.1.1 *HVAC consumption*

As illustrated in Figure 1, the modern building expends substantial amount of its energy on the HVAC. This is due to a complex of reasons, but within this context, it is as a result of the combination of the material of the building envelop, building orientation, sizes of opening, design construct, and deliberate dependence on artificial heating and cooling. Furthermore, theoretically 75% of heat loss and heat gain happens through the building envelop, therefore, the enormous energy expended is due to poor thermal property of the building envelop which is made of hollow sandcrete blocks. On the other hand however, the traditional buildings expend lesser energy—which in this context—is a function of the material employed for the building envelop. The earth friendliness of the material encourages the usage of the passive heating and cooling through the thermal mass of the 750 mm thick adobe walls and the usage of courtyards and traditional heating.

4.1.2 *Lighting consumption*

Paradoxically, however, despite the overwhelming advantages of the built heritages, the modern building still has a more judicious use of electricity in terms of lighting energy consumption. The modern building uses lesser energy on lighting because of the modern age LED energy efficient lighting system. Therefore, it can be discussed, that, heritage buildings need to improve the existing lighting systems to meet the contemporary requirement.

4.2 *Carbon emission—Built heritage versus modern building*

The data illustrated in Table 3 proves that heritage buildings have lesser carbon footprint in comparison to modern buildings. This data also emphasizes the correlation between energy consumption and carbon emission. The modern building with the largest energy expenditure also produces the most carbon yearly (2 metric ton/year). Therefore, to achieve earth friendly building and lesser carbon prints, the trajectory of energy consumption and carbon emission must be addressed by learning from the heritage buildings. Such lessons includes the typology building envelop materials and design construct—which in this case—includes the building orientation, courtyards, dimension and orientation of openings.

5 CONCLUSION

The result gathered from this research buttressed the argument that built heritage plays an irreducible role in the debate on environmental sustainability. The heritage buildings in Louroujina village show the mutual adaptation between man and his environments and also illustrate how the older culture relates consciously and carefully with the earth. The energy efficiency and earth friendliness in this specific case study is as a result of the choice of building envelops (adobe and stone), use of passive heating and cooling, orientation of building, use of courtyards and sizes and orientation of openings. The Louroujina typology of built heritage further demonstrated that it is possible to have comfortable interior without necessarily depending on HVAC but instead, by the use of passive heating and cooling through thermal mass and courtyard systems. Therefore, the absence of industrial tools—generally and in this specific case—is not a mere echo of primitivism, but a carefully orchestrated provision of ecological balance between culture and nature. Furthermore, the results also demonstrated the linkage between energy consumption and carbon emission. The modern building is energy intensive and the consumption makes it plausible for the buildings to emit such enormous GHG per year. Lastly and more importantly, despite the overwhelming advantages built heritages, the lighting systems need to be upgraded to meet the modern requirement of energy efficiency.

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Adobe vernacular heritage in Mexicali, Mexico

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ABSTRACT: The importance of this paper focuses on the development of architectural assessment of the typology of adobe buildings in Mexicali, Mexico, which has not been documented to this day; these buildings are largely abandoned because users feel unsafe living in an adobe house in a seismic zone. This assessment supports the patrimonial value, absent for this city's building, which is highly related to the adequate behavior of these buildings in seismic events. The classification of these buildings supports their conservation because of their local singularity, but also in order to identify the components that have allowed adobe structures, with these characteristics, to have an adequate adaptation to local weather and seismic conditions.

1 INTRODUCTION

The migration of workers from states like Sonora, Baja California Sur or Jalisco brought to Mexicali's first constructions the use of adobe. In the beginning, they were mainly irrigation canal builders for Imperial Valley in California and later, crop workers for US companies established in the Mexicali Valley.

The indigenous population, which after 400 years of the discovery of America had had very little contact with the world brought by the different conquerors of the continent, had its own way of living and building. The Cucapa lived adapted to the environment, with one type of construction in the summer and another in the winter—houses without walls in the summer and open in the winter (Gifford 1933). The houses were built with trunks of mesquite and lined with arrowweed (*Pluchea sericea*) (Instituto de Cultura de Baja California, 2013) and smeared with mud, a kind of wattle and daub technique common in distant lands where it was normally known as Tabasco to mention some. The first Mexican customs office in Mexicali was built based on this type of system. This demonstrates what Mexicali was like in the early twentieth century—an unexplored desert with a native population—and indicates that vernacular construction was not used any further. The constructive traditions of newcomers from different parts of the country, in combination with the new constructive techniques that came by rail from the United States, were developed in the city.

The neighboring situation with Calexico, California, a "mirror city"—cities with certain characteristics separated only by a national or international administrative limit, in this case between the United States and Mexico (García Amaral 2008)—was considered one city in its early years since the transit between its inhabitants was free, which resulted in an easy economic and social exchange. The way of living, including traditions and the physiognomy of the city, was mainly influenced by the Californian life, much of it brought from Los Angeles.

In Mexicali, the lack of knowledge of the origins of the city has caused the population to believe that there is no cultural identity, as explained by Lynch, (1975), the study of the recent past and everyday life must occupy a place in what is done with the investigation. Architecture, with social roots aspects, is an example of what was generated, but over time has been lost by the same citizens who abandon this type of constructions or demolish them (Fig. 1).

It is in the adobe constructions where these disinterests are reflected. Surrounded by the seismic situation of the city and coupled by the little value that an adobe construction has for both the inhabitant and for the governmental dependencies, (Government of the State of Baja California 2007) it is considered rubbish. The permanence of the adobe constructions, many of them with more than 60 years of age, several without the adequate maintenance, are a reflection of the ability and knowledge of the constructors that arrived to Mexicali and built their houses thinking they had a long life.

On the other hand, this material was the solution for those first families who arrived in a city with warm and extremely dry weather, with



Figure 1. Abandoned adobe bungalow house (Olvera 2016).

maximum average temperatures of 42°C (with maximum extremes of 49°C) and average temperatures of 8°C (with minimum extremes of -3°C) (Luna 2008). There was no mechanical system of climate conditioning however, the passive systems allowed the population to live in a desert.

For these reasons, it is necessary to know the adobe construction techniques used by Mexicali residents in their first decades, since they have been able to endure in spite of extreme climates and earthquakes that have occurred, within more than 100 years, in this city.

2 METHODOLOGY OF THE INVESTIGATION

2.1 *Routes and planimetry*

The qualitative approach of the research, intends to explain the adobe constructions' constructive typologies in an area considered of high seismic activity and extreme temperatures. Adobe buildings planimetries in the city of Mexicali, Baja California were made for those buildings in which the following activities could be completed: defining an approximate construction date, having access to the building, being able to carry out photographic surveys and planimetry. Once these activities were finalized, a comparative analysis of the data obtained proceeded.

2.2 *Comparative analysis*

The research has identified constructive differences as well as similarities between the constructions analyzed—constructions which also sought thermal comfort in an extreme warm climate such as that of Mexicali. The terminology developed by Caniggia (1995) was used as a guide to define the constructional typologies of adobe buildings. Comparisons with other localities in Mexico that also used adobe as a wall-building material were made, considering the climate and geological situation. There is a large number of populations that used adobe for construction, but for this case study, the city of Colima's cases were used, due to their high seismic risk and their large number of constructions with adobe. Despite Colima's climate difference to that of Mexicali, its seismic zone situation renders it a reference case. Reviewing Mendoza Jimenez's doctoral thesis a comparison of structural elements used in the city of Colima in houses of adobe is made.

3 ADOBE

3.1 *The city of Colima*

In Mexico, the economic, political and social developments mostly occurred in the center and northeastern part of the country. The architecture was affected since it was where the population was developed and consequently the necessity of housing and public buildings arose during the nineteenth century and earlier.

Constructions such as religious spaces, public buildings or theaters were mostly built of stone or concrete, but the houses of the centers of the population were in most cases built with adobe. Historically earth architecture has been a fundamental part of Mexico's traditional societies (Guerrero 2014).

In cities like Colima, in the state of Colima, adobe is considered a historical material for the construction of houses (Mendoza et al. 2005) and it is worth noting that this system's use has been reduced since 1941, mainly due to the deterioration resulting from the earthquakes that affect the city, as well as the change and waste of the construction tradition. There are several studies on adobe constructions, mainly by researchers from the University of Colima, mentioning construction language and the quality of constructions during the seismic occurrences in the city.

The city of Colima's adobe buildings described by Mendoza Jimenez, have 60 to 100 cm thick walls, primarily 60 cm, with adobe pieces made from regional clays, gravel and organic material (straw or grass), grouted with the same adobe clay 2 to 4 cm thick, sometimes covered with tile pieces to prevent erosion of joints. These walls, laid on a foundation of broken boulder stone, at a depth of 80 to 120 cm, had a baseboard between 40 and 60 cm above the ground level. Columns and wooden beams were used as the main structure, confined with adobe walls, using materials such as fired clay or terracotta tiles for the foundation or for roof reinforcement (Fig. 2).

Roofs are classified into two groups: two-dimensional and three-dimensional systems. The two-dimensional system is characterized by forming a single plane of load bearing elements, classified

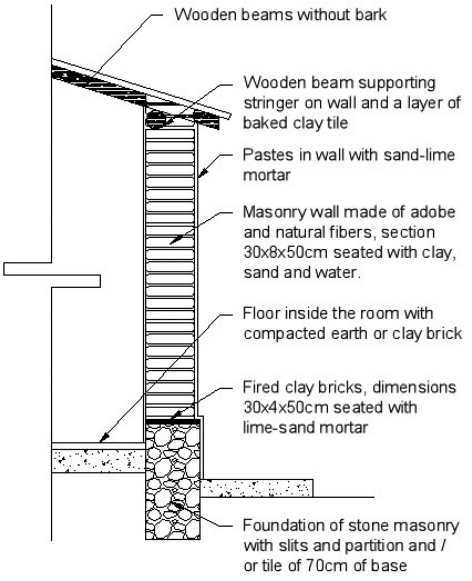


Figure 2. Housing section of the nineteenth century in Colima, with adobe walls and tile roof (Mendoza 2005).

into two types: 1.) inclined wooden beams covered with grass, *palapa* (thatched roof made of dried palm leaves), *tejamanil* (thin wooden slats) or clay tile and 2.) a horizontal system, flat roof, denominated *terrado**, with wooden beams in one direction and layers of clay tile and lime-sand mortar. The three-dimensional systems are interwoven wooden elements, including the diagonal house and the *palapa* (Alcántara Lomeli & Gómez Amador 2000).

3.2 *Adobe and its loss*

Adobe during the second half of the twentieth century ceased to be the main material of housing construction in many parts of Mexico, replaced by industrialized materials such as brick and later concrete blocks. When it stopped being used, it also stopped being produced. This knowledge is lost with each person who ceases to build and with each building being destroyed, due to lack of maintenance, abandonment or the fact that they consider it a waste material or not suitable for construction (Government of the State of Baja California, 2007).

In cities of northern Mexico, this situation has been recurrent in what are considered the initial population nuclei (historical center), where most examples of this type of constructions are found. However with the passage of time, the constructive and architectural typology is lost to give way to an modern ill-understood mentality in which everything that is old is not useful and must be destroyed. This is why it is necessary to identify the constructive and architectural typologies of adobe constructions in the city of Mexicali.

4 THE CONSTRUCTIVE ADOBE TYPOLOGIES IN MEXICALI

4.1 *Adobe construction in Mexicali*

In order to discuss adobe in Mexicali, it is necessary to know the two systems that were used and are still used in the agricultural zone and the limits of the city: 1) sitting adobe and 2) standing adobe. First we will talk discuss sitting adobe. This system is generally well known because in all the places where adobe construction is practiced this system is practiced with different dimension pieces; 30 × 43 × 8; 30 × 40 × 8; 30 × 50 × +/– 9 cm. A constant in the width of the pieces is observed, whereas the thickness can reach up to 12 cm.

The construction with sitting adobe was done on a premixed cement slab, in many cases without a baseboard, so the only protection against erosion of the base is the coating or finishing given to the wall. The height of the walls vary according to the use of construction, although in the commercial buildings like businesses, the height observed was up to four m of 30 cm thick walls (Fig. 3).

On many occasions the construction of the pieces were done in situ since the size of the land, such as those of the Segunda and Tercera Seccion (also called Pueblo Nuevo), were originally 16.66 × 47.00 m, as established in the plan approved by the City Hall in 1920. Family members or somebody else who knew the adobe constructive system made the pieces. Due to the high amount of clay in Mexi-cali soil, the stabilizing processes of the material required the adding

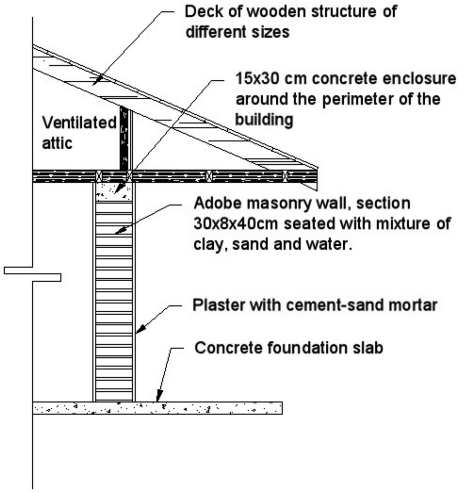


Figure 3. Section of adobe wall with wood structural roof in Mexicali (Olvera 2017).

of vegetable fibers to reduce cracks and increase the cohesion of the mixture (Minke 2001).

The fit of the adobe pieces is horizontal, in rows and in a staggered manner, with joints of two to four cm, made with the same material as the adobe. Wooden window and door lintels support the weight of the pieces. The rectangular windows, varying in dimensions from 40 to 80 cm from ground level to windowsill, using wooden frames and sash or casement windows of two or up to twelve panes.

Lime-sand finishes were not common; however, the most common was cement-sand mortar, placed on a hexagonal mesh, directly on the surface of the adobe wall, but creating a separation from the contact surface due to the difference of materials, which with time gives the appearance of deterioration

Sitting adobe was the most widespread technique in Mexicali, however there are also cases in which adobe served as a filler in walls of a wooden frame structure, which is known as standing adobe. The wooden frame wall is commonly used in balloon frame houses, in which the wood is the structure that reinforces the walls and later to be cladded with wood or drywall.

In the Mexicali case, adobe pieces were placed on the side of the header of this frame, one placed on top of the other without the use of mortar, because the piece was balanced on both sides by the wooden structure and sustained in the vertical direction and the ends by other adobes. The dimensions of the adobes for this type of wall are maximum 9 cm, because it had to rest on a standard measuring board of 10 cm. Cases, where as in figure 4, where the wall is completely apparent and due to the structure of the wood, the wall remains stable, were observed. In some cases, the wall is finished with wood screens or only with hexagonal mesh to be plastered with cement-sand mortar (Fig. 4).

Architectural and constructive typologies based on the adobe sitting and standing walls as a construction typology that was used in housing construction in the city of Mexicali are described hereunder.

4.2 *The quarters*

The Tercera Seccion, locally known as Pueblo Nuevo, was developed as a colony of workers and immigrants who arrived in the city in the hope of working. Formally drawn out in 1919, but populated years ago (Robles 2009), this generated a mixture of knowledge in the adobe construction propitiated by the variety of people's origins whom came to the locality and the influence of United States constructions.

The quarters responded to the needs of a floating population, as an analogy of what the



Figure 4. Adobe standing construction, Primera Seccion, Mexicali (Olvera 2016).

neighborhoods of the interior of the country are (Robles 2009) like those in Colima. Two or more modules of a single bedroom and bathroom, located on the property's margins with a single-sloped roof, form the longitudinal side of the building.

Unlike the adobe constructions in Colima, the walls are built on a foundation slab that carries the weight of the walls. High parapets allow a ventilated attic, a typology adopted from the Californian bungalows that allow the passage of air to force out the heat that rises to the highest internal part of the house. On top of this, a wooden roof brought from United States. In Mexicali the *terrado** technique was not used for the roofs of the adobe constructions, only wood and the *tejamanil** were used. It has a single window and the main access, which leads directly to the sidewalk. The ornamentation is simple; in some cases, it has a detail in the upper limit of the wall, as a sort of cornice. Some of these quarters still stand to this day, but risk being demolished if they are abandoned (Fig. 5).

4.3 *Adobe bungalow*

The remoteness of the Baja California cities with the center of the country and its proximity to California formed an urban image that was not related with any other major population center in southern Mexico (Calderón & Robles 2015). Although California's major cities, such as Los Angeles or San Francisco were relatively far, they were perfectly connected by the Intercalifornia railroad, which allowed wood and balloon frame houses or "Ready Cut House" construction systems to arrive (Faragher 2001).

During the first decades of the twentieth century, the bungalow house phenomenon had a great influence, initially in California, where it was created, marketed and later expanded to the United States.



Figure 5. Quarters on Obregon Ave. Mexicali (Olvera 2016).

The characteristics of bungalow houses are the front porch as a means of interaction between the neighbors and the passer-by, which was also used as an outdoor living room to enjoy cool afternoons.

Square architectural layouts, in cases of open social areas, in reference to this, studies such as those of (Minke 2014) where the buildings' square layouts work best during earthquakes in adobe constructions, is supported by the studies at the University of California, Berkeley (Brenner 1979).

Double-sloped roofs were designed to take in the sun's heat in the winter and ventilate the interior during the summer months. The open plan, adapted from the Japanese house, is a basic characteristic of the bungalow type house. The open plan allowed for greater light and ventilation (Faragher 2001).

In addition, White (1923) mentions that many bungalow houses were designed to take full advantage of cross-ventilation, making them more comfortable on summer days in warm-weather towns.

These typologies were used in the construction of walls of adobe houses, in their two modalities of sitting and standing adobe (Fig. 6). The wooden roofing for both walls was double-sloped with a shingle finish. Other elements such as conical columns or bay type windows have been used in the adobe housing in Mexicali, where a hybrid between the construction system brought by Mexicans from the interior part of the country and the architectural typology brought from the United States can be observed (Fig. 7).

The use of wood as mentioned by Alcántara Lomeli & Gómez Amador (2000) in the structural aspect of some constructions of Colima, can be observed in bungalow type houses, The difference being in the construction of a complete wooden structure, and varying in placing the adobe vertically on its short side, which provides thermal insulation in an area of extreme temperatures.

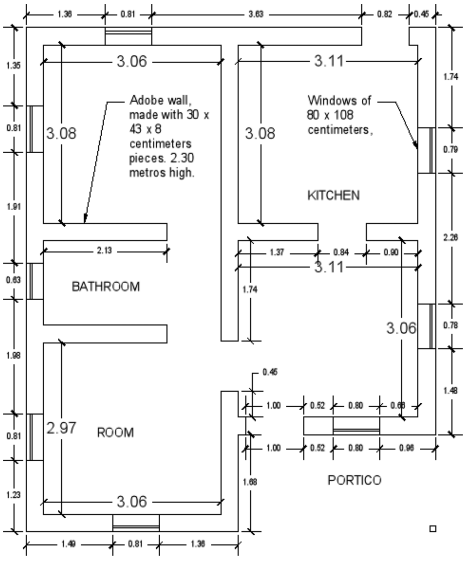


Figure 6. Architectural plan of bungalow type adobe house in Mexicali (Olvera 2017).



Figure 7. Bungalow type house, built with adobe satanding walls in Segunda Seccion, Mexicali (Olvera 2016).

5 CONCLUSIONS

Adobe was one of the basic materials used by human settlements in many parts of the world and in this case, Mexicali was not the exception. However, in this city's case, negligence of this origin is observed with the disappearance of this heritage and the extinction of these 20th century constructors' knowledge which was applied to develop an highly seismic and extreme temperature area.

The constructors' capacity to adjust the buildings to the balloon frame system was observed in the buildings shown. They learned that the passive air-conditioning techniques, such as cross ventilation

and the ventilated attic, accompanied with the thermal capacity of the adobe, created adequate spaces to live in during the extremely hot and cold months.

From the structural point of view, the adaptation of the balloon frame system with the adobe allowed the construction to be more stable for the seismic forces with the adobe standing walls. Contrasting with the sitting adobe, that is more likely to be damaged during an earthquake. Although many constructions still exist, they have overlived the strongest earthquakes that have hit the region, hence the necessity to study the material and the geometry of the buildings that are still preserved.

Consequently, it is important to mention that there is no study of any type, at least on the city of Mexicali, about this phenomenon of hybridization of adobe and balloon frame houses. Nor is there a scientific reference that discusses adobe standing construction. In the search for information, there were a few comments in cities' chronicles, such as Ciudad Juarez in Chihuahua or Los Mochis in Sinaloa, but without examining the topic.

Unlike Colima—where there are studies on constructive typologies, constructive language, classification and study of constructions according to the constructed period—in Mexicali, the minimal general investigation has been the rapid processes that the city has seen. Processes such as changes in the constructive style, urban development and the municipality's landscape variations that the agricultural area has suffered at the beginning of the century with what at that time was called town.

The deterioration and its consequent demolition have caused an accelerated heritage loss. It is important to point out that if it is not in the interest of the population to keep these houses, the authorities will not rescue them. Mexicali's architectural language and identity is in these buildings, which is why it is necessary to document and study them.

For that reason, this lack of appreciation of adobe heritage may be because of the lack of information on the subject, which is why this type of research is necessary; to give this type of housing a heritage status and so that it can continue being part of Mexicali's construction systems. It is partly up to the academic community, in this case in Mexicali, to carry out such investigations in order to improve the construction system and so that the population can adopt it again.

NOTE

**Terrado*: Rooftop technique based on a structure of wooden trunks that support a light framework (weaving of reeds, oleander ...) covered with an intermediate layer (shrubs, algae ...), covered with a layer of well compacted soil.

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Balconies in traditional urban architecture through typology and solar radiation

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ABSTRACT: The analysis of traditional urban architecture all over Europe shows that the balcony is an element with a strong variation in use. In some territories like the Iberian or the Italic peninsulas, balconies are typical elements in traditional urban fronts while in other territories balconies appear only under specific conditions. This communication analyses different urban cases in Spain, Italy, England and Poland matching in a unique theoretical framework Caniggia's typological theory and the solar radiation influence on pre-modern architecture in order to explicate the erratic appearance of this architectural feature.

1 STUDY OF THE TYPE

Though never written, Gianfranco Caniggia's sentence "the balcony is what is left of the area of appurtenance", recorded by his disciple, the professor Matteo Ieva at the Università Politecnica di Bari (Italy), is very important to truly understand the typological essence of the balcony.

The area of appurtenance (Caniggia 2008: 135) is the free space of the plot that, due to the progressive urban densification, is gradually reduced in size till its disappearance. Analysing the diagram an urban plot's evolution, several phases can be recognised.

The first phase is characterized by a small dwelling and a wide area of appurtenance usually dedicate to agriculture (Fig. 1.A). This single floor building possesses, in synthesis, all the fundamental elements of the façade's composition: the basement, the roofline and openings to access the interior as well as to let light and air in; nevertheless, there is no balcony.

Following the urban densification trend, other constructions would occupy part of the area of appurtenance always maintaining natural ventilation and lighting (Figs. 1.B, 1.C). When the plot is saturated, a second floor is usually built (Fig 1.D). In the new upper part of the façade the openings would reach the floor in order to maximize their function and a parapet would be installed for protection. The last step of the evolution is reached by adding a floating area of appurtenance directly to the upper floor openings: the balcony. This feature, while maximizing the penetration of light and air, provides an additional space to the unit (Fig. 1.E).

In the compact urban fabric, the balcony evokes the original agricultural function of the area of appurtenance. Moreover, where urban economic conditions are still precarious, like in La Habana (Cuba), balconies with farming vocation can still be found, reinforcing Caniggia's thesis on the relation between the balcony and the area of appurtenance (Fig. 2).

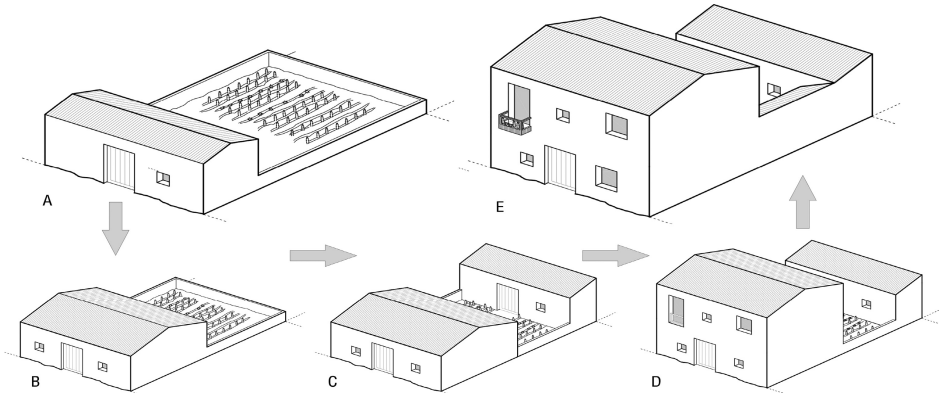


Figure 1. Evolution diagram of an urban plot (Privitera).



Figure 2. Balcony with farming use, La Habana Vieja. (Privitera).

Nevertheless, it is necessary to assume that balconies were not common elements in all traditional settlements. The reasons for their presence or absence have to be researched in a complex network of cultural factors ultimately related with the weather of the region where the settlement emerged (Hulme 2015: 7).

Previously (Privitera et al. 2014) it has been demonstrated the existing relation between a specific climatic factor, the solar radiation, and the characteristics of urban buildings' openings. In synthesis, the less annual solar radiation (on horizontal surfaces), the more the openings tend to be glazed and taller in order to collect the maximum amount of natural heat in winter and to reduce the natural ventilation. On the contrary, the more solar radiation, the more the openings tend to be protected by opaque shading elements that block the sunlight and allow the natural ventilation. In the transitional zone, openings find intermediate solutions, being the balcony the main typological feature.

According to the solar radiation's theory, traditional architecture pursues the strongest climatic coherence in order to rationalize the use of natural resources disposable in a set environment. Nevertheless the migrations of architectural models as well as local regulations are capable of producing solutions incoherent with the climatic characteristics.

2 BALCONIES AS COHERENT SOLUTION WITH THE AMOUNT OF SOLAR RADIATION

Traditional architecture of Southern Europe adapted its openings in order to reduce the penetration of the sunlight during the warm season, especially in summer, when the sun is higher in the sky and the maximum values of radiation are reached. In order to completely prevent solar rays from reaching the interior of the building, external obstacles can be interposed such as cantilever roofs or covered balconies with pillars resting on the projecting structure of the balcony itself. A common protection system against sunlight is the vertical superimposition of several balconies that cast shadows one on the other. This design could explain the profusion of balconies in the traditional urban architecture of the Iberian Peninsula and the southern territories of the Italic peninsula.

In the most dense urban settlements in Sicily it is common to find buildings with an absolute prevalence of balconies among all kind of openings. Thanks to the abundant use of this element, the formal evolutions of the railings and the technological solutions of the cantilever structure present a very wide range of models including stone solutions for the richest buildings and metal ones for modest dwellings.

Especially in Palermo, a city where the balcony represented a distinctive feature of its urban landscape starting from the 16th century onwards (Fatta 2000), the variety of decoration and technical solution is considerable.

Moreover, it needs to be highlighted that Palermo lies on a high risk seismic territory and for this reason modern building regulations applied a strong control on cantilever structures yet from the beginnings of 19th century, short after the earthquake of 1823 (Pescia 2005). Balconies with a metal structure were then preferred to stone bracket whose great inertia, during seismic events, could represent a danger to both people and building.

The most common type of balcony in the 19th century buildings of Palermo is a light structure made of a white marble flagstone supported by cast iron I-beams (Fig. 3). The mastery of local bricklayers was necessary to place the brackets that, if not perfectly aligned, would easily break the marble floor. Such peculiar balconies are located in every floor and almost in every opening of urban façades, without any reference to the internal distribution of the units. As previously said, the primary need of Sicilian buildings is to gather the maximum natural ventilation and to shield summer sunlight; in line with this objective, the repetition of balconies on every floor allows every balcony to project a shadow on the openings underneath.

In southern Italy it is common to come across unfinished buildings that are waiting to be raised one more floor. Even in this precarious condition, the balconies of the non-existing floor are already constructed in order to cast a shadow on the lower level (Fig. 4).

It is necessary to emphasize that although a balcony on the top floor provides certain protection during the central hours of the day when the sun projects an almost perpendicular shadow, during the rest of the day, when the sun is lower on the horizon, it is completely ineffective. For this reason, in pre modern architecture, external curtains were extremely common.

In the city of Barcelona, external curtains use to cover most of the windows radically transforming the urban fronts from May to October, the period of major solar irradiation. These curtains, hanging from the external walls and resting on the balconies' railings, permitted to keep the shutters wide open without affecting the intimacy of the house and, at the same time, created a preferential conduit to channel the fresh draughts. The curtains use to have fringes at the bottom and were traditionally made with natural fabric either left undyed or coloured with blue and red striped. From the forth decade of 19th century curtains coming from the Philippines made with raffia and rice straw became fashionable. Though these new curtains had a lighter impact and a brighter aspect, they tended to get dirty just after the first rains, giving the façade a humbler and shabby appearance (Curet 1991). Yet, this traditional form of shading is no longer present in the cities of the Mediterranean coast because, from the second half of the 19th century, they fell from the graces of the public opinion (Espadeler 2000: 48).



Figure 3. Typical 19th century balconies in Palermo (Privitera).



Figure 4. Upper balconies in a waiting for being raised up building, Bisceglie, Italy (Privitera).

The same tradition existed also in the city of Valencia as demonstrated by engravings showing coloured and cheerful curtains hanging from the buildings around the old Market Place (Fig. 5). Nowadays the memory of the traditional shadowing method lingers in the form of metallic rods on the outside of the windows that were used to hang the curtains (Fig. 6).

In the city of Cádiz, in the very south of the Iberian Peninsula, the balcony-textile shading system was traditionally improved with an additional external stretcher that allows to keep the curtains separated from the wall in order to improve the tangential ventilation and to be able to use the balcony (Fig. 7).

A permanent solution for the balcony shading is to cover it with a roof. Even though roofed balconies were commonly used until the end of the 18th century in the Iberian Peninsula, the national regulation inspired by the Age of Enlightenment banned their construction and conservation since they were built with wood, a perishable that, if not correctly maintained, could easily become a danger for the people passing underneath (Anguita 1997).

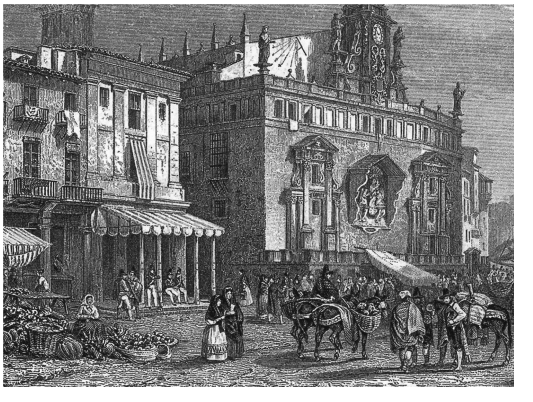


Figure 5. Detail of Valencia's Market Place (Laborde).



Figure 6. Wrought iron useless stretchers in Valencia inner city (Privitera).



Figure 7. Additional external stretchers, Cadiz (Privitera).

Nevertheless, in the Canary Islands, wooden balconies with roofs managed to survive, together with other types of shielded balconies like the *ajimeces,* wooden boxes enclosed with lattices. Scholars are not able to proper understand the survival of this particular kind of cantilever elements against the national regulation (Crespo 2012). Yet, one of the reasons could be that, since the need of shading the balconies is much more compelling under the solar radiation conditions of the Canary islands compared with the rest of the peninsula, the local administration could have limited the application of the national regulation only to specific decayed balconies.

3 BALCONIES AS CONFLICTING SOLUTION WITH THE AMOUNT OF SOLAR RADIATION

In the traditional architecture of Northern Europe, the geometry of the windows tend to be stretched upward, while there are no glazed surfaces underneath the window sill, in order to maximise the collection of solar radiation during winter time and to reduce the cold external air intake.

Since there is no need to shield windows against summer sunlight, no projecting structures, such as balconies, are built because their maintenance would be too expensive due to the snow and frost.

Starkie (1911) stated that the balcony arrived to England during the first decades of the 16th century. Tomas Howard Earl of Arundel, English diplomatic and art collector who travelled to Italy, is considered to be the one who introduced the taste for the balcony in English mansions as a distinctive element and a sign of wealth. An example is the balcony with stone structure and wrought iron railing built in Kyrby Hall, Essex, and residence of the Royal chancellor of Queen Elizabeth I (Fig. 8).

Already in 1659some of the most important houses of Covent Garden in London displayed one balcony on the main facade.

However, it was only after Charles II's *Act for rebuilding the Citty of London* that the balcony was established as a safety equipment for all the buildings along the "High streets". In fact, after the Great Fire, the rulers pushed the normalization of the construction activity in the city in order to avoid further tragic and devastating events. The balcony as a safety device would allow people inside the building to escape the flames and to wait for help in open air (Law 2000: 2).

In other northern territories, like the Tsardom of Russia, balconies can only be found on the façades of outstanding palaces, where the established architectonic code was a demonstration of the power and the intellectual level of the aristocracy. Therefore, even if the balconies became part of the architectural composition of the most distinguished buildings in Northern Europe they did not spread to the domestic architecture of the



Figure 8. Balcony in Kyrby Hall, Essex (Evans).

bourgeois and popular class, as the latter maintained a strong climatic coherence.

Nevertheless, some exceptions can be found, like the case of Warsaw, capital city of the Crown of the Kingdom of Poland from 1596, where, due to political and cultural relations between nations, Mediterranean architectural models were introduced starting from the renaissance period (Estreicher 1945).

In fact, the prolonged cultural exchange between Poland and the Italian States stimulated the migration of Italian craftsmen, doctors, merchant, tailors, royal secretaries, artists and architects to Warsaw where Italian families working for the nobility, influenced the whole society of the Polish capital.

Thanks to the *Vedute* of Bernardo Bellotto, the Varsovian urban front from the middle of the 18th century can now be studied. Two paintings of the Krakowskie Przedmiescie, Cracow's suburb Street, make possible to observe the architecture of this important urban artery during a period of profound transformation.

The first painting (Fig. 9) represents the part of the street closer to the inner city and the Royal Castle: a crowded street without pavement, with shops and chariots. Most buildings have two or three floors while some of them reach the fifth floor. Looking closer to the composition of the façade, it can be noticed that windows' geometry is compatible with the typical northern shape, climatically coherent.

Thanks to the woman staying at the window, is possible to compare and understand the real dimensions of the openings that are so high that the glazed shutters are horizontally divided in two parts, being the upper ones fixed.

In the other *Veduta* of the same street (Fig. 10), the view towards the suburb is painted next to Saint Cross's Church, built by Giuseppe Simone, another Italian architect working in Warsaw.



Figure 9. Detail of *View of Cracow Suburb leading to the Castle Square,* Bernardo Bellotto. Warsow Castle Museum (Artinpl).



Figure 10. Detail of *Church of the Holy Cross in Warsaw.* Bernardo Bellotto Warsaw Castle Museum (Artinpl).

In this view, the typical tall windows are sometimes combined with balconies with cantilever stone structure and wrought iron railings. Balconies are connected with the main floor of the building, marking the hierarchy of the composition even in bourgeois buildings.

The late 18th century was a dynamic period of transformation for the Polish capital that led to a neoclassical redefinition of the suburbs, where the Italian influence spread to the architectural composition of the urban fronts converting the balcony to somehow an autochthon feature. An interesting example of this cultural phenomenon is the new house of Baron Stanislav Lesser, built in the Miodowa street between 1850 and 1851 and designed by George Vlöck, a Bavarian architect exponent of the Maximilanstil, a central European architectural style that originally did not use the balcony as an element for the design of the façade. Nevertheless, it is recorded that the Baron himself made Vlöck change the project in order to add balconies to the main façade (Grygiel 1991).

The result was so impressive that the population got involved in the project through the local press. The balcony was replicated vertically on several floors and horizontally on most of the windows turning it into a rhythmic factor, like in southern Europe, overcoming the inherited tradition of marking, with the balcony, only the main floor of the building.

Nowadays Krakowskie Przedmiescie's façades (Fig. 11) represent a completely different architectural environment if compared to the inner city of Warsaw as rebuilt after the II World War by Russian Government. The neoclassical design of this street was completed by other generation of Italian architects, like the Marconi dynasty (Uchovicz 2007), with a historicist design, using the balcony again as a composition element of the façade even if enjoyable only during few weeks per year.



Figure 11. Façade of the building 57/59 in Cracow Suburb street in Warsaw (Privitera).

4 CONCLUSIONS

Solar radiation theory can be applied to the study of traditional architecture due to its strong coherence with the climate of the territory where it was built.

Caniggia's typological theory on balconies must be mediate with solar radiation coherence in order to achieve a universal value.

The cases in conflict with the meta-typology theory need to be justified with an external agent that influenced the development of traditional architectural models. These agents can be recognised as cultural issues such as religion and fashion, or microclimatic oddities.

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The Chilean adobe as a seismic vernacular technology, the study of the "Norte Chico" area

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ABSTRACT: Chile is one of the most seismic countries in the world where large earthquakes have occurred in the past and surely great earthquakes will occur in the future. The "Norte Chico" is an area of transition from arid to vegetation. It is located between the big Atacama Desert and the Chile's capital Santiago. There is a large influence of colonial constructions, making adobe block widely used in the vernacular architecture. It is possible to identify a particular culture of adobe construction with seismic technologies which had been proved on the 8.3 Mw earthquake that took place in September 2015.

1 INTRODUCTION

1.1 *Chilean seismic cultures*

The Chilean territory exists because of the confrontation of two tectonics plate: The Nazca plate and the American plate. The permanent glide of one under the other generates subduction that gives origin to the principal characteristic of the territory: The Andes mountain range.

The ancestral cultures that inhabited this territory knew this well and adapted to it, creating seismic structures that could resist the high intensity earth movements. In the arid north they built with stone and earth, and earthquake resistant strategies based on the geometry of the buildings. In the centre and south of the country wooden reinforcements are the most common seismic resistant solutions (Jorquera & Pereira 2015). About 40% of the official heritage declared sites are built on earthen techniques predominating the raw earth masonry and the mixed techniques of wood and earth (Contreras & al. 2011).

1.2 *The territory of the "Norte Chico"*

Limited to the north by the arid Atacama Desert and to the south by the Aconcagua river. Located between aridness and fertility. It is a territory with over 700 km of the Copiapó river (27° 19′ 00″S 70° 56′ 00″W) and the Aconcagua river 32° 54′ 54″S 71° 30′ 30″W).

This territory has been inhabited since 10,000 B.C. and around 2000 B.C. the first sedentary people settled in this area. Until the arrival of the Spanish conquerors, and since around 95BCE, the territory was inhabited by people grouped into the *Diaguita* culture (name given by the *Quechuas*), who were dominated by the Inca empire.

During the Spanish conquest it was a transitional area, from the capital of the Peruvian Viceroyalty and the south. For this reason, the second city of Chile was founded here: the port of La Serena in 1544.

The "Norte Chico" is composed by a diversity of small cities and villages, distributed between the two mountains range: The Andes and The Coast.

Around the second half of the 18th century, because of the improvement of mining and farming activities, the territory became more populated, with about 200 years of the Spanish presence in Chile and two centuries of earthquake activity.

2 CONSTRUCTIVE TYPOLOGIES

2.1 *Building typologies*

The traditional architecture of the territory is characterized by its simple aesthetics with neither a clear style nor fine decorations. Its simple definition is supported in context with the environment and available resources (Ferrada & Segovia 2007).

Three principal types of building may be distinguished by its purpose: the agricultural, the religious and the dwelling, the latter. two used predominantly nowadays.

The religious buildings are located mostly in urban areas but with isolated construction typologies. While the houses are also located in urban as well as rural areas, the urban dwellings are composed of several units attached one to another, making one constructive unit (Fig. 1). There are also different typologies in rural settlement. First the *casonas patronales* are the landowners houses that are isolated and built around an interior courtyard. It acts as an independent structural

unit. There are also smaller houses much more compact and related to farming activities that also had their own independent structural unit.

2.2 *Earthen constructive typologies*

The territory features mixed wooden-earthen construction as well raw earth masonry.

The *quincha* or wattle-and-daub construction is a technique built with a main structure of medium-sized branches with thinner branches from local bushes which were filled in with a mix of mud and straw. It is the main native constructive typology, used by the *diaguitas* (Fig. 2).



Figure 1. Continuous façade at the urban area of Combarbalá after the 2015 earthquake (Amanda Rivera 2016).

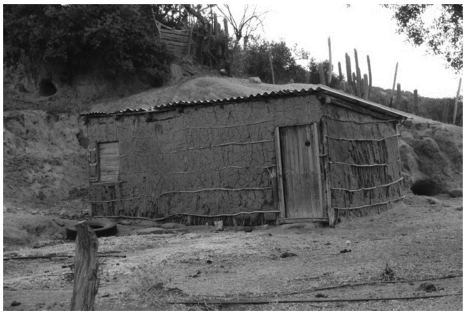


Figure 2. *Quincha* of the "Norte Chico" with medium size branches as structure (Amanda Rivera 2016).

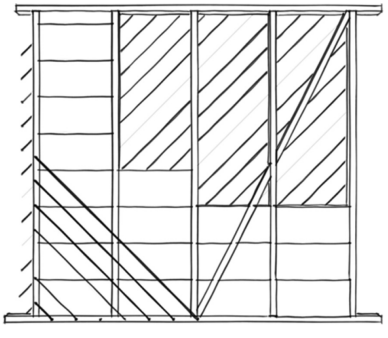


Figure 3. Scheme of the "adobe en pandereta" system (Amanda Rivera 2012).

The colonial constructions, both in cities and in the countryside, have a raw earth masonry as main structure and a secondary structure of wood and earth called *pandereta* (Fig. 3), where the earthen block is used edgeways. In this area it is possible to identify a culture of adobe constructions with an anti-seismic technology of horizontal timber embedded as horizontal ladders and with large wall thicknesses of at least 60 cm. Structures of two floors made of load-bearing earthen masonry are not uncommon.

3 THE RAW EARTH MASONRY AND THE SEISMIC STRATEGIES

3.1 *The mass*

The mass strategy gives the main importance to the thickness of the walls, making it the centre of the structural system together with the geometry of the building. It is the first basic strategy for seismic areas. The adobe construction found have a minimum slenderness ratio of 1:8, with the most used being 1:7. For this reason, to maintain this relationship and increase the height of the buildings there are thick walls, being 50 cm the minimum found in traditional architecture, to reach the height of 3.5 m. In spite of that, walls of more than 60 cm of thickness are much more frequent, to reach thus at least four meters' height, where the most common earthen block size is $60 \times 30 \times 10$ cm. At greater heights, the walls increase to 90, 120 and up to 150 cm thick, measures that arise from the modulation of block (Fig. 4). The adobes, in the traditional construction, are always disposed of blight, where the length of the block becomes the thickness of the wall (Muñoz & Rivera 2012). The continuity of the walls, reducing the door and window spans are of great importance for this strategy, as they decrease the wall volume. Also the structure has to guarantee a box-like behaviour that can be achieved through firm connections in the corners between perpendicular walls (Dipasquale & et al. 2014).

3.2 *The stability*

The counterforts were the first elements of reinforcements that can be observed in the traditional construction to counteract the effort of the earthquakes, supporting the walls in the dynamic moments, and avoiding their overturning to the outside. These stability devices have been used in great length walls which lack interior support elements. This feature is found mainly in the central nave of churches (Fig. 5).

The counterforts are the continuity of the wall to the exterior in their perpendicular direction. It must be united to the rest of the wall as in two perpendicular walls: in each one of its threads.

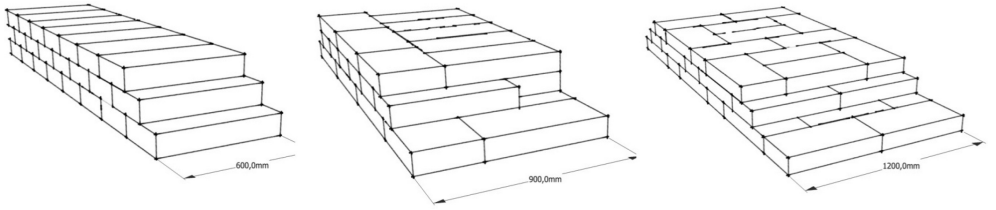


Figure 4. Different thickness of the walls with 60 × 30 × 10 cm block size.



Figure 5. One of the few buildings with counterforts in the area. San Antonio del Mar church of Barraza built in 1795 (Amanda Rivera 2016).

It generally has, an angle that generates a push towards the wall. This lowers the centre of gravity of the wall, reducing its fragility.

3.3 *The reinforcements*

Reinforcement systems are built with complementary materials to earth, in traditional architecture are made of wood, because of its great elastic properties. Its characteristics of flexibility, lightness and deformability without reaching the breaking point, offers good resistance capacity against horizontal loads, and enables the dissipation of substantial amounts of energy (Dipasquale & Mecca 2015). This is the reason why most of the reinforcement strategies are based on wood as a seismic solution.

Roof system are always present but not always thought of as part of the structural strategy of adobe construction. In the traditional architecture of the area they contribute to the horizontal stiffening, to the bracing and to the distribution of the loads.

The *trabas* are specific wooden elements (Fig. 6) used to support the joining of other wooden elements of the construction, such as mezzanines and roof structures, with the outer adobe walls. Within the reinforcements are the most precarious devices and made with the smaller woods, which means less access to reinforcement resources.

They can be found perpendicular to the wall, where the element crosses the wall and on the inside



Figure 6. Trabas: Wooden pieces to join perpendicular walls in the town of Cogotí 18 (Amanda Rivera 2016).

is attached to the structure of wood or mezzanine. Or when it is the same roofed wood or between the floor that crosses the wall and it is hooked with a piece of wood of a smaller section to avoid its displacement These *trabas* have also been observed in diagonal positions, where an element independent of the wooden structure is arranged as a square and is hooked in the same way by a wood of smaller section in both outer points. This system is of great vulnerability, especially when the pieces of wood are exposed, they are in permanent exposure to water and xylophages, which generates their frequent rotting and finally, added to the absence of maintenance, its disappearance in the reinforcement system.

The punctual reinforcements in the join of the walls are frequently founded, either in T or in L. They are wooden elements of different dimensions that are inserted between the layers of adobe in the most critical points of the construction, due to their material they give flexibility to the system which works primarily by its weight. There is a great presence of these elements, mainly with

woods of reduced section that are arranged in the outer and inner part of the wall, being united by perpendicular elements of wood like a horizontal ladder. They are sometimes reinforced with a diagonal element that ties two perpendicular walls going from outside of both wall and passing trough the interior of the enclosure (Fig. 7).

The horizontal chains join elements of roof systems with raw masonry walls. They are not always present, and the importance has been verified, mainly by the contribution of the distribution of loads and the ceiling bracings, besides contributing to the unification of the system in the point of greater risk in vertical terms. The chains can be executed in different ways, the most recurrent being woods of smaller sections placed in parallel and joined by third elements in the form of a ladder laid on the top of the wall.

3.4 *Horizontal ladder culture*

The *escalerillas* are horizontal ladders that are composed of woods of different sections, which generally comprise two parallel woods of small section joined by thirds as a ladder, thus its name. These devices have also been found with woods of larger section that come to represent the height of a block. They are introduced in the points where they can generate continuity in the construction, in mezzanines, line of lintels, and in window supports. If the wood is of sufficient length it is used to replace the lintels of doors and windows. In masonry with horizontal inserts of wood, its massive and rigid character assumes a primary importance (mass and rigidity). However, the inserts give them a certain flexibility to the walls thanks to the elasticity of the wood and its resistance to the tensile forces (flexibility). In these structures the dissipation of a part of the seismic energy is due to the level of friction between the insertions and the units of masonry as well as between them, which contributes an increase to their capacity of deformation (ductility). The friction that allows the dissipation of seismic energy can be favoured by the absence of mechanical links between the wood parts and freemasonry, thus allowing a displacement in the interface planes (Hofmann 2015).

This system represents the greatest technology present in the adobe construction of the area and even after many great earthquakes has verified its efficiency in the dynamic moment. It is hard to find earthen masonry in the area without the horizontal ladders, and even in modest dwellings these horizontal ladders are present. Even when many of the others seismic strategies are not present. The most common finding is the mass and the reinforcement strategies together, but the counterforts as a stability strategy, are only present in some larger structures such as churches. Most of them are based on the horizontal ladder strategy (Figs. 8–9).

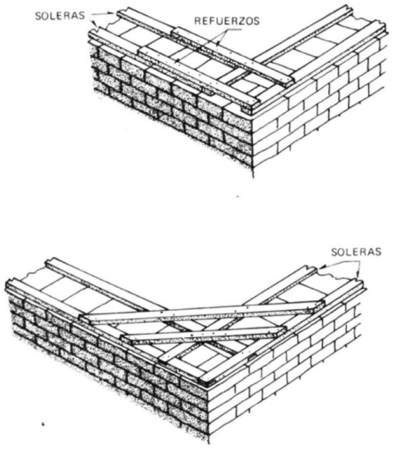


Figure 7. Wooden reinforcements in L with parallel and diagonal elements (Eucllides Guzman).



Figure 8. Corazón de María church in Ovalle. Case with mass, counterforts and horizontal ladders. State after the earthquake of 2015 (Amanda Rivera 2015).



Figure 9. Rural two-floor house in Monte Patria. Case with mass and horizontal ladders. State after the earthquake of 2015 (Amanda Rivera 2016).

4 THE "NORTE CHICO" EARTHQUAKE OF 2015

Since 1570 until the present there have been over 40 earthquakes of large magnitude, seven of which have surpassed 8 Mw. The first were recorded in 1604 and 1634 both in La Serena, of unknown magnitude but with terrible and devastating consequences. Papudo earthquakes that happened in 1703 had a magnitude of 8.7 Mw, Valparaíso in 1822 of 8.5 Mw, Vallenar in 1922 of 8.7 Mw, and the last in Canela in 2015 of 8.4 Mw.

The last big event occurred on 16th September 2015 at 22:54 UTC, which had a magnitude of 8.4 Mw and a depth of 22.4 km. Paradoxically it produced small damage, both to material and lives. Although the magnitude of the event is not synonymous of destructive power, it is a fact that the strength of the local construction culture is precisely one of the main factors to reduce seismic risk. The territory is expressed in its splendour and especially in the internal reinforcements that represent the horizontal wooden elements in the constructions.

The most common damages seen in the territory, during our visits ten days, one month and four months after the latest earthquake in 2015 were:

- Problems of humidity and water from the interior to the exterior of the buildings, generally in bathrooms and kitchens. This erodes the structure of the masonry walls of earth, even reaching to rot and to undo the structures of the wooden reinforcement inside the walls.
- Changes to the original configuration, great opening and in inadequate locations that weaken the structural system.
- Separation of perpendicular walls, caused by the inefficiency of the anchoring system and reinforcement of the corners, mainly due to the presence of xylophages and the rotting of wooden elements because of their Exposition.



Figure 10. Rural abandoned church in Río Hurtado. Case with mass and horizontal ladders. State after the earthquake of 2015 (Amanda Rivera 2016).

- Absence of maintenance that provokes quickly deterioration process, the most typical the presence of excessive humidity (Fig. 10).

Other damages frequently encountered were vertical cracks at the junction of the wooden frame and the earthen mortar fill; this represents just the discontinuity between both materials, but neither a structural nor life-threatening problem (Jorquera & Baglioni 2011).

5 CONCLUSIONS AND PERSPECTIVES

The earthquake had its epicentre on the shores of the Canela commune, Coquimbo Region. The locality of the same name was closest to the epicentre, which is why most of the post-earthquake activities have been carried out in this locality: volunteerism, seminars, earthen murals, children's workshops, the Adobe Festival, and other activities. All of these activities have helped to reinforce the culture around the construction, to relearn the constructive techniques and to promote new reinforcement methods.

The traditional constructions have survived at least four major earthquakes greater than 8 Mw, but the lack of information and discontinuity of the constructive tradition have been the main threats to the preservation of the built heritage. Public policies reacting to catastrophe led to the demolition of structures by authorities without fully evaluating their state of damage, resulting in a number of families losing both their homes and their heritage.

In el "Norte Chico", due to the learning through experience of great earthquakes prior to 2015 in Chile (2005, 2007 and 2010) and to the strength of citizens' movements, protection and subsidy strategies have been implemented to repair damage built heritage in the area. Including achieving the protection of the epicentre town, Canela, as a *zona típica* by the Chilean Monuments Law, in addition to processing the same protection for at least two more important cities in the area.

The earthen construction culture of the area may not presently appear threatened, but it is of main importance to reinforce the culture and preserve the information to ensure the permanence of the built heritage of the territory, which has so much to teach the world about anti-seismic strategies.

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Tracking down constructive techniques: Farmhouses preliminary studies

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ABSTRACT: The text presents results about a preliminary study, undertaken in a couple of rural buildings scattered throughout the green belt of Valencia city (Spain), well known as an area featured by historic orchards and orange groves. The Alquería Falcó and Alquería Tallarròs are two ancient farmhouses, dating back to medieval origins that have changed through the centuries, maintaining their features in spite of decay and lack of maintenance. The study has tried to overcome typological approaches that have characterized expert studies in the 1980s and it has reached a first material characterization of the buildings, above all thanks to a focus on local construction techniques and on raw materials. This work, undertaken in the frame of Bachelor Final Projects, helps to preserve these two fragile buildings, considering that they are testimony of local vernacular architecture and they are examples of self-generated mechanisms linked with traditional architecture.

1 TOWARDS A CONSTRUCTION CHARACTERISATION OF VALENCIAN FARMHOUSES

On the outskirts of the city of Valencia, even in some neighbourhoods of the same urban grid, it is common to find very charismatic examples of traditional and rural architecture: the *alquerías* (farmhouses). These buildings are historically used as residential and service spaces, tied to the crops of the orchard, a large fertile irrigated area that surrounds the city.

They are agricultural estates with very heterogeneous construction characteristics that have continued to evolve over time, adding structures or workshops, covering new functions; places that today are frequently found in a serious state of disuse, abandonment and degradation.

Professionals, groups, institutions and the media are increasingly interested in the potential of these spaces, with regard to restoring the farmhouses with new uses (more or less orthodox), following a speculative or folkloric approach.

In many cases, preliminary studies conducted since the 1980s (Del Rey, 1983/2004) have deep historical, morphological and typological considerations, but only recently important traces of the material culture of the city and the Levantine region have been properly identified in these buildings. In this context, as outlined below, the main results of two preliminary case studies are presented: the Alquería Falcó (Romero Iglesias 2016) and the Alquería Tallarròs (Martínez Lledó 2016), located on the outskirts of the city. These buildings have been selected among others for their varied materiality, their construction authenticity, and for the possibility of studying several exterior elevations.

These are works that follow an academic approach, whose purpose is to design and execute a basic protocol to characterise the external surfaces, to identify construction variations in them, and to work out their material complexity (Cazorla Marín 2015).

Unfortunately, due to security and accessibility reasons, it has not been possible to study the inner parts of the buildings.

1.1 *The Alquería Falcó*

The farmhouse, located in the Poble Nou neighbourhood in the north of the city, features two main blocks: the manor house and the property administrator's house, as well as other service structures, distributed in a number of farmyards and patios, including a tower for the production of pellets (Fig. 1). The main façade, which points to a certain Herreran taste, built in the 17th century (1698 is engraved on the façade), homogenises the



Figure 1. Alquería Falcó (Romero).

set of much older stratified spaces, some of them dating back to the 15th century (Del Rey 2010).

The manor house has an access that is not located in the central axis of the floor but shifted laterally, leaving to one side the stairs to access the dwelling of the manor owners on the upper floor, while the ground floor is reserved to the services and the caretaker. This house is the one that has undergone the most changes over the years in its interior due to the different purposes it has served, a nursery school among them.

The second dwelling, located in the east wing and original structure of the Alquería Falcó, is the one that is destined to the tenant of the farmlands. This house indeed has its access axis centred in the floor; in addition, the ground floor is the one intended for dwelling in this case, while the upper floor is a typical dryer room of that period (Fig. 2).

1.2 *The Alquería Tallarròs*

Also located in the Poble Nou neighbourhood, in the north green belt of the city, this building in its original form follows the typology of a compact hamlet. The interest of this building lies in the construction study that has been carried out of its southern façade, where you can appreciate the evolution that the farmhouse has experienced, from being a single-nave structure with a shed roof, to a larger building, with a gable roof and a granary, now ruined and destroyed (Fig. 3).



Figure 2. Details of the material survey and decay survey, Alquería Falcó (Romero).



Figure 3. Alquería Tallarròs (Martínez).

With an origin that points to the 15th and 16th centuries, it consists of a primary bay parallel to the main façade (1629 is engraved on it) to which an attached structure has been added (Del Rey 2010). The access leads to a double-height space featuring a mezzanine with different living quarters and a large kitchen with a slightly lower elevation than the access, where domestic life is usually centred. Next to the kitchen is the holding pen, with several service spaces and low aisles added more recently.

2 THE FAÇADES: CHARACTERISATION OF THE CONSTRUCTION MATERIALITY

The study is mainly based on field work, aimed at the preparation of orthophotos and plans to make catalogues of materials, traditional construction techniques, and pathologies present in several façades of these buildings. Maps and charts help in extracting data and drawing conclusions, which in turn help to make possible conservation proposals.

2.1 *Understanding the masonry of two pluricentennial farmhouses*

The farmhouses have an incredible wealth of construction techniques and material, as a result of changes in agricultural and residential requirements (Fig. 4). A total of 11 traditional techniques may be identified in just two façades of Alquería Falcó, and 10 in the single south elevation of Alquería Tallarròs—additional factors to be taken into consideration for the conservation and recovery of these historic buildings.

In the two buildings, most techniques are related to wall construction (brick-supplemented rammed earth wall, brickwork wall, formwork brick wall, masonry wall and a few related repairs) and use

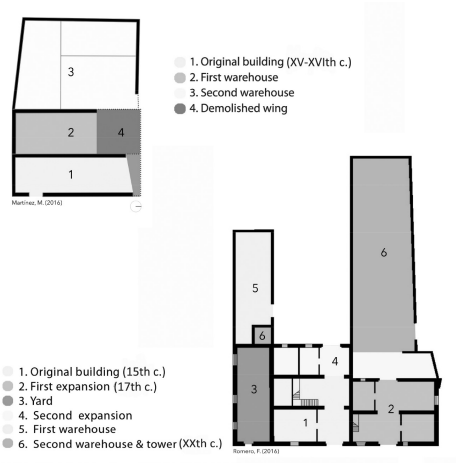


Figure 4. Constructive evolution of the two case studies. Alquería Tallaròs (upper) and Alquería Falcó (lower) (Romero-Martinez).

earth as a constituent material either in mortar or in component form. In both cases the constructions are characterised by simple volumes topped by pitched roofs with cladding tiles and ceramic eaves.

An interesting detail shared by both farmhouses is the use of the brick-supplemented rammed earth wall, typical of East Spain domestic architecture between the 15th and 16th centuries (Mileto et al. 2014, Martella 2014).

The brick-supplemented rammed earth wall consists of a lime-crusted and brick-supplemented rammed earth wall, with the bricks normally placed in header bond, placed against the formwork on the inside.

This addition increases the strength of the masonry and, most importantly, contributes to a greater interlocking of the assembly.

The bricks are laid out more or less regularly in horizontal courses. Each time a brick layer is tamped down, the lime mortar overflows and covers part of the brick (Cristini et al. 2010).

In the case of the Alquería Falcó, this expertise in the use of the formwork is evident in some parts with buttresses of brick formwork, specifically where the façade has been extended.

The mortars used are also worth mentioning because in the Alquería Falcó there is no cement in any wall (which indicates the age of these elements), but mortars of clay, earth, plaster, or a combination of these.

In the case of the Alquería Tallarròs the use of this material is limited to very specific patches of the eaves, given the presence of the original crusts of the masonry and the gypsum plaster of the brick walls (Fig. 5).

There are other interesting details to investigate, such as grates, arches with threaded bricks or wood lintels. The various openings do not date from the same time; they have been opened and covered up according to the evolutionary demands of the buildings and the varying purposes of the rooms, with arches for living spaces and wooden lintels for storage or service spaces (Fig. 6).



Figure 5. Details of the material survey and decay survey, Alquería Tallarròs (Martínez).

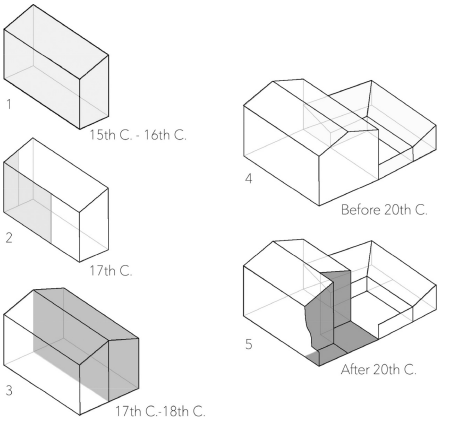


Figure 6. Matched scheme: Volumes and constructive elements, Alquería Tallarròs (Martínez).

2.2 *Material degradation*

The degradation issues of the two buildings discussed here mainly reside in the coatings, and it's worth emphasising that thanks to their level of degradation, many techniques may be observed that are left exposed, such as the threaded arches covering the openings of the three façades, or all types of masonry in which one can appreciate the bonds, the granulometry of the aggregates, and mortar types due to lack of coating.

A section of the Alquería Tallarròs has undergone a major demolition, and for security reasons it could not be included in the study.

However, the problems detected in the examined façade can be ascribed more to lack of maintenance and use than to issues in the execution, construction performance, or flaws in the installation.

The variety of materials and techniques employed (Figs. 7–8) is inevitably manifest in fissured areas with micro and macro cracks due to discontinuity of the materials used, differences in bonds, supports and layers.

The sequence of heterogeneous layers (three-coat plaster, parget, whitewashing…) leads to detachments, pulverisation and progressive loss of coatings that have been covered up for centuries.

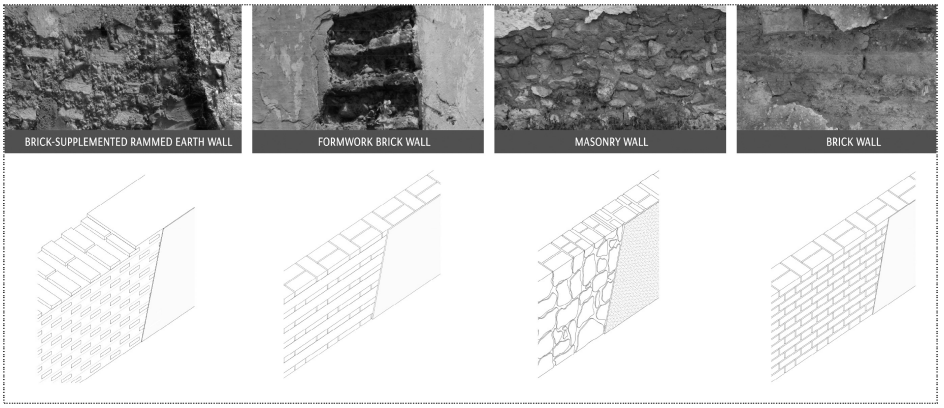


Figure 7. Details of material characterization Alquería Falcó (Romero). Differences between brick-supplemented rammed earth wall, and formwork brick wall.

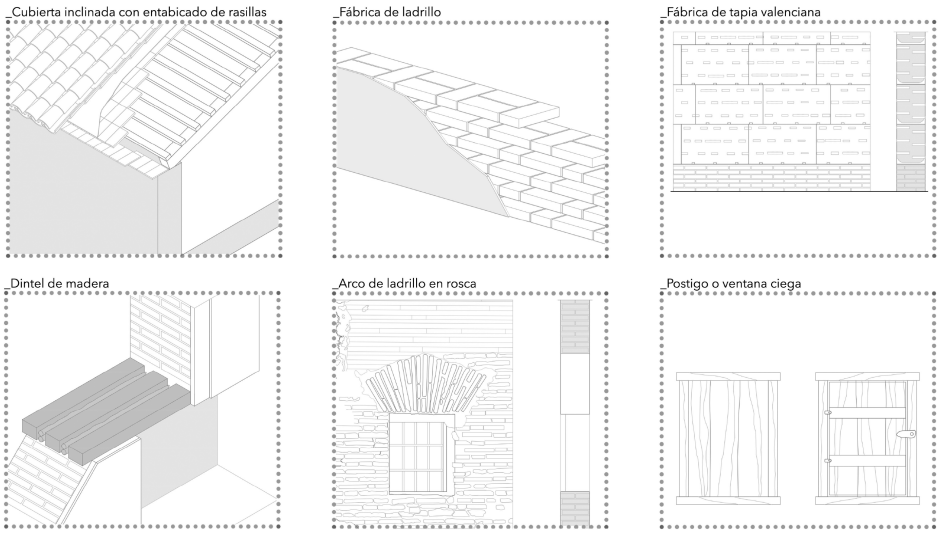


Figure 8. Details of material characterization, Alquería Tallaròs (Martínez). From topleft: details about curved aged-ceramic roof tiles over ceramic brick boards, formwork brick wall, brick-supplemented rammed earth wall, lintels, arches and wooden shutters.

3 CONCLUSIONS

In the *Catálogo de Bienes y Espacios Rurales Protegidos del Plan de Acción Territorial de Protección de la Huerta de Valencia* (Conselleria GVA 2010) there are references to the current problems of the historic heritage of the green belt.

According to this document, 72% of high-value heritage elements inventoried in the Huerta de Valencia are abandoned or in a serious state of degradation.

Unfortunately, all too often nowadays there exist devastated and abandoned buildings that have been subjected to various acts of vandalism, fires (as in the case of the Alquería Falcó), and numerous plun ders in the last decades, despite their status of catalogued and protected properties (Del Rey 2010).

Hence the need and importance of understanding these construction systems, in order to carry out rehabilitation or intervention projects that can be more thoughtful and focused on the construction reality and its effective diagnosis. Nowadays there is no witness of books, publications and texts that treat the Valencian farm-houses from the point of view of the constructive materiality. These two Bachelor Final Studies try to deepen and to advance this line of research.

Thanks to them the idea is to begin a possible cataloguing of the technics that exist in these (and others) buildings.

This has to make think about the limits of historical indirect studies and about the importance of constructive studies, based on stratigraphy of constructive phases and *in situ* survey works.

On the façades of both farmhouses are inscriptions that date back 'only' to the seventeenth century: 1698 is engraved on the façade of the Alquería Falcó and 1629 in the Alquería Tallarròs, while the detailed study of the construction techniques allows us to date these buildings through parts dating back to the late medieval period.

They're so frequent in the green belt of Valencia city, and it's so crucial "overcome "supposed dates of construction and historical studies.

Brick-supplemented rammed earth wall, bricks fabrics, lintels are common to both buildings, in spite of being typologically and morphologically different (Figs. 7/8).

In this frame the work tries to realize a real, practical and useful catalogue of constructive elements of the two farmhouses.

The different constructive systems have been analyzed depending on the methodology followed by each author of the Bachelor Final Works.

In the above mentioned catalogues we can appreciate always a brief description of the elements, pictures and constructive details for the complete understanding of the building technology.

NOTE

This work is part of the research project "Restoration and rehabilitation of traditional earthen architecture in the Iberian Peninsula. Guidelines and tools for a sustainable intervention", funded by the Spanish Ministry of Science and Innovation (Ref.: BIA2014–55924-R; main researchers: Camilla Mileto and Fernando Vegas López-Manzanares).

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Water-related built heritage in Campania, Italy. Knowledge for conservation of a sustainable vernacular architecture

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ABSTRACT: The paper illustrates an ongoing applied research on architectural structures, such as water and paper mills, that use water as their main functional component. The aim is to draw up an Atlas of architectural heritage with ancient hydraulic technologies, building techniques, and vernacular skills in the Campania Region in southern Italy. The authors assess natural and artificial components along with the buildings' materiality and vulnerabilities. They pay special attention to ancient infrastructures and systems for channeling water from nearby watercourses—such as aqueducts or canals—as well as how the mechanical equipment of preindustrial utility buildings worked. Starting from a more general backdrop, the paper focuses on the case-study of the Valley of the Mills in Gragnano (Naples), where 13 medieval mill buildings that formed an integrated system are still preserved, although they are at high risk of destruction. The authors' interpretation of the multiple components of this unitary heritage as a 'monument' in itself seeks to establish a basic framework for ongoing decision-making processes involving synergic actions aimed at the identification, preservation, and accessibility of water-related built heritage.

1 THE RESEARCH FRAMEWORK

Over the centuries, the life of communities has been inexorably linked to water, a natural key factor in the identity of landscapes. The satisfying of basic nutritional needs and the production of fundamental goods such as bread, paper, or textiles depended on the circular harmony between natural resources and empiric, efficient and sustainable decisions related to human settlement.

Starting from this general consideration, an ongoing research and teaching project of the University of Naples is investigating water-related built heritage in the Campania Region, in southern Italy. The project focuses particularly on forms of architecture whose existence and potential loss is actively and symbiotically dependent on the presence of water in landscapes from the Early Modern Age to the 19th century (Fig. 1).

Because of the mountainous nature of Campania with many valleys crossed by rivers, such as in Sannio, Irpinia and Sorrento-Amalfi Peninsula, ever since ancient times various systems of water management have constituted a precious source for the development of civilization. Many forms of lay or ecclesiastical rule or local community management significantly contributed to determine scattered forms of settlement in urban and rural milieus, both along the coast and inland. This settlement pattern was strongly dependent on water availability. During the 19th century, when water power was gradually replaced by steam and, later on, motor and electric power, human beings' relationship with nature changed and extensive industrial landscapes arose, while preindustrial factories gradually became relics of a bygone life.

The research starts from an awareness of the high risk of obsolescence and serious alteration inherent in the current lack of scientific comprehension of vulnerable paleo-industrial vernacular architectural heritage, which is constituted by buildings such as watermills, paper mills, tanneries, copper and ironworks, aqueducts, canals, and drainage systems, often simultaneously present in the same area and exploiting the same watercourse. Consequently, research questions seek to ascertain how the obsolescence of these buildings in many contexts, both rural and urban, was brought about by the sudden transition from preindustrial to industrial societies (e.g., through the electrification in mills) and the consequent abandonment of ancient manufacturing sites and architectures. If this kind of heritage owed its existence to its ability to satisfy primary needs in the past, what could its utility to contemporary communities be? Can study and reuse grant new roles to this heritage, a relic of past generations and skills which is slowly losing both its physical and its intangible identity?

The study approaches these themes from a comprehensive perspective embracing the *longue durée* of the history of this heritage and the progressive character of material culture. Under this regard,

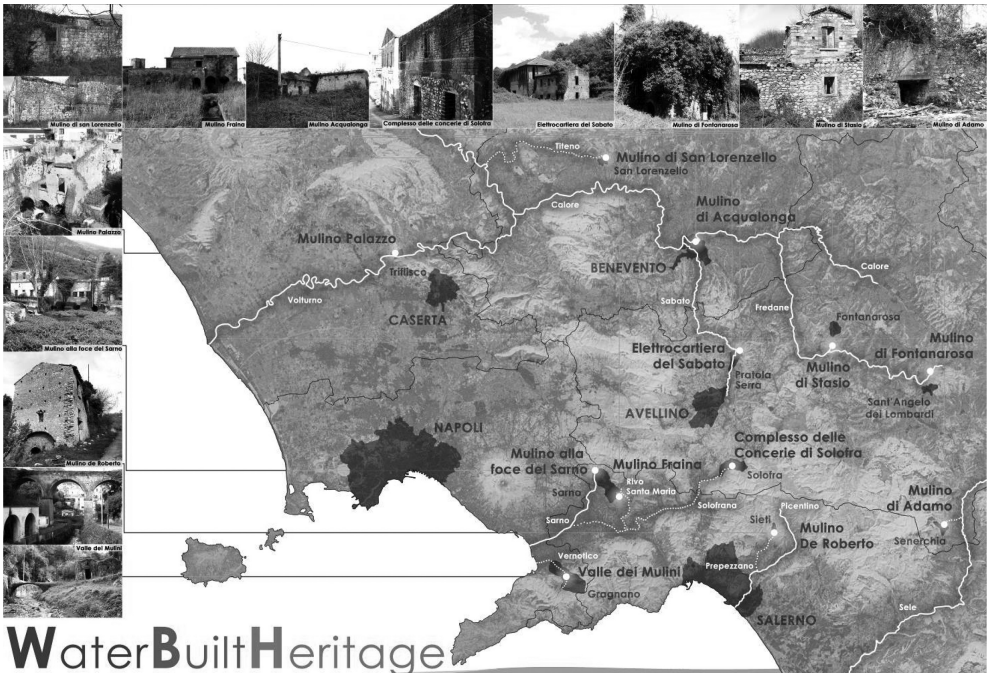


Figure 1. Campania (Italy). A synthesis of the case studies examined by the research on water-related built heritage. The attention is paid to water mills, paper mills, and tanneries in five Provinces in the Region (drawing by Zizzania P. & Romano L.).

water-related built heritage was not only a physical tool for the production of goods, but also an immaterial crossroads of knowledge, skills, and development and dissemination of experience handed down from one generation to the next and related to social dynamics in different areas.

We selected preindustrial systems—characterized by different natural factors and building traditions—according to both tangible and intangible criteria in order to establish a comparative framework.

Methodologically, to document the cultural dynamics that underpinned the relationships between the buildings under study and the use of water, the research combines on-site study with the collection and systematization of a rich database of information. Historical research in a number of contexts scattered across the five Provinces of Campania has been carried out, in order to gain a broad historical overview of construction and technical skills, historical trajectories, and contemporary risks. Archival and iconographic tools such as ancient land registers and assessments are extremely useful, as are historical photographs and oral testimonies.

Site-specific investigation relies on accurate dimensional and thematic surveys to highlight past and current uses or misuses, structural damages, and decay of building materials. These surveys help us to interpret water-related cultural heritage—constituted by 'architecture as landscape', ideas, traditions and skills –, understanding how individuals and societies use it today and used it in the past, how it was built or modified in various contexts, and which role it has had over the centuries. This may lead us to an understanding of the processes of socio-historical change that inevitably underlie changing uses of architectural heritage.

The ongoing research aims at defining an Atlas of *Historical Water-Related Built Heritage* in Campania with the primary goal of boosting stakeholders and local communities' awareness of the need for active protection of a vernacular heritage that is presently on the brink of oblivion.

2 A 'SUSTAINABLE' ARCHITECTURAL HERITAGE: THE CASE-STUDY OF THE VALLEY OF THE MILLS IN GRAGNANO

2.1 *The mill system in the cultural landscape*

The Valley of the Mills in Gragnano, at the starting point of the Sorrento-Amalfi Peninsula, where thirteen mills are still present (Fig. 2), is currently

the object of a significant experimental collaboration between scholars and policy makers.

Within the broad range of water-related built heritage in Campania, the Valley stands out as an especially significant case study due to its complexity as a system, and to the fact that this system is still largely preserved and well recognizable. Here the coexistence of natural elements and material vestiges of human activity is such that one can speak of a "cultural landscape" (Fig. 3), characterized by a combination of high environmental and botanic biodiversity and a rich palimpsest of hydraulic structures, aqueducts, canals, and water mills bearing witness both to the strategic role of the valley and to skillful human exploitation of natural resources.

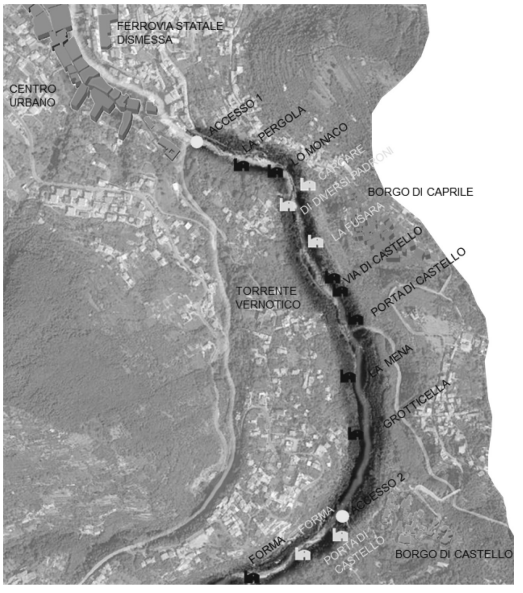


Figure 2. Gragnano Valley (Naples). Distribution of the mills along the Vernotico stream in relation to the urban settlements (drawing by Serrelli M. & Tesone D.).



Figure 3. Gragnano Valley (Naples), Grotticelle Mill. Here the relationship between architecture and the natural features of the ravine is particularly strong (by Serrelli M. & Tesone D.).

The site lies within the municipal boundaries of Gragnano, in the Province of Naples, on the north side of the Sorrento-Amalfi Peninsula, at the foot of the Lattari Mountains, but outside the limits of the Lattari Mountains Park. The Vernotico stream, originating from the Forma springs, runs along the bottom of this deep ravine, which ever since the Middle Ages was an important route between the north side of the peninsula and the Amalfi coast (Camardo & Notomista 2015).

Although some sources mention the existence of several mills in the valley as early as the High Middle Ages, a more reliable testimony dates the earliest of these preindustrial structures back to the second half of the thirteenth century. However, most of these mills were built in the seventeenth century, by initiative of the Chiroga family. By the eighteenth century, the Vernotico valley counted fourteen mills, activated by water conveyed by an aqueduct and several canals (Camardo & Notomista 2013; 2015). Another group of mills is reported around the end of the 18th century in the area of the hamlet of Caprile (Amirante & Pessolano 2009), which is still partly preserved nowadays.

In spite of its present state of abandonment, which started around the second half of the nineteenth century as a consequence of the rise of large-scale industrial production of pasta, the complexity of this mill system is still evident. What immediately strikes the viewer is the close relationship between the mills and the valley landscape, as well as their strong connection with the orographic and geophysical characteristics of the site. The buildings appear to be the result of an ability to adapt to specific environmental conditions, reflected in the use of materials found on site to build them. Where necessary, little bridges across the stream were added, and in some cases the mills are partly built and partly rock-cut. At the same time, this whole approach, which has given this place its character as an anthropized landscape, was and remains a major vulnerability factor.

The landscape of the Valley of the Mills is a renowned environmental heritage site, documented ever since the second half of the eighteenth century in drawings and photographs (Fino 1994; Naclerio & De Riso 2010). Today, a strategic conservation program is called for to keep it from losing its multilayered identity. Actions should be taken to mitigate landslide risk and the negative effects of the weather and high humidity on the vernacular material. At the same time, conservation actions should not compromise the particular physical and perceptive relationship between nature and the vestiges of human action that characterizes this place.

2.2 *Architecture without architects: building materials and techniques*

Any interpretation of the complex system of the mills in the Gragnano Valley should take account of the strong connections between populations occupying areas that are only apparently far apart within the Sorrento-Amalfi Peninsula and the consequent migration of building skills amongst them.

The historical connection of the valley to the town of Amalfi and the strategic proximity of Gragnano to the northern border of the Republic of Amalfi resulted in the importation of milling as well as the spread of typical construction techniques of the Sorrento-Amalfi Peninsula. There are evident similarities in plan, materials, and construction techniques between these small proto-industrial buildings, merging naturally and harmoniously into the landscape, and the rural architecture of the simple coastal dwellings of the Peninsula (Fiengo & Abbate 2001). Their adaptation to the natural surroundings, exemplified by the Grotticelle (Fig. 3) and Lo Monaco mills (Figs. 4–5), is a very common feature with the early vernacular architectures of the Peninsula, too.

The mills in Gragnano Valley are the vernacular result of a rigorous although empirical construction process whose conception did not involve a planner. The small buildings placed along the stream and connected to it by canals comprise single or multiple spaces covered by extradosed barrel vaults. In most cases they stand next to a water tower and a water main (Figs. 4–5).

The tower lies opposite the entrance and is built in either of two shapes, cylindrical, or with a rectangular base and a round top. The oldest ones are built of limestone ashlars—laid without taking care to vertical stagger the joins—or blocks of grey tuff about one meter thick. Although nowadays their interiors are not accessible, we can assume that they were waterproofed with a layer of lapillus or *cocciopesto* aiming at contrasting humidity.

Six of the mills lie next to the main stream, lengthwise or crosswise to it. The surviving parts of these buildings, which are built on arches, are made of limestone ashlars bound with a mortar composed of lime and volcanic rock inclusions.

The construction material—limestone ashlars (between 5 and 45 cm) or grey tuff blocks—is an especially evident feature that the Gragnano mills have in common with other traditional buildings in the Sorrento-Amalfi Peninsula. In some cases, the masonry was evidently built in successive sections ('yards') between larger and more regularly shaped blocks in the corners. These features are made clear thanks to stratigraphic interpretation, which is very useful for understanding the evolution of architecture when few archival data are available (Fig. 6).



Figures 4–5. Gragnano Valley (Naples), Lo Monaco Mill, northern façade and plan (drawing by Vannelli G. & Zizzania P., Course in Laboratory of Restoration, Dept. of Architecture, University of Naples Federico II, September 2016).

The vaulted ceilings of the Gragnano mills are built of limestone ashlars or—only in later buildings—of grey tuff. The extrados is covered by an impermeable layer of 'beaten lapillus' made of *lapilli* mixed with lime and *pozzolana* (Fravolini et al. 2008; Ceniccola 2014). Remarkably, the same materials and construction technique are used in small coastal buildings in the fjords of Furore and Crapolla in Amalfi coast, known as *monazeni* (Vitagliano 2014).

According to Roberto Pane, extradosed vaults were used in areas where timber for construction was scarce, while excellent materials for vaults, such as *pozzolana*, lapillus and volcanic *scoria* were available (Pane 1936). The pitched roof is indeed essentially absent in construction in the Sorrento-Amalfi Peninsula in Medieval and Early Modern times. This is also true of the Gragnano area, which, although it lies inland, was strongly influenced by the culture of the neighboring coastal settlement. The use of arches and vaults is thus the key feature in these forms of architecture, whose walls largely appear as the result of a sculptural process.

2.3 *The hydraulic system*

Gragnano was served by an extensive system of aqueducts branching out from three springs:

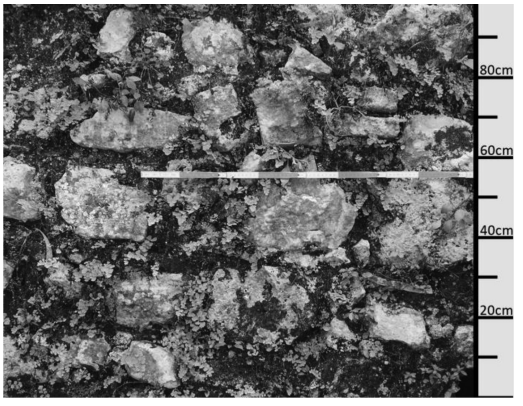


Figure 6. Gragnano Valley (Naples), Lo Monaco Mill, northern façade. Sample of masonry in irregular limestone blocks with lime mortar (drawing by Tregrossi C.).

Forma, Acquafredda, and Imbuto (Camardo & Notomista 2015). Built in the early seventeenth century under the impulse of the Chiroga family (Camardo & Notomista 2015), to bring water both to residential areas and to the mills, various sections of these aqueducts are still visible today.

A map dating from 1748 (*Pianta topografica formata per ordine dell'illustriss Sign Luigi D'Antonio Chiroga Nob Patrizio della città di Lettere*) reproduces the hydraulic system of Gragnano in the mid-eighteenth century, showing both the aqueducts and the mills. Some ruins of the mills marked in this map are still to be seen in the Valley, concealed in the thick vegetation near the Lo Monaco Mill, where a building with arches looms six meters above the ground. More vestiges of aqueducts run along the current path granting access to the Valley, or extend into the riverbed of the Vernotico stream.

These aqueducts are built on arches or walls only where there is not enough slope to keep the water flowing. Their height varies as needed, sometimes even exceeding ten meters. When the gradients are sufficient, instead, they consist of stone channels or are merely dug into the ground (Fig. 7).

Minor channels branch out from the main aqueducts to carry water to the mills while other channels drained away excess water from the mills. The inflowing water was conveyed to a tower (Fig. 8). Its height and its downward tapering inside caused the water pressure to increase as it flowed, through a stone channel or copper or wood pipe (*doccia*), into the base compartment (*carcerario*) to drive the wheels (Cinque 2013).

The walls of the base compartment are thickened or buttressed to withstand the water pressure in the cylinders.

Since during low-flow periods there would not have been enough water to turn the wheel blades, accumulation tanks would have been needed along the aqueduct and before the first tower. The Chiroga Map indicates the presence of such tanks in the Gragnano mill system, although they have not yet been located in the field. As in other mill systems in the Campania Region, the tanks were also used for the storage of water to irrigate the fields (Milante 1836) against the payment of a fee to the owner of the water.

The wheels, equipped with concave blades, are connected to a crankshaft coupled to a mill-stone placed in the upper compartment, where the grain was ground. As almost everywhere else in Campania,

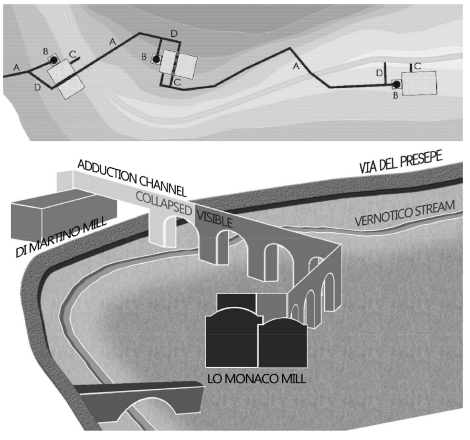


Figure 7. Gragnano Valley (Naples), operating scheme of the aqueduct system: A—adduction channels; B—towers; C—discharge channels; D—connecting channels (drawing by Tregrossi C., Course in Laboratory of Restoration, Dept. of Architecture, University of Naples Federico II, 2016).

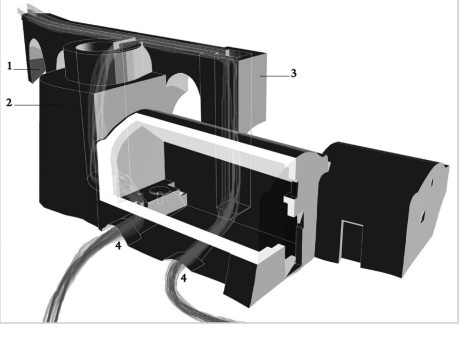


Figure 8. Operating scheme of the Lo Monaco Mill in Gragnano: 1—aqueduct; 2—first tower; 3—second tower; 4—*carcerario* (drawing by Tregrossi C., Course in Laboratory of Restoration, Dept. of Architecture, University of Naples Federico II, 2016).

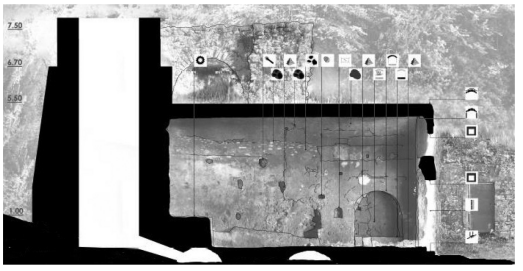


Figure 9. Gragnano Valley (Naples), Lo Monaco Mill. The longitudinal section shows the position of the tower (not accessible for surveys) and the underground discharge channels at the bottom (drawing by Vannelli G. & Zizzania P., Course in Laboratory of Restoration, Dept. of Architecture, University of Naples Federico II, September 2016).

the mills employ horizontal instead of vertical wheels, which would have required a constant flow of water. The system is designed to deal with variations in the water supply, since a mill needs to be fed regularly to work appropriately, without wasting energy or grain (Cadolini 1835: 443).

Since excessive water pressure might damage the building, there is a second tower, usually smaller in size, which helped to drain the water in the *carcerario*. Between the two towers was a metal or wooden sluice, which would be lifted when water needed to be drained into the second tower. After having activated the horizontal wheel, the water was finally conveyed through earth or stone channels back into the Vernotico stream (Fig. 9), or next to the mill in order to cyclically restart the process.

3 CONCLUSIONS

According to the first results of our research, a heritage-conscious project for the conservation and enhancement of the rich water-related built heritage of Campania should be characterized by a multiscalar and multidisciplinary approach. Consequently, any project to restore these historic buildings should be underpinned by an awareness of the fundamental relationship between their architecture and their natural surroundings, and strive to preserve this relationship. In particular, it is necessary to enhance the theme of 'water', in the tangible and intangible sense of the word, as a common thread connecting all regional water management systems, while focusing, at the same time, on the specificity of hydraulic mechanisms, on vernacular details, and on the construction techniques used in each building.

Such an approach could help to include these fragile vestiges of preindustrial buildings, now regarded as mere relics of a bygone lifestyle, into a broader cultural network, allowing them to be actively preserved through adaptive, sensitive, and inclusive contemporary uses.

NOTE

Although the present paper is the result of a common research, Par. 1 was authored by V. Russo, par. 2.1. by S. Pollone, par. 2.2. by L. Romano and par. 2.3 by G. Ceniccola. The conclusions are by all the authors.

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From vernacular to contemporary: Kilwa (Tanzania) and Albreda (The Gambia) tourist information centres

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ABSTRACT: Over the last few years the number of architects engaged in the search for solutions to address our planet's critical situation, has been happily increasing. While most of the research has taken the path of innovative technology, CRAterre and other teams have turned towards the knowledge that each culture has developed over the centuries to extract the intelligence it can provide in terms of sustainability. This paper presents two buildings that have drawn inspiration from local heritage, one in Albreda, The Gambia, and the second in Kilwa, Tanzania. Both buildings are tourist information centres connected to World Heritage Sites. They aim to demonstrate how vernacular architecture contributes to socio-economic development while protecting cultural landscapes. In both cases CRAterre organised participatory design workshops with local craftspeople and tourist guides, to search for clever architectural features before deciding which materials and spaces they would like to have in their new buildings.

1 INTRODUCTION

This article analyses the sustainability of two recently built information centres in Africa. The first one is located in Kilwa, Tanzania, and the second one in Albreda, The Gambia (Fig. 1). Both structures are connected to World Heritage sites where massive old stone structures dating several centuries back, blend with humble vernacular earthen architectures of today. In the two communities, skills to handle these two architectural typologies are still alive and well mastered. The Tanzanian and Gambian craftspeople are equally comfortable either building new houses with local resources or conserving old stone monuments.

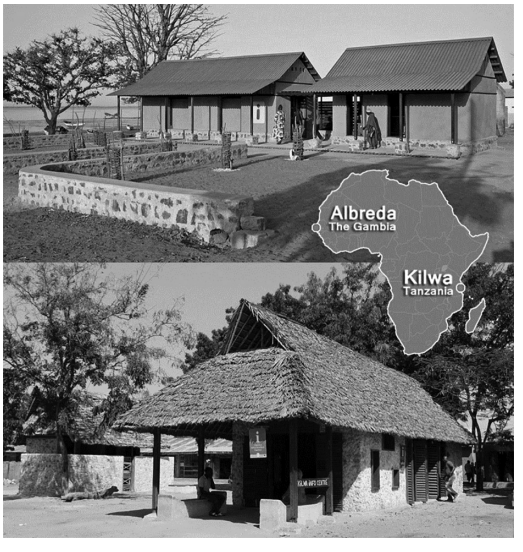


Figure 1. Location of Albreda and Kilwa information centres.

Vernacular architecture is restricted to available resources, which leads to more thoughtful design. It takes full advantage of each individual's potential and promotes his connection to the community, spreading best solutions and opening to further evolutions. Results are greatly adapted to particular means, needs or desires. Analysing the vernacular culture of a place to reinterpret it in the contemporary context has proven to be a solid method to create more sustainable buildings.

These projects not only have a visitors reception role, they also strive for a better recognition of the local building genius. They seek to showcase African construction talents by producing quality buildings with well-executed construction details using as many local resources as possible to contribute to the sustainable development of their area.

The direct involvement of local communities promotes greater collective awareness of the cultural and natural values. This idea applies not only to the construction process, but also to the design stage.

2 PARTICIPATORY PROCESS

2.1 *Sustainable local architecture*

One of the goals of both projects was to come out with designs that do not simply mimic old buildings.

The architects wanted to achieve something distinctly contemporary and appealing for visitors, yet familiar for the local population. It was important to pay tribute to the genius of the local architecture and to demonstrate the value of this heritage in terms of sustainability (Guillaud et al. 2014). The projects also wanted to showcase that alternatives to industrialised products exist. Nevertheless, both projects integrate some industrial materials such as cement, nails or electric fittings that were locally available.

2.2 *Participatory inventory*

The first step was to inventory the existing architectural typologies, techniques and materials available. To do so, field trips were organised with the participation of key stakeholders, not by the architects alone. In Albreda-Juffureh for example, a two-days participatory workshop gathering 40 people including masons, carpenters, guides and civil servants was organised. Participants were introduced to sustainable architecture principles and then split into 3 groups to hunt for clever details still available in the village (Figs. 2 and 3). One group was focussing on walls, another on roofs and the third on details and comfortable atmospheres. They spent a whole afternoon observing and taking pictures on the field, and on the second day each group presented a selection of images and ideas that could be integrated in the information centre. Thanks to intensive group discussions, by the end of the workshop solid foundations for the architectural concept were compiled, and the architects involved had enough material to finalise the drawings.

2.3 *Learning from local craftspeople*

In Kilwa, the process was similar but the group smaller. For one week, the architect worked on the design through work sessions with tour guides and craftsmen. Details were discussed and local references tracked on site, and so his first sketch evolved gradually integrating ideas coming from all stakeholders (Figs. 4 and 5). A 3D modelling software facilitated the immediate inclusion of every new suggestion, as if the contributors were drawing themselves (Fig. 5). The final design showcases the collective intelligence of 15 people.

Architects also tried to provide room for further creativity. For instance, the roof of Kilwa Information Centre was built by a skilled and creative thatcher. During the construction, he was able to suggest several details that were not on the original drawings. He, together with the architect, was able to improve the roof during the construction process. Another innovation of this building was the use of locally woven mats as ceiling boards. This was not in the original plan neither; the idea came out while looking at women weaving these mats in the village.

2.4 *Architectural design*

For both projects, designs were deliberately kept simple. Every construction element can be technically understood when looking at the building; there are no hidden details apart from the underground foundation. This is to ensure that builders can easily duplicate what they see (Figs. 6 and 7).

These participatory design processes have ensured ownership of the structures by the local population. No one actually claims paternity of the design, not even the architects (Arnaud Misse for Kilwa / The authors for Albreda), because many people can recognise themselves in the whole



Figures 2–3. Albreda: Walk in the village to hunt for clever architectural and landscape features.



Figures 4–5. Kilwa: Discussing details on site with future users and using 3D software to design with craftsmen.



Figure 6. Kilwa Information Centre under construction.



Figure 7. Albreda Information Centre under construction.

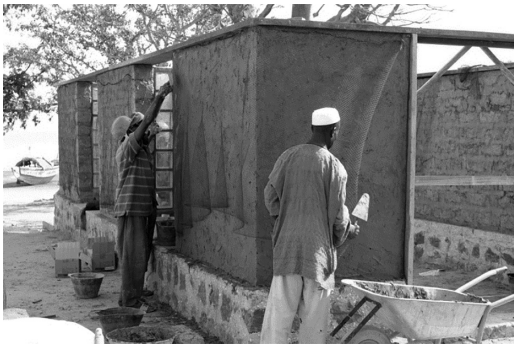


Figure 8. Fishing net to reinforce lack of clay in the soil.

layout or in specific details. The architect's role was to turn people's ideas into drawings, not to dictate his ideas as an untouchable creator.

2.5 *Building in phases*

The construction of Albreda Information Centre was deliberately developed in two phases. This allowed to improve logistics organisation of the second construction phase, as well as to reinforce several construction details after the rainy season, which brought unexpected strong winds that even blew off a tree and the roof of a nearby building. The information centre withstood the test of storms, but a few details had to be modified, taking advantage of best practice examples.

Also the finishing and furnishing of Kilwa Information Centre was done a few months after completing the structural works. This allowed users to more clearly define their needs and so the building enjoyed a more accurate completion.

It is also remarkable to mention that in Albreda, fishermen and women who work near the building as well as some tourist guides, who actually form part of the principal future users of the building, participated in its construction on a voluntary basis.

3 ENVIRONMENTAL IMPACTS

3.1 *In respect of nature*

Significant green gas emissions arise from the transportation of building materials from the production plants to the construction sites. To avoid CO2 emissions, materials were sourced as much as possible in the villages, where much of the transportation was done with donkey carts (Albreda) or sailing boats (Kilwa and Albreda). In order to decrease embodied energy rates, the use of imported industrial materials was deliberately reduced to a minimum, and mainly where no equivalent materials were available in the village. In Albreda, for example, the soil lacks clay. Instead of replacing the adobes with cement blocks, the earth plastering was reinforced with fishing nets to increase its tensile strength (Fig. 8), and with lime to improve its resistance against rainwater. The use of cement was limited to the slabs only. The same occurred in Kilwa, where cement was also used for foundations because time was a limiting factor and cement blocks were available. However, in this case transport was not much increased as cement is directly produced in Kilwa.



Figure 9. Wood-raffia-earth ceiling blocking the radiating heat of the roof in Albreda Information Centre. Ventilation holes were left in the adobe wall below and above the ceiling.

3.2 *Taking care of inhabitants' health*

The use of iron sheets to cover the Albreda Information Centre is justified considering that they have been recycled from the old warehouse building, which had to be demolished because it was incongruous and was under serious risk of collapse. The low insulating capacity of metal roofs was improved by installing a traditional ceiling system consisting of one layer of raffia sticks covered with a cotton cloth and a thick earth layer (Fig. 9). In addition, some ventilation holes located below the ceiling help release the excess of hot air.



Figure 10. Use of locally woven mats as ceiling boards in the guides' office in Kilwa Information Centre.

Many more ventilation holes were inserted in the adobe walls, already well known for their good hydrothermal behaviour. Both elements, earth blocks and ventilation holes, are features of the traditional architecture. Vernacular houses also have a veranda to protect people and the building itself from weather severity, either against excessive sun radiation or strong rains. In Kilwa, local mats replaced industrial ceiling boards (Fig. 10). Finally, both buildings left no construction waste behind because all materials were used in one way or another.

4 SOCIO-ECONOMIC IMPACTS

4.1 *Heritage and its economical potential*

The construction of these buildings was only one of several activities programmed as part of wider Action Plans. The main objective of both projects was to develop a "sustainable tourism product" encouraging more visitors to stay longer and therefore increase benefits to the population. For that, the Action Plans focused on the inventory and promotion of all heritage resources available aside from those inscribed on the World Heritage List. As avowed in the Ngorongoro Declaration (Arusha 2016), the idea is that when local populations are directly employed for the promotion of their natural and cultural heritage, they would be the first ones willing to protect and preserve it (Fig. 11).

4.2 *Raising local economy*

Another pillar of both projects was the development of a sustainable economy for the people of Kilwa and Albreda, to have positive socio-economic impact on their territories. If local labour is to benefit from the construction, the premise of relying on local techniques is basic. In the case of Kilwa, 82% of the money injected ended up in local pockets, 57% as labour and 25% as materials production (Fig. 12).

Albreda statistics show that the percentage is reduced to 49% (half of it as labour and half as materials production) because of an excessive dependence on timber brought from Banjul, which is 35 km away.

The production of construction materials was intentionally diversified in order to fairly split the benefits derived from the construction. This idea also helps increase the potential availability of local craftspeople whenever repair or periodical maintenance works are needed.

In addition, both projects integrate spaces dedicated to the sale of local craft products that ensure fair trade and avoid the exploitation of endangered natural resources (Fig. 13).



Figure 11. Kilwa tour guides promoting their heritage resources to visitors in the information centre.

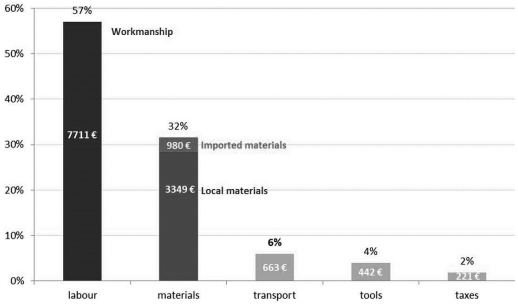


Figure 12. Distribution of expenses for the construction of Kilwa Information Centre.



Figure 13. Selling local Arts and crafts in Albreda Information Centre.

5 SOCIO-CULTURAL IMPACTS

5.1 *Ancient building traditions*

Both projects benefit from the skills developed many centuries ago and still in use. For instance, the stones of the foundation and basement of Albreda Information Centre are bonded with the lime that is manufactured by burning shells on the South shore of the Gambia River. The same occurred in Kilwa, where lime is produced after burning dead coral stones on Songo Mnara Island, as they did for the construction of outstanding heritage buildings such as the Great Mosque dating back to the 10th century.

5.2 *Everybody is aware*

From the very first day of the construction, some information panels were installed at the construction sites to inform locals and visitors about the nature and architectural features of the building. This allowed everyone to understand the purpose of the projects and helped exchange opinions (Figs. 14 and 15).

These information centres were thus naturally adopted by the entire population, without forcing them to come, without any kind of advertisement.



Figure 14. Information panel in Swahili installed in front of Kilwa Information Centre during construction. The site was open to visitors.

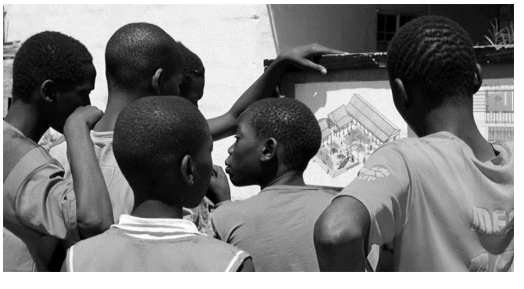


Figure 15. The exhibited plans of the information centre being discussed by a group of kids from Albreda.

Kilwa Information Centre has indeed become a cultural centre dedicated to heritage and tourism.

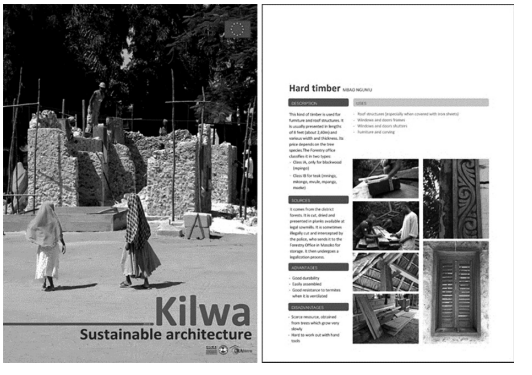
5.3 *Intercultural debate*

Although no local research teams such as technical schools or universities were involved, which would have been a good opportunity to help develop the ideas of sustainable architecture and further employment, the link between conservation and contemporary construction through trained craftsmen was evident. They demonstrate the genius of today's local craftspeople as much as the old ones. The use of ancient techniques mixed with vernacular ones, such as the roof of Kilwa Info Centre, motivated an interesting debate on contemporary vernacular architecture and its so rich and diverse expressions. But instead of academic environments, this debate was produced in the very heart of the building. Whether sitting in the long veranda of Albreda centre or in the Swahili front *baraza* in Kilwa, these information centres are deliberately porous to let people come in, sit and discuss about heritage issues. From the design stage to the construction process, the layout of these buildings encourages intercultural exchanges. Guides are proud to explain "their" building to anyone coming to visit. As a result, both projects present a strong cultural identity.

A document entitled *Sustainable Architecture in Kilwa* was published after the project (Figs 16 and 17). It describes the construction process of the information centre, and presents information sheets on the fourteen local materials available in town, their uses and advantages. It aims to raise awareness on sustainable development and inspire other builders, either from the private or the public sector.

5.4 *Involving authorities*

Albreda project was entirely funded by the Government of The Gambia; therefore finances were



Figures 16–17. Kilwa Sustainable architecture publication.



Figure 18. Ministers and Directors visiting Albreda Information Centre during the 2016 Roots festival.

managed by two government institutions, tourism and culture, working in collaboration. Authorities have taken ownership of the building and feel so satisfied about it that they have expressed their desire to build their own houses in the capital city Banjul with the same materials. They have presented the information centre as a living museum within the Roots Festival (Fig. 18), and published two articles where the Ministry describes some features and advantages of building this way.

6 CONCLUSION

These buildings serve various purposes at various times, including functions that came naturally, without being planned. All kinds of public were invited during the design and the construction processes: fishermen, villagers, tourists, kids and craftspeople. The possibility of permitting people entering and discussing at any stage of these projects, together with a deliberate permeable layout of the buildings, allowed for taking into account many people's ideas, and made these buildings become a rewarding result of a collective effort.

These projects have changed the minds of local authorities about local materials and vernacular architecture, including local urban planners. If the wealthiest layer of a society approves this architecture as a good option, others are likely to follow. The approach of these two projects favours the expansion of a more sustainable development and helps dignify local architecture as the best departing point of inspiration to regain balance between humankind and nature.

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Passive design principles in vernacular architecture of Castilla-La Mancha, Spain

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ABSTRACT: In hot dry or warm humid climates, more than half of the urban peak load of energy consumption is used to satisfy air-conditioning demands alone. The pressure placed on energy resources to satisfy the future requirements of the built environment will be huge, unless more effective measures can be introduced. Most of the political and economic efforts are currently focused on how to build according to passive design principles and using XXI Century building technologies, but eventually it is forgotten that vernacular architecture design strategies constitute a big knowledge background. This paper demonstrates via a vernacular architecture study case of Castilla-La Mancha, how this type achieves most of the requirements of the passive design principles. The validity of the constructive resources used in Castilla-La Mancha vernacular constructions shows that they can be as valid or better than those provided by other construction solutions employed today.

1 INTRODUCTION

In 2014, buildings sector reached about 38% of the final energy consumption in Europe. Residential buildings were responsible about one quarter of this final energy consumption, being non-residential buildings responsible about the remaining 13% (Eurostat 2016). One of the ways to reduce the energy use in buildings is to consider the implementation of passive strategies in the building design, what leads to a reduction in the energy demand for both heating and cooling (Suarez & Fragoso 2016). The European Commission has proposed long-term targets for energy demand reduction and countries throughout Europe are introducing a range of policies to deliver that reduction (Sorrell 2015). Under the Energy Efficiency Directive, Member States have already developed National Energy Efficiency Action Plans setting out actions to reduce demand for heating and cooling (European Commission 2016).

Bioclimatic passive design tries to reconcile energy saving issue as well as the associated environmental impact reduction with the quality of the environment inside the buildings (Cañas et al. 2011). Even if policies focused on the energy demand reduction have entered into force relatively recently, vernacular architecture based on bioclimatism concepts has been developed and used through the centuries by many civilizations across the world (Singh et al. 2009). Since vernacular architecture was performed by the people as a direct response to their needs and values, these buildings show a greater respect for the existing environment. They do not reflect theoretical aesthetic pretensions and use local materials and techniques, repeating throughout history models which take into account the constraints imposed by the climate (Coch 1998).

By applying the six main principles developed by the Passive Design Guide for the Built Environment (Alonso et al. 2014) to a selected vernacular dwelling case study, this paper will prove that some recent relevant achievements in the field of bioclimatic architecture can be considered as lessons derived from vernacular heritage.

2 METHODOLOGY. PRESENTATION OF THE CASE STUDY

The Passive Design Guide for the Built Environment was conceived as a tool to establish a guidance which enables the achievement of the energy consumption reduction goal in buildings by means of energy demand limitation. By prioritizing the use of passive solutions that take advantage of the climatic and the surrounding conditions, the guide contributes to reach users comfort and also promotes economic savings for them (Alonso et al.



Figure 1. Case study main façade ©Google.

2014). Although the guide is envisaged to serve as a starting point for decision making in early stages of the building design, it is also possible to observe if these passive strategies were employed in a building already built and, therefore, if the mentioned principles were taken into account for this existing building design.

For this research, the methodology selected has been the second one. That means to make an exhaustive and comprehensive analysis of an existing case study to identify what passive strategies had been previously considered during its design and construction, as well as how these passive strategies have been applied. The selected case study is a current single-family dwelling between party walls located in the old town of Argamasilla de Alba, a small location in Castilla-La Mancha (Spain) (Figure 1). It was built in the eighteenth century and numerous refurbishment works had been undergone since then, according to the different needs and uses required by the occupants over the time. The choice of this dwelling as a case study is due to the fact that it constitutes a representative example of both the popular housing and the vernacular architecture in La Mancha. The characteristics on this building typology are analyzed below.

3 DISCUSSION OF RESEARCH RESULTS

3.1 *Main principles in the passive design*

The Passive Design Guide for the Built Environment proposes a valid methodology for analyzing the applicability of the most adequate passive strategies at any geographical location regardless of the building typology. The six main principles developed throughout the guide take into account a series of previous general recommendations related to the location and the architectural design of the building, which should be reconsidered by their importance in the energy efficiency ("*DIS*–General building design" and "*MET*–Improved thermal envelope" principles). Since suitability of a passive system for a particular site depends on the climatic conditions of the location and on its geographical characteristics, different instructions for checking the suitability of the cooling and heating strategies are provided ("*CS*–Solar heating", "*PS*–Solar protection", "*V*–Natural ventilation" and "*TA*–Air treatment" principles) (Alonso et al. 2014). These main principles are explained below:

DIS. Considerations about the location, shape and orientation of the building are decisive for capturing the sun radiation and taking advantage of it.

MET. The building thermal envelope is composed of all enclosures and partitions limiting living spaces from the outside or from the non-habitable spaces. An adequate design, including layers of thermal insulation and inertial elements, is essential to ensure the efficiency of other passive strategies.

CS. Only through the different building elements design and composition, it is possible to employ solar radiation as an energy source to increase the interior temperature of the building in the cold months.

PS. To avoid overheating caused by an excessive solar radiation, there are several systems whose aim is to protect the building envelope from sun impact, especially in heat periods where thermal gains have negative effects to achieve interior comfort.

NV. In natural ventilation, air renewal is exclusively produced by wind action or by the existence of a temperature gradient between the air entry and exit points.

TA. Air introduced into the building can be pretreated to reduce its temperature or to increase its humidity degree.

3.2 *Vernacular architecture in Castilla-La Mancha. The traditional house typology*

The selected study case is a typical vernacular house in La Mancha. The traditional dwelling in this region arises in response to the need of housing people and, additionally, for tools and agricultural products storage and for animals' husbandry (Jerez García & Sánchez López 2002). The ground floor scheme is constituted, therefore, by two adjoining parts: one intended for housing and another relegated to work. An absolute segregation of functions in both areas is not fixed, since in the dwelling zone it is usual to find spaces related to work—as a winery or cellar-cave in the basement. Both housing and working parts are organized around an open free space. While the house dependencies are usually

distributed around a central courtyard called *patio*, the work area does around a wide barnyard—the *corral*- which in most cases has direct access from the street, provided with a wide wooden doorway capable of allowing vehicles called *portada* (Flores López 1974) (Figure 2).

Houses are usually two-storey with access through a hallway. This piece leads to the *patio*, which is in most cases flanked by the kitchen. A corridor connects the remaining rooms and sometimes also the cellar-cave, although its common access is from the *patio*. Regarding to the constructive system and the materials employed, earthen walls support wood beams and the elements which configure the double-pitched ceramic tiled roof (Feduchi 1976). One or several tiles layers are hanged space onwards of the facade plane (García Mercadal 1981). In the facades, the opaque part predominates over the openings, who do not obey any aesthetic criteria; they are arranged according to the interior distribution conveniences (Fisac 1985).

3.3 *Application on the case study of the principles in the Guide*

3.3.1 *General building design (DIS)*

As already mentioned, the selected case study is integrated into a consolidated urban plot (Fig. 3 and 4). The urban plot density will vary depending on weather conditions. In this case, houses are crowded together to achieve thermal protection and to form a dense structure for shading, which shows that it is possible to find in an urban layout



Figure 2. Case study. *Portada* ©Google.



Figure 3. Case study plan ©Google.

the same characteristics and tendencies that have influenced the building design (Olgyay 2002).

Regarding to orientation, even if in this case the building location is not the most favorable one, a less suitable position can also be improved by taking into account measures for satisfying the other passive design principles. As a matter of fact, other studies indicate that more than a 60% reduction in energy demand could be achieved (Jones et al. 2014).

3.3.2 *Improved thermal envelope (MET)*

In this case, the principle Improved thermal envelope was applied using high thermal inertia walls: earth walls. Earth walled building has been common in different regions of the world (Heathcote, 2011). According to recent studies, the energy for construction and maintenance of an adobe house is much lower than the energy needed for a conventional one, with an energy payback of 1.54 years (Shukla et al. 2009). Earth offers a great variety of sustainability criteria as a building material, like unlimited supply—it is possible to use land from the excavations themselves too, which favors the reduction of the transporting material costs—and simple production processes—without a high energy combustion consumption such as bricks and concrete-. It does not generate either toxic emissions during its service life, discarded waste materials can be returned in place and the demolition of an earth element can be done with mechanical means no needing excessive energy (Bestraten et al. 2011).

In addition to its sustainability benefits, rammed earth is characterized by its thermal inertia and excellent hygrothermal behavior (Von Mag & Rauch



Figure 4. Case study scheme. Own elaboration.

2011). The advantage of this material has always been attributed to its resistance to a cyclic heat input, the so called thermal mass effect. The argument is that the high thermal mass of earth walls delays the passage of heat through them in summer and in doing so the magnitude of the internal temperature fluctuations is diminished (Heathcote 2011).

The window opening is also one of the most important elements on the thermal envelope, since it is more sensitive to external conditions as the opaque part. Window openings will be analyzed in more detail in solar heating and solar protection sections.

3.3.3 *Solar heating (CS)*

Solar radiation received by window openings can contribute to decrease heating needs in winter. Depending on the altitude and latitude characteristics of the location, and on the window geometric characteristics, solar contribution through window openings can be an important conditioning strategy (Larrumbide & Bedoya 2015).

In La Mancha traditional architecture as it is seen in this specific case, a common solar gain space is the greenhouse (Figs. 5–6), which works as an isolated element attached to the upper building floors. Through the creation of a glazed space connected to a habitable area, this space works as an amplifier of the thermal oscillations of the outside (Martín-Consuegra 2006–2008).

3.3.4 *Solar protection (PS)*

Although this principle can be generally applied to the building envelope, in this case study the solar protection is focused on building openings (Manzano-Agugliario el al. 2015). Solar protection elements effectiveness largely depends on their position relative to the facade opening. The most effective systems are those blocking solar radiation from outside, before heat penetrates the building interior (Alonso, et al., 2014). These are the systems employed in this case study (Figs. 7–8).

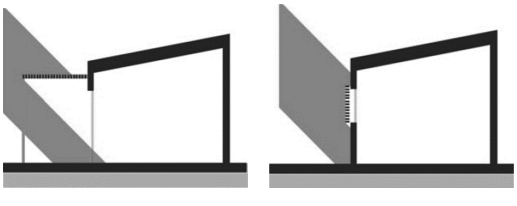
When correctly applied, vegetation can greatly reduce the need for internal and external shading devices. Selective planting can shade not only windows and other apertures but also whole facades and roofs, reducing conductive as well as radiative heat gains. Strategic vegetation around a building and on structures such as pergolas and beam overhangs can help to modify the microclimate (Stack el al. 2002). As a transition space, the one originated under the pergola prevent solar exposure radiation from heating the high inertia earth walls (Ferreira Vaz et al. 2015). This measure is also analysed below, in the air treatment section.

Solar protection elements adjustable for users play also an important role in the case study. The awning covering the access courtyard works as a protective moving mechanism, inspired by the popular textile architecture (Monjo Carrió 1985) (Figs. 9–10).

Otherwise, roll blinds with wooden laths (Fig. 11), inspired in those appeared in the last quarter of the 19th century, are also employed in almost all window openings. By hanging down vertically or sloping over the handrail of the balcony,



Figures 5–6. Glazed space. ©Google + Own picture.



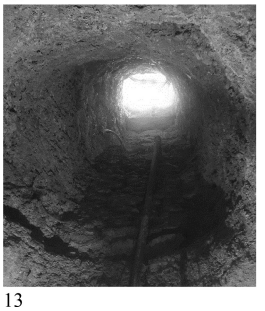
Figures 7–8. Passive Design Guide for the Built Environment (IVE, 2015 / http://www.five.es).




Figures 9–10. Textile solar protection. Own pictures.



Figure 11. Rolls blinds ©Google.


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Figures 12–13–14. Natural ventilation trough the cave. Own pictures.

Figure 15. Solar obstruction. Own picture.

for example, they provide, as well as shading, light and breeze.

3.3.5 *Natural ventilation (NV)*

The basement cave in the case study plays an important role on the building ventilation. Access to the cave is from the kitchen, through a wooden door with upper ventilation grilles (Fig. 12). In these caves, it is usual to find pits (Figs. 13 and 14) to absorb moisture built in the ground, as well as vents or ventilation openings which are connected to the outside at an immediately upper level above the street pavement (Feduchi 1976).

3.3.6 *Air treatment (TA)*

Evaporative cooling is a very advisable strategy for air treatment in dry and arid climates. It aims to achieve comfort by reducing the temperature through water evaporation while simultaneously increasing the relative humidity (Manzano-Agugliario et al. 2015). In the study case, evaporative cooling is based on vegetation, which absorbs heat excess and increases the moisture degree by evaporation (Fig. 15).

Vegetation achieves evaporative cooling in two ways: directly by obstructing solar radiation through shadows thrown over buildings, as seen before, and indirectly by the evapotranspiration phenomenon. Trees use heat to evaporate water through their leaves. A tree is capable of evaporating 500 kg of water per year per outdoor sqm, which means that indirect cooling can be much more important than direct one (Alonso et al. 2014).

4 CONCLUSION

In recent times, from the end of the nineteenth century to later in the first half of the twentieth century, technological advances seemed to eclipse other important long-ingrained cultural phenomena. It seemed to be forgotten that, besides producing aesthetic pleasure and having high authenticity interest, popular architecture provided us with useful teachings. In fact, this is not the first study proving that a Castilla-La Mancha vernacular building uses resources which could be considered as valid or, even better than those provided by other constructing solutions employed currently.

This architecture uses constructive systems with materials such as earth, wood, with a much lower energy cost embedded than the manufactured

products. Also, during the demolition processes the impacts on the environment are very low.

The ability of the vernacular architecture to reach the thermal comfort conditions is observed, especially in summer, through strategies of solar protection, heat dissipation and ventilation, without the need to use thermal installations.

For all this, the vernacular architecture presents a great interest, beyond its unquestionable patrimonial and cultural value, with bioclimatic designs efficient and respectful with the environment.

NOTE

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Local pre-industrial communities in Tuscany and the exploitation of water

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ABSTRACT: Since the middle ages, local communities which were able to channel water, organized water powered manufactories and mills, creating over time what were actual "pre-industrial districts", indivisibly bound to the network of channels that drove the vertical or horizontal blades of the millwheel. Canals, watercourses and waterfalls were as much as factor of production as the land and iron, coal and silver mines, and with time, communities learned to exploit water power with increasing efficiency. Water is by its very nature highly dynamic, and as a consequence, since ancient times, human activity has been directed at taking advantage of it power. The Tuscan case studies in point—Calci (Pisa), Rio dell'Elba (Livorno) and Colle di Val d'Elsa (Siena)—still legible on the land, even if confusedly, vouch for the value of the work culture and that of the land and environment, which belong by right to the resident community.

1 INTRODUCTION

The harnessing of animal, water and wind power and the conversion of the resultant motive power to drive millstones, fulling stocks, weaving and textile machines, saws, pumps and the whole range of crushers, grinders and mixers resulted in a significant increase in productivity, which in turn helped sustain a greatly increased and growing population (Oliver 1997).

In Tuscany the prevalent system of social organization was based on village economies, that is, managed by small, usually self-consuming communities, tied to local, intensive forms of transformation of the original nature of the land—terracing, for example—Pierotti & Ulivieri (2009).

A system of management of runoff waters was organized in Tuscany's mountain and hill areas, but also on stretches of river in the valleys, adapting it to the different features of the land and the morphology of the soil. Beginning mainly in the Middle Ages, natural and artificial water courses constituted the energy source that powered the different kinds of mill widespread throughout the towns and countryside. Agricultural activities integrated with those of a semi-industrial nature, and both needed a continual supply of water.

Water, especially if channelled with the right declivity for repeated "falls", constituted an inexhaustible source of motive power for use in numerous activities, and to drive devices of various sizes and types. Ditches, watercourses and waterfalls were a factor of production like land, or iron, coal or silver mines. Local communities learned to take advantage of hydropower. Communities, therefore, undertook to make the water systems efficient and prevent embankments and levies from collapsing. To strengthen these wealth-creating production systems, a series of specific regulations regarding water management was introduced.

Historic Tuscan water regulations show a series of similarities and continuity with the provisions of local by-laws concerning rivers and canals, the "free flow of Rivers" and the "maintenance of their Banks". The Grand Duchy's policy regarding the supervision of water courses was not far removed from the numerous provisions included in the by-laws of local communities (Ulivieri 2009).

2 THE ECO-HISTORY METHOD

Eco-history reconstructs the history of peoples without history, those ignored by official sources, but who left evidence of their existence and their culture in a material product. Ecohistory is the history of the *oikos*, that is, the history of human settlements however they were formed.

The neologism was coined on the fringes of an international, multidisciplinary conference promoted by Piero Pierotti and organized in Lucca in 1975, for the purpose of grouping together studies on the history of cities and territories. During discussions, an invitation was made to find a common term that defined this vast field of study. Thus it was that the term "eco-history" was introduced. In this word, the prefix *eco-* was derived strictly from its etymological meaning (*οἶκος* [*òicos*], that is, house or dwelling place) (Pierotti 1982).

A home or dwelling place is one of man's primary needs: this is the basic concept assumed as a guideline. The field of application of ecohistory

encompasses homes, places of work, communication routes, landscape and environment: in practice, the whole system of changes made by man to his environment to shape it into a habitable place, usable for his purposes. Since the beginning of time, the culture of a dwelling place has belonged to individuals or individual communities which were probably not in the habit of rubber stamping plans, and almost certainly did not design their cities on paper. If they have left visible traces in their ways of building and of adapting the spaces they inhabited, these are documents for eco-history (Pierotti 1999).

Eco-history relates, therefore, to the study of material culture, anthropology, archaeology and, more specifically, vernacular architecture.

The eco-history method was therefore applied to analyse local communities who left evidence of their passage and their culture in a material product. In particular, this study examines those communities that based their economy on the exploitation of the land and water sources.

Case studies on the Calci valley, a short distance from Pisa, where the waters of the Zambra torrent were harnessed, the Valley of Watermills in Rio nell'Elba on the biggest island in the Tuscan archipelago, where water captured at the "Canali" spring was channelled towards the coast, or the complex system of "gore" (artificial channels) in Colle di Val d'Elsa, a hill town north-west of Siena, represent just some of the many integrated water usage models still legible throughout Tuscany.

3 MONTE PISANO AND THE "VALLEGRAZIOSA", CALCI (PISA)

A network of millponds and artificial channels that carried water from one mill to another (known as a *gora*, or in the Calci Valley as an *aldio*), drove the mostly vertical-bladed wheels of the mills and oil presses that carpeted Monte Pisano, which separates the Pisa plain from that of Lucca. Monte Pisano is a small mountain chain that rises abruptly from the lower Arno Valley. To the eyes of a medieval wayfarer, Monte Pisano appeared as isolated between two valleys, circumscribed by two rivers, two canals and a lake, besieged by swamps fed by the waters of the Arno and the Serchio, which totally encircled it (Ulivieri 2006). This area replicated a perfect intermodal transport system, where goods and passengers travelling by water along the main rivers and canals connecting lakes and swamps, could change carrier and travel overland along cart tracks in the foothills. The area's optimal hydrography, with perennial springs flowing down the slopes of the mountains, also supplied a "precious" resource, the hydropower needed to move the waterwheels of the mills in the villages scattered throughout the territory (Fig. 1).



Figure 1. The arrangement of houses in Calci is closely tied to the diffusion of mills (M. Rossi 2015).



Figure 2. Calci "stands almost at the centre of Monte Pisano, in the most eminent position in the valley" cut through by the Zambra torrent (M. Rossi 2015).

Calci, "a minute, industrious and wealthy town", "stands almost at the centre of Monte Pisano, in the most eminent position in the valley" cut through by the Zambra torrent (Fig. 2)

Since the Middle Ages, the people of Calci had known how to harness the waters of the Zambra and organized mills "worked by water, creating over time nothing less than a "pre-industrial district" bound inseparably to the network of channels and canals that moved the mostly vertical waterwheels (Ulivieri 2015).

The Calci area was so productive as to be described as Valgraziosa (a valley rich in resources and natural beauty) since the 14th century, not only for the imposing presence of the Charterhouse, but above all for the great number of mills. Most of the mills in Calci had overshot waterwheels, vertical wheels activated by a "fall", over 3 or 4 metres high, with the tallest reaching 12, 13 metres (Chini 2003).

The overshot wheel was turned primarily by the weight of water in the buckets. Overshot wheels required a head of water, invariably achieved by construction of a leat to collect water higher up the stream (Oliver 1997).

In 1865 there were no less than 104 watermills in Calci, arranged along the ridges flanking the steeply descending Zambra torrent, following one after the other, each with its wheel turned by

a complex system of channels that derived water from the Zambra (*aldium*) and conducted it into leats created to feed the mills (*aquis ductura*, *aquiductor*, *aqueducio*, *aquiducio*, *aquiducium*).

Brick-lined artificial channels carried water to the mill, where it was directed via waterfalls (*gittos de lapidibus et aldios*) to the wooden chute from which it fell to hit the blades of the wheel (Panduri 2001).

In 1768, Peter Leopold of Hapsburg-Lorraine noted that "the Zambra river...turns 105 waterwheels, one above the other, which grind all the wheat for Livorno…and the province of Pisa" (D'Asburgo Lorena 1970).

This type of "overshot waterwheel"—sometimes identifiable in some documents as *molendinum franceschum* (Muendel 1984)—was particularly suited to areas, such as Calci, which featured considerable slopes and abundant water to ensure a good height of fall. The Zambra torrent, in fact, is characterized by a complex water system, which goes from an altitude of 350 metres at the source to 25 metres at the mouth, divided into a succession of gullies that form a series of falls and changes in levels in the riverbed (Manetti 1985).

If on one hand, milling was essential for the production of flour, indeed, the so-called "White Art" was one of the mainstays of Calci's economy, on the other hand it is not at all strange that such mills could be adapted to other kinds of production depending on market demands. It was, therefore, usual to flank the old mills for grinding grain with "falls for sharpening" and fulling stocks for the treatment of cloth.

There again, the *molinum franceschum,* or overshot waterwheel", is also associated with the development of the wool industry and the production of cloth *a la francescha*—this type of cloth was an "medium" product, of good quality but at a relatively affordable price—which flourished in Pisa from the second half of the 13th century to the 14th century, a period of particular prosperity for the city's industry.

In Calci, however, flour production reached levels far superior to that needed to meet the simple demands of local self-consumption. Grain brought to the nearby towns by sea was taken to be ground in Calci, and sent back to the town in the form of flour (Deri 2015).

The arrival of steam and electrically-operated machines during the early 1900s sealed the fate of this centuries-old activity. Devoid of any kind of protection, in the post-World War II years the mills were demolished, "disassembled" and "redeveloped".

Despite everything, the millstones and gears, the occasional surviving mill and the complex system of channels in the Calci valley still remain as testimony to the area's history.



Figure 3. Two of the three millstones from the Gangalandi Mill, Calci (D. Ulivieri 2006).

The complex system of watermills that involved Calci's entire housing system, and which is still legible today, vouch for the value of the work culture and that of the land and environment, which belong by right to the resident community (Fig. 3).

4 COLLE DI VAL D'ELSA: "DAUGHTER OF WATER"

In Colle di Val d'Elsa, situated "a little below Florence, a little above Siena" (Maccari 1926), the abundant springs located at the Caldane and the Vene ensured the year-round supply of water to drive the millstones and other mechanisms of the "water-driven edifices" as they were called.

There are different types of gora, or artificial channel in Colle. Some are located in open countryside before the San Marziale Bridge (Le Vene Gora, Calcinaia Gora, Le Nove Gora), about 1.5 km from the town, others (Maestra Gora, Spugna Gora and Piazza Gora) originate from it and take water into the town. To exploit the perennial waters of the Elsa to the full, a "steccaia", or sluice-gate was built at the foot of the bridge, which served to raise the level of the water and direct it towards the Callone Reale, a small edifice to activate the floodgate (Gelli 2009) (Fig. 4).

The series of canals deriving from the Elsa River, and which formed a complex system of locks, millponds and aqueducts, provided driving power for millstones and fulling stocks for wool or paper, and also for grinding grain and sharpening iron and steel tools (Ninci 2002).



Figure 4. Sluicegate, San Marziale, Colle di Val d'Elsa (F. Spalletti 2014).

Colle, "daughter of water", is a true "pre-industrial district" bound inseparably to the series of canals deriving from the Elsa river that make up the complex system of gore, or artificial channels, and provided driving power for millstones and fulling stocks for wool or paper, and also for grinding grain and sharpening iron and steel tools.

All the edifices that benefitted from these gore, or artificial channels, used horizontal water wheels to turn the millstones and other machinery. The waterwheel, located in a chamber beneath the mill, was driven by the fall of water coming from the millpond and channelled into a mill race. The rapid turning of the waterwheel buckets turned the two millstones above. Vertical waterwheels are to be found to a much lesser extent in Colle, and are associated with secondary uses (Gelli 2014).

"Water driven" mills in Colle were so numerous that when the Arno in Florence burst its banks in 1333 and put the city's mills out of action, the people of Colle sent the stricken inhabitants a great quantity of flour for their sustenance.

The production of paper increased to become the main industry in Colle for at least five centuries, so important as to be included in the Town By-Laws from 1307. At the end of the 15th century, paper production was the most socially relevant industry, and in full expansion—by this time, there were at least ten working paper mills. In the following centuries, the role of paper mills as the driving force for Colle's economy became increasingly incisive and exclusive.

From 1311, the Town Council organized the "pruning of the canals", or their periodic cleaning to keep them open and the flow of water constant. Maintenance of the canals on which the "water-driven edifices" operated was constant and thorough. From one set of bylaws to another, the numerous records of work carried out are more exact, and regulations become more detailed, to the extent of very carefully defining the duties of the curious figure, the guardia gore or Conduttore d'Acqua (the person designated to monitor the canals). These regulations were reiterated until the 20th century, to the extent that the Statuto Regolamento del Consorzio Utenti Gore (the statute and regulations for the canal users consortium) drafted in 1936 implements the 1491 Capitoli sulle acque e sulle gore (Chapters concerning waters and canals), and proposes the role of Guardia gore—Callonai or Canals and Locks Guard, a descendent of the long-ago "Conduttore d'Acqua", who has more or less the same duties.

The downturn in the paper manufacturing industry, which began around the mid-Nineteenth century, and the introduction in the early 20th century of modern electric turbines in the place of old watermills, led to the inevitable closure of most of Colle's workshops, and from then on, the water served only to irrigate the few remaining orchards. In the 1980s, the last working watermills ceased operation, and in the same years the paper mills also closed their doors. Nonetheless, the canals still continue to flow, even if hidden from sight in many stretches, and some mills (about twenty) still standing, continue to have hope in a not yet near future (Figs. 5–6).



Figure 5. La Buca Paper Mill, Colle di Val d'Elsa (F. Spalletti 2014).



Figure 6. Machinery for the production of paper, La Buca Paper Mill, Colle di Val d'Elsa (F. Spalletti 2014).

5 RIO NELL'ELBA VALLEY OF WATERMILLS

The Valley of Watermills winds for about two kilometres, most of it through the Rio nell'Elba municipal area, with just the final part in the Rio Marina area.

Rio nell'Elba, situated three kilometres inland on the eastern side of Elba Island, two hundred metres above sea level on a well-ventilated iron oxide hill, is a maze of stairways and steps. The inhabitants of Rio Alto (its old name), iron ore miners since ancient times, had long known how to exploit the power of water (the oldest document traced that mentions watermills dates back to the mid-16th century).

The Fosso dei Canali is the watercourse that once fed the millponds and thus the succession of watermills that descended from an altitude of 146 metres for the first to 21 metres for the last. During a field study in the summer of 1991 led by Piero Pierotti, in addition to the watermills (7 of the 22 watermills had been destroyed, two were used for other purposes, and the rest were abandoned by 1991), and the hydraulic systems, it is possible to identify a series of edifices directly connected with the subject of the valley and the exploitation of water (houses, churches, orchards, gardens, an oven, a wash trough).

A network of 22 watermills in 1,600 metres of valley with a 125 drop in height, with an average of one mill approximately every 73 metres and 5–6 metres in altitude Pierotti (1993).

They were horizontal waterwheel mills, the type most widespread in Tuscany, less powerful than those with vertical waterwheels (Fig. 7).

The horizontal waterwheel needed small volumes of fast-flowing water to grind modest quantities of grain, and so was tied to domestic production for self-consumption (Cadolini 1835).



Figure 7. Waterwheel chamber of the Orzali mill: the scooped blades of the horizontal wheel were turned by the jet of water issuing under pressure from the pipe, Rio nell'Elba (P. Pierotti 1993).

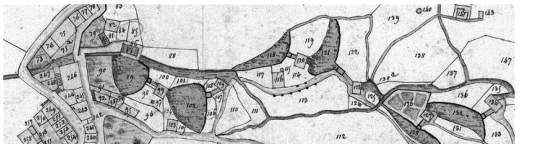


Figure 8. The ancient landscape of millponds, detail from 1824 cadastral map (Livorno State Archives, Land Registry Maps, 1587).

The millhouses are simple, compact and functional, with a single millstone, that is, one pair of grinding stones, and mostly consisting of a single room. The watermills of Rio are typified by those functional elements connected with the specific exploitation of water, a millpond, a cistern and a chute, which constitute a clear landscape context to analyse in its entirety. The millponds, placed in succession to act as reservoirs, feeding the millraces and increasing grinding power, were partly used to irrigate crops in the fields. The valley was marked by a network of secondary canals that branched off from the millponds and distributed water to the fields, gardens and orchards, a system that allowed for total recycling of the water. Most of the watermills were concentrated in the upper valley, where declivity was greatest. Here the mills were arranged to the right and left of the Fosso dei Canali, and generally those on the same bank had millponds that filled in succession (Fig. 8).

The last stretch of the valley features a lesser slope, and the watermills, most of which have been destroyed, were located a good distance from each other. The Valley of Watermills, which is now part of the Tuscan Archipelago National Park, has changed. Water is collected at the source and piped towards the coast, the watercourses have been deviated and the dried up millponds are used for crops. Between the Fifties and Seventies, the abandonment of crop growing and of everything connected with farming the land, together with the decline and finally closure of the iron ore mines, led to the desertion of these once-working ruins, which unused, preserve the memory of themselves.

The historical research begun in 1991 has restored a cultural and social sense to the Valley of the Watermills, abandoned and forgotten until then, and has renewed the relationship between the town, the valley and its inhabitants (Fig. 9).

The political will to recover this area and transform it into an eco-museum has often been declared since then, but to date no-one has yet found the key to restoring this heritage to the community.



Figure 9. The Lanza millhouse and mill, Rio nell'Elba (P. Pierotti 1993).

6 CONCLUSION

Three valleys of watermills located in different areas of Tuscany, three integrated water usage models with different characteristics—Calci and Colle closely tied to commercial production and thus to specialized form of industrialization, and Rio nell'Elba, on the other hand, connected to the grinding of grain for domestic self-consumption. The variety of ways of exploiting the dynamic power of water is typical of a region such as Tuscany, where diversity is a collective culture. These models allowed for the total recovery of the water collected, opportunely channelled and fed to the mills through a series of functional elements connected with their particular use, and then returned to the river "pure, fresh and crystal clear". When Colle Val d'Elsa native Ferdinando Morozzi (1723–1785), a granducal engineer, expert in hydraulics, mathematics and cartography, was asked in 1775 if the waters of the Borro di Romiccioli in the village of Sant'Agata Mugello "would be muddied" by "a waterwheel for grinding Grain", his irritated reply demanded how "a water that was clear when collected in a millpond and clear when let out" could muddy anything? (Ulivieri 2009). Nevertheless, this subject should not be tackled under the aegis of fogeydom or even less so of nostalgia. It is true, however, that this type of model has become a very topical again because of the question of renewable energy.

Besides, modern wind turbines used to generated clean electricity are increasingly popular, exemplifying that the technology may still have much to contribute to the provision of sustainable future built environments (Vellinga et al. 2007).

Past and present are bound together in continuity, and often opposition is only apparent. An eco-historical reading of the territory reveals convergences with the present, and suggests the recovery of theoretically obsolete models. After all, it is true that the history of peoples follows a changing course, but basic needs remain the same. This raises the political problem of the so-called re-use of the existing.

Among its aims, the Tuscany Region's territorial plan, which also includes the landscape, includes the "valorisation of the historic-testimonial evidence connected with the water resource and the strongly identifying places along the river, also subsidising for that purpose, projects for the recovery of historic-testimonial artefacts connected with water resources". The public administration's intent should not be limited to the concept of not losing the memory of the "strongly identifying places", but should have a sense of how much and in what way such recovery can be realized, taking a lesson from history and the functionality of such edifices Pierotti & Ulivieri (2009).

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Contemporary earthen architecture in the northern temperate climate

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ABSTRACT: Earth was used as in rural Denmark until about 1860. In the 20th century, some progressive social communities saw earth as one of the answers to their building experiments. Contemporary ecological tendencies are rooted in these early experimental houses. Especially the number of experimental family houses designed using passive strategies and renewable materials have increased. Often the earth material, with its low environmental impact, is involved in the construction process. Building qualities include both pleasant living spaces and comfort in terms of better indoor climate. During the last few years new developments towards industrialized earthen building components can be seen. Hence the research question is: how can earth as a building material contribute to future Danish architecture? The results point out possible future developments in earthen architecture in Denmark.

1 INTRODUCTION

When investigating vernacular housing in Denmark it may be seen that local materials such as boulders, turf, clay-earth and timber shaped the earlier building structures that served as shelters for our ancestors. These building types were characterized by one or 1½ story structures. At the beginning of the 17th century Danish building culture was characterized by two main building techniques: half-timbered houses built from wood, wickerwork and clay by ordinary people in the rural areas, whereas baked clay was used for monumental buildings and structures for the wealthy. The new rammed- earth technology reached Denmark just before 1800 in a textbook called: 'The art of building non-flammable and pleasant houses of rammed earth' processed after the Frenchman Cointereaux's authorizations (Risom 1952). In addition to the squires usual techniques, the French techniques, using rammed earth, and the British using cob, became popular. These wealthy people were aware of the properties of the material, which reduced use of solid fuel for heating and gave a healthier indoor climate. But between 1860 and 1870 brickyards became common in Denmark, baked clay became the preferred material and the use of clay earth as primary building material disappeared (Risom 1959). Looking at the 20th century the consequences of industrialization and two European Wars influenced new building techniques and modern movement dictated materials such as steel, concrete and glass. Risom did his research work in the 1950s and invented the word 'clay-earth' as a precision in the Danish context. After the youth rebellion in 1970 common habits were criticized among young people, who wanted to change society and lifestyle. All aspects of life were questioned, including the ruling modernistic building culture. Experiments copying old traditional building techniques became common among these youngsters: they wanted to live and build an alternative life. Simple and low cost building techniques were explored, resulting in low impact materials and experimental sculptural expressions. Clay earth was revived as a building material in some experimental communities.

The aim of this paper is to investigate how you might create and propose the basis for a future Danish earthen architecture based on the embedded knowledge of previous earthen buildings.

2 METHODOLOGY

The methodologies used are both theoretically and practically based and take their departure in the preindustrial heritage: experience based knowledge of the building resources are extracted by reading the narrative sources and analyzing building techniques through reviewing historic reports, visiting existing cases and studying the applied materials and techniques.

The architectonic analysis has defined the scientific parameters which are supported by contemporary technical values found in architectural

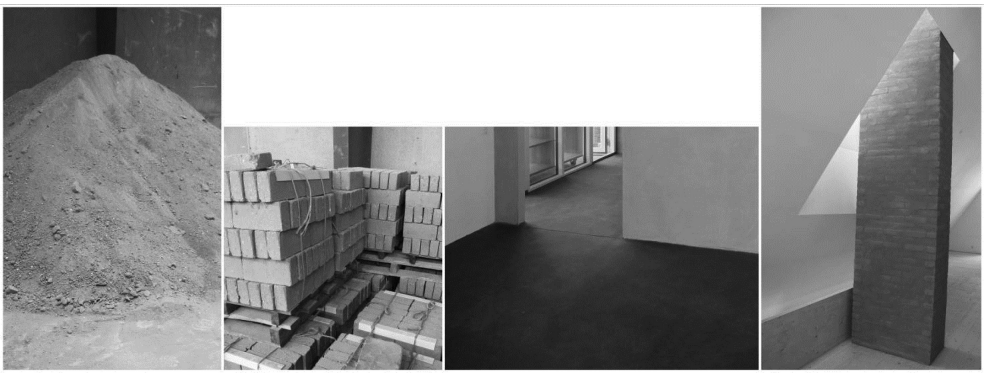


Figure 1. Earth ready for compression, CEB blocks, earth floor/linseed oil, masonry of earth and earth mortar (Vestergaard).

and technical manuals, international research and production information.

The discussion of these values meets the qualities and innovative consciousness of resource effective and healthy development towards a change regarding circularity and responsiveness.

Overall attitude to lifecycle is argued in the fact, that the material can be found at nearly all building sites in Denmark. This basic understanding is the foundation of the conclusions.

3 DEVELOPMENT TOWARDS CONTEMPORARY CLAY-EARTH ARCHITECTURE

3.1 *Clay-earth as part of an ecological building culture*

Ecological building requires skills in dealing with local climate and resources. Actual knowledge from the Anthropocene compels to take a critical look at both architectural form and construction, and furthermore to look at our use of materials and the lifecycle of the resources. Accelerating the use of the clay-earth material in the ordinary building industry would be a step towards a more ecological building culture that respects context and local climate.

Building in the Danish temperate and humid climate requires a specific attitude to building techniques: the primary construction must be under roof, the foundation based on solid ground, detailing must lead water away from the building and, finally, the building must be properly insulated during cold and humid periods.

3.2 *Clay-earth as experimental development*

The revival of clay-earth building began in 1987 with a group of young people who wanted to live in cheap houses with a proper standard and wished to build their future homes themselves. From the very beginning the Danish Architectural Studio Vindrosen (Vindrosen) was involved in planning and developing this pilot project, which combined the use of clay-earth with passive solar strategies. This work resulted in a building authorization (Vindrosen 1993). Combining the wishes of users with and a knowledgeable architectural office created an immediate connection to recognized and acknowledged research institutions in Denmark. Research onto how the material might be used was carried out. From this point of departure an ecological movement started growing.

In 1994 the cooperate society Hjortshøj continued the development related to their intention of creating a living laboratory and developing demonstration projects for sustainable life styles (Hjortshøj). The Hjortshøj people used an already existing building technique: they experimented with both rammed earth and Compressed Earth Blocks (Figs. 2, 3). Local fabrication of the blocks was established in cooperation with Oscam Company (Lecuelle 2000, Correia 2011). The company later developed an industry based on the possibilities of applying clay as plaster with machines (Terraincognita).

Around the year 2000 other groups experimented with straw bale houses. Especially in Jutland a number of these houses were built, preferably by the users themselves, using a loadbearing wooden frame, straw as insulation and clay-earth as plaster for the construction wall both outside and inside. Floors were built from clay and experiments carried out to make the floors water-proof by using linseed oil. A report and documentation were drawn up in order to secure information for future users (Munch-Andersen & Andersen 2004).

In the beginning of this century clay experiments developed from user requirements for good



Figure 2. Detached house built of rammed earth (Vestergaard).



Figure 3. Detached house built of CEB (Vestergaard).



Figure 4. The Breathable House (Vestergaard).

indoor climate properties in nurseries and from requirements for a larger library archives. Interior walls were constructed from unburned clay stones: the indoor climate was stabilized with unbaked bricks and utilized the hygroscopic character of clay. Since 1970 the Danish entrepreneur Egen Vinding og Datter has specialized in ecological building techniques (Fig. 1). The so-called Breathable House project (Fig. 4) was established in 2014 as a pilot study with the intention of quantifying the qualities of the building techniques they had learnt (Refsgaard& Friberg). The project is built, measurements and documentations has not been completed and published.

4 APPLICATION OF CLAY-EARTH IN BUILDINGS

4.1 *A palette of product types*

The applications of possible clay-earth construction in buildings are many. The documentation of the material properties has not yet been completed in Denmark, but several projects strive towards this goal. The most important properties are building with earth is good financial stewardship and the material is cheap and found nearly everywhere in Denmark as a local mineral resource. Therefore, using the material requires a minimum of transportation and has a very low CO2 emission, 1–10% compared with concrete (Lecuelle, Refsgaard & Friberg). At the end of the materials life, the material returns directly back to the earth.

Clay-earth appears in the several form and functions in buildings. As primary building material adobe, cob and rammed earth and have been used in preindustrial buildings (Correia 2011). Half-timber framing with adobe also belongs in this period, and clay-earth is here used as infills while timber has the loadbearing role. Mass produced compact earth blocks (CEB) and clay stones have been used for contemporary buildings. CEB blocks are compressed using mechanized processes (Berge 2008, Correia 2011). Daub, clay plaster and clay floors, in both wet and dry rooms are used as secondary building materials (Refsgaard & Friberg) and this use is in particular seen in experimental buildings. The material is extremely user friendly and easy to work with. Earth was often used inside horizontal separations for its sound and fire protection properties (Berge 2008). Moreover, the material is efficient for protecting tubes under floors. Nowadays, clay is used for purposes such internal wall panel insulation and climate regulation and as clay-paint (Claytec+Ecotec).

4.2 *Structural properties and thermal mass*

Rammed earth's load bearing capacity, which has been known for long time and has good compression strength for building, should be minimum value of 2, 4 N/mm^2 (Rauch 2015) which makes it possible to use the material for as load bearing structures in buildings. CEB is often used for

indoor walls in combination with timber and external insulation and cladding. Contemporary construction legislation, however, has to be controlled.

In preindustrial time it was customary to add natural biological resources such as straw or manure to the earthen mix. This gives the material a higher flexibility and structure, reinforces it and also provides better material insulation. The thermal conductivity as the lambda- values are described by Barbeta Solà & Massó Ros in comparable thicknesses, clay-earth in relation to CEB and concrete: rammed earth is 1.10 W/mK, CEB is 0,81 W/mK and concrete is 2,3 W/mK (Barbeta Solà & Massó Ros 2015). In the Danish climate it was recommended to construct outer walls with a thickness of 50 cm (Risom 1952). The thermal transmittance as the U-value of a 50 cm rammed earth wall is calculated to 1.35 W/m^2 K (Röhlen & Ziegert 2014). With contemporary Danish building regulations in mind and with a future perspective of nearly zero energy building a U-value of 0, 09 W/m^2 K (Isover 2010) is required. The consequences are that buildings need to be heavily insulated. Hjortshøj carried out two building construction experiments, which were rammed earth and CEB inner walls. Solid clay-earth was used for the inner wall and insulated from the outside, the inner wall contributed to both loadbearing ability and to excellent comfort properties. The Hjortshøj concluded rammed earth construction being the cheapest and having the lowest CO_2 consumption (Lecuelle 2000), leading to the conclusion that rammed earth can be recommended for self-builders and that CEB can more convenient for industrialized building processes. Cob can be used for self-builders and is not preferred for industrialized use.

4.3 *Comfort properties*

4.3.1 *Hygroscopi*

For external walls in a humid climate like the Danish it is recommended to cover the outdoor surface of raw clay with cladding. Lime painting can only achieve legally prescribed water resistance if redone every year (Munch Andersen & Andersen 2004). This practice was common for pre-industrialized clay-earth facade materials. For internal walls the capillary structure of the material gives excellent properties for obtaining and storing humidity. Documented 2 mm paint obtains 12 g/m^2, whereas 25 mm plaster obtains 59 g/m^2 both over a period of 12 hours (Eckermann & Ziegert 2006). While the hygroscopic property is actually a disadvantage for outdoor exposition of clay-earth, it is an advantage for the indoor climate to stabilize the relative air humidity between 50–35% (Eckermann & Ziegert 2006).

4.3.2 *Temperatures*

In relation to high indoor temperatures and cold climates it is important to prevent radiation from cold internal surfaces by breaking the thermal bridges. The clay-earth wall offers excellent temperature stability, which is extraordinary (Lecuelle 2000, Eybye & Vestergaard 2017) compared to other materials.

4.3.3 *Acoustics*

Documentation of acoustics properties has not been found in this research. But according to the open capillary structure of the material, it is logical that this structure results in a shorter reverberation than concrete. This fact is also documented by case study interviews, in which the owners experience better acoustics properties compared to other conventional houses built from concrete (Lecuelle 2000, Eybye & Vestergaard 2017).

4.3.4 *Air quality*

Earth's material air-cleaning capabilities are mentioned in several sources. It has not, within this research, been possible to find a calculation of this property, but the case study of Jarlsminde documents by interview that the owners experience improves indoor air quality in the rammed earth walls compared to other contemporary houses (Eybye & Vestergaard 2017).

4.4 *Atmosphere*

The Austrian building artist Martin Rauch (Lehmtonerde) has innovated the use of clay-earth by making a number of experiments with aesthetic possibilities: among others Reconciliation Chapel in Berlin (Fig. 5). In the preindustrial cases, both indoor and outdoor surfaces are usually protected by lime; but in these extraordinary examples is seen a total exposure of the rammed earth material. The exposed way of using the material highlights the beauty and the tectonic properties of the materials



Figure 5. Reconciliation Chapel in Berlin (Vestergaard).

(Fig. 6). Hence our experience is transferred to the texture of the material, and the material gives us wellbeing when exposed to the weather and to the viewer. Architects provide this awareness of aesthetics to create quality and atmosphere.

4.5 *Innovation of contemporary industrial productions*

Martin Rauch (Lehmtonerde) uses the earth- clay as innovations of water-protected outdoor surfaces and also to industrial production of earth panels. These panels are produced indoors using different techniques: it is now possible to customize the building process and move the panels. When the panels arrive at the building site the assembly is carried out and the panels are put together using clay mortar in the produced patterns in a homogeneous way which seems quite convincing for the wall texture. Rauch even develops the component as a cavity wall with the opportunity to insulate in between and thereby prevent the thermal bridges (Fig. 7) (Rauch 2015).

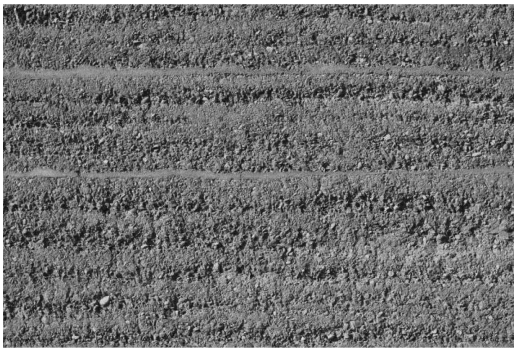


Figure 6. Material tectonics—rammed earth (Vestergaard).

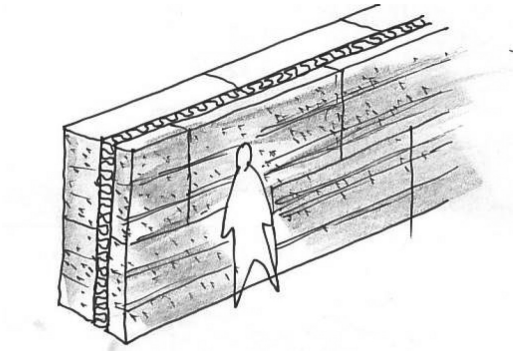


Figure 7. Prefab cavity wall.

5 DISCUSSION

Clay-earth is a widespread Danish resource which has an extremely good lifecycle if handled locally in circular loops. Clay-earth offers a large palette of potential building and material products such as main structures, building blocks, stones, panels, plaster and paint. Some of the available products are current being imported, but a local production would improve ecology. Clay-earth has advantages in terms of indoor climate, such as stabilizing the humidity, the acoustics and the temperature. The material has good comfort properties and is visually appealing, which can be utilized. Many actual questions regarding contemporary building complexity, such as price, aesthetics, mold, humidity, noise and many more can be answered by using clay-earth with a very low environmental impact. For external walls in a humid climate it is important to cover the outdoor surface of raw clay with cladding, as it may be seen that hygroscopic properties are a disadvantage for the outdoor use of earth.

In principle there are two ways of making clay-earth buildings. Because of its low cost and rather simple construction technique it has been possible for self-builders to handle the construction with ordinary tools. When having enough labor power, one can quite easily build a house with all the impressive qualities one could expect. But it is also obvious that the lack of knowledge among non-skilled people must be addressed by means of good authorizations and consultants. In recent years a few initiatives for using prefabricated clay-earth products is seen in the building industry that have the potential of being very promising. Seen from an ecological perspective the knowledge of and access to products on all of our country must be more widespread: in Denmark only few building companies work with these ecological attitudes, and many products are imported. Off course importing products provides quality products for the building industry, but it is not efficient from an ecological perspective.

Nowadays an emphasis on material properties is seen in respect to haptic and visual expression. The texture and the feeling of wellbeing are fundamental elements in architecture. At present growing comfort demands is seen as a reaction to sick building syndrome. Here clay-earth can play a role in both retrofitting and new buildings. For a long time, building materials with smooth and non-permeable surfaces have been the way developments were going. However, by using clay-earth, architects can add aesthetics and texture to buildings by exposing the clay-earth. Clay-earth has many advantages, and increasing the use of this material would be an ecological step forward. Furthermore,

the materials are easy and healthy to work with and the design can take many architectural forms.

Is this the time to embrace clay-earth's many qualities and raise the question whether modernistic building construction has become too complex? Is this the time to simplify and rethink the large number of layered construction materials, each of which represents a specific functional property? Is it possible to make the fundamental change to begin to use clay-earth constructions? Put in another way: is clay-earth the answer to contemporary building construction?

6 CONCLUSIONS

The background of the paper refers to Danish vernacular architecture. In the paper an important written source of Risom's research is mentioned and the resurrection of the construction of earthen buildings is argued for. A further implementation of earth- clay in local contemporary architecture looks promising. There might be a natural resistance again the earth-clay, as the material is nearly only used in our vernacular building and in the alternative ecological movements buildings. These alternative craftsmen know by experience all the qualities of the material, but a more widespread implementation affords performance tests and technical marking.

The architectural experiments of the alternative settlements of the 1970s benefit from vernacular architecture in its basic form in terms of resources, climate and place. In parallel with this, research institutions became involved, and a few cases in conventional architecture and a beginning industrialization were seen. As found in the current research it is now possible to use highly industrialized products although imported from Germany. The fact that the products are at the market serves great perspectives for further use.

Focusing on structural and comfort-related properties is an attempt to make clear the advantages and disadvantages of using clay-earth in buildings. When looking outside Denmark, promising industrialized production may be explored. Looking at latest development of contemporary architecture in Denmark there is a growing interest for natural and renewable materials. Also a demand for nearly zero energy buildings is growing to secure a better level of comfort in buildings. Earth- clay has huge potentials here as already shown in practice by Lehmtonerde.

The contemporary renewal is positive, but the development must set a new agenda in the market. In order to create an ecological alternative to a thriving building industry a joint initiative comprising material developers, construction markets, builders and research institutions must be initiated: the necessary knowledge is already here. However, when looking at the possibilities for easy application of clay-earth in contemporary building construction, it is necessary to document and describe norms for building regulations in order to promote an ecological alternative to the major existing industry.

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Sustainability of rammed earth building tradition in Tepeyahualco, Mexico

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ABSTRACT: This text analyzes a building system that originated in the municipality of Tepeyahualco (in the State of Puebla, central Mexico) and used to make rammed earth walls. It describes the geographical and historical context and presents information from architectural and structural surveys along with testimonies of local craftsmen. These data have been verified in laboratory work at the Universidad Nacional Autónoma de México, UNAM (National Autonomous University of Mexico), and the Universidad Autónoma Metropolitana-Xochimilco, UAM-X (Metropolitan Autonomous University-Xochimilco); the initial results of which are presented in this paper, which also seeks to emphasize the cultural values of the technique and to explore its possible application in sustainable dwellings, as an alternative in satisfying the growing demand for housing in Mexico.

1 INTRODUCTION

Architectural rammed earth techniques have been scarcely studied in Mexico. This building tradition, which must have originated at some time during the Viceroyalty, spread along a section of the *Camino Real* or principal road from the port of Veracruz to Mexico City without penetrating much further afield. Despite its value from the cultural heritage point of view, this building tradition is unfortunately disappearing fast, owing to the development of industrialized systems.

This paper sets out to identify the possible contributions in terms of architectural sustainability of this building system as used in the municipality of Tepeyahualco, State of Puebla, where it is applied in building walls, using pumice stone, earth and lime residues. Although the system is not in itself very old, we can assume (according to fieldwork data) that it grew out of a fusion of two older building techniques, one of them being traditional rammed earth construction.

The use of local materials, together with the continuity in the use of formworks to build the walls, allows us to affirm that it is an evolution of a traditional technique, which, by evolving, has found a way to avoid its disappearance, as is the case with most other traditional building methods in Mexico. This phenomenon is worth studying as a contribution to the recuperation and updating of local building traditions. To this end, it is worth considering the following questions:

In the face of cultural homogenization and socioeconomic globalization, how can traditional building systems (still alive in some areas of rural Mexico) be transformed while retaining something of their original cultural context?

What lessons can be learned from traditional building systems that might serve for application in a sustainable architecture?

These are the exploratory questions that support our research work, however in this paper we only intend to point out the experimental work we have done to date.

2 RAMMED EARTH EVOLUTION IN MEXICO

The development of this building system in Mexico can be traced to several different points of origin, and different historical moments (Fig. 1). The use of rammed earth was common to many Pre-Hispanic cultures, which used it in building pyramidal bases and platforms; this building technique was combined with others such as adobe or stonework, so as to obtain structures that acquired strength as the confined earth was compacted. Outstanding examples of this combination can be found in almost all of Teotihuacan's pyramids, built during the first six or seven centuries of our era (Guerrero 2011).

On this point it is important to mention that Pre-Hispanic remains have not been regarded as examples of rammed earth architecture, because



Figure 1. Traditional rammed earth wall. San Andrés Payuca, state of Puebla, Mexico.

their building process did not involve any type of molds or formwork, seen as characteristic of this building system. To date, the existence of Prehispanic rammed earth walls of that type has not been confirmed, not only as regards Mexico but for all of Ibero-America (Guerrero 2016).

On this point it is important to mention that Pre-Hispanic remains have not been regarded as examples of rammed earth architecture, because their building process did not involve any type of molds or formwork, seen as characteristic of this building system. To date, the existence of Prehispanic rammed earth walls of that type has not been confirmed, not only as regards Mexico but for all of Ibero-America (Guerrero 2016).

After the arrival of the Spaniards, the fusion of existing American building systems with those from Europe facilitated the consolidation of this technique in Mexico; in the colonial period, it was used in several types of buildings. Nevertheless, the use of this technique was not widely disseminated, development taking place mainly on Mexico's central high plateau, in a region formed by the States of Puebla, Tlaxcala and a part of Veracruz, all associated with the route of the *Camino Real* or principal highway from Mexico City to the port of Veracruz (Guerrero, 2014).

The importance of this technique during the colonial period can be seen in vernacular buildings following its adoption as a traditional method of construction that made it part of daily life. Its viability is due to the plentiful availability of earth as principal raw material, and the very little water required in the process. Besides, the speed of building was assisted by the possibility of producing components *in situ*, and reusing the shuttering several times over.

Thus, the rammed earth, or *tapia*, building system became part of the memory and building tradition of people in the places where it was developed, and an important element in vernacular architecture in Mexico.

3 TEPEYAHUALCO'S RAMMED WALLS

In the municipality of Tepeyahualco, located in the State of Puebla, an interesting variation of this building system has been found: rammed earth walls maintaining the same building process but substituting some of the materials. Earth has been complemented, and in some cases replaced, by a mixture of lime residues with pumice (a light stone produced by volcanic foam, known here as *poma*). These are local materials, and this fact, together with the continuity in the use of formworks to build the walls, allows us to affirm that it is an evolution of a traditional technique, which, by evolving, has found a way to avoid its disappearance, as we have said in the introduction.

The local rammed earth system using pumice stone and lime residues is relatively new (Figs 2, 3).



Figure 2. Vestiges of rammed lime and pumice wall. Tepeyahualco, Mexico.



Figure 3. Lime residues and pumice wall. Tepeyahualco, Mexico.

According to data from field work, it emerged in the early twentieth century as a product of learning and the fusion of two older traditional building systems also present in northern Puebla: on one hand, a system for constructing intermediate floors and flat roofs (known as *terrados*), using a substrate of pumice stone and lime instead of layers of soil; and on the other, rammed earth walls used in the same region in localities a few kilometers distant (Figs. 4, 5).

Tepeyahualco's pumice stone rammed building system uses various materials found in the region: Igneous rock, used where base components are in direct contact with the ground; pumice stone which, because of its physical properties, gives rigidity and lightness to the rammed wall; and finally, residues from local lime processing. These residues are used for cementation, and are obtained from the calcination of limestone to transform it into calcium oxide in a limekiln located in the same region. A portion of medium-sized acid tuff particles is also added, which is locally known as *cacahuatillo*. This, together with sands from lime residues and pumice stone, yields granulometric variety allowing friction jointing between components. Finally earth in varying amounts, mixed with water, contributes to the cohesion of the building system.



Figure 4. Lime and pumice filled timber beam roofing. Pizarro farm, state of Puebla, Mexico.



Figure 5. Traditionally used formwork for rammed earth walls. San Andrés Payuca, state of Puebla, Mexico.



Figure 6. Case study wall materials: lime residue, pumice, black clay and *cacahuatillo*.



Figure 7. Case study wall materials: ready mixture.

The materials previously described are mixed in the following proportions: 1 part of lime residues, 1 part of pumice stone, 1 part of *cacahuatillo*, 1/3 part of clay-bearing earth and approximately 5% of water (according to the humidity of the materials). The fragments of pumice and the *cacahuatillo* should be of different dimensions to guarantee greater consistency of the rammed walls (Figs. 6, 7).

Once the mixture has been prepared it is deposited into the formwork in the trench in 20–30 cm rammed layers. Once the mold is filled, the surface is leveled with a trowel; the shuttering is then removed and moved aside from the foundation trench (Fig. 8).



Figure 8. Building process: timber formwork and compacting.



Figure 9. Rammed wall finished.

4 EXPERIMENTAL WORK

We have begun processing this information in the laboratory using digital models and also scale models that aim at a reliable reproduction of the building system so as to identify its performance and main features. As far as possible, the same materials and procedures are used as in actual practice (Fig. 9).

4.1 *Methodology*

Our approach to the research methodology is based on systems thinking (Capra, 2014); which means thinking in terms of relationships, patterns and context, as we have stated through the research questions mentioned in the introduction to this essay.

Information is supported by fieldwork, using drawings and photographs to document ancient rammed earth remains; likewise, interviews with traditional builders who are still familiar with this technique have been recorded in video. Finally, scale models have been built to identify the main variables associated with this building system, as regards materials, granulometry, water dosage, process of execution, degree of compacting and hardening time. This essay shows the preliminary results of lab tests examining compressive resistance of three mixtures obtained in Tepeyahualco, plus one test mixture. In later stages, a study will be carried out comparing these test results with some rammed earth walls remains.

So far, we have identified the natural reserves of materials and relationships between the elaboration processes of the two building systems involved in this case of study. As we have described, on one hand, these involve flat roofs made with pumice stone and lime residues; on the other, rammed earth as a technique used for walls that originated during the colonial period and evolving in nineteenth century.

We have also found that in Tepeyahualco, builders use to build with two mixtures, the one described on the Tepeyahualco's rammed earth walls section, and another one using the same proportions, but without clay.

Another mix from a nearby locality named El Fuerte was found; this sample uses a mixture of industrialized lime and sand, instead of lime residues. These three mixtures were used to begin with the experimental work, in order to find out the compression resistance of this building technique, and prove our first empiric conclusions form observations at fieldwork, such as improved structural performance, optimization of raw materials that can be compared with industrialized ones in terms of sustainable issues, such as energy savings on the building process, living qualities, economic advantages, etc.

With data from the fieldwork, experimental tests have begun at the laboratories of the Universidad Nacional Autónoma de México (National Autonomous University of Mexico: UNAM) and the Universidad Autónoma Metropolitana-Xochimilco (Metropolitan Autonomous University-Xochimilco: UAM-X). The two samples from Tepeyahualco and the one from El Fuerte were used to make the first compression tests.

To obtain a wider variety of data, a fourth sample was tested combining the variant mixes from Tepeyahualco and El Fuerte, in order to obtain more information about the behavior of the clay. The following table shows the proportions of the different mixes:

For simple compression tests, $5 \times 5 \times 5$ cm test cubes were made using each of the mixtures. Improvised sedimentation tests were also carried out to identify the composition of the materials

Table 1. Four mixture variations. Materials and proportions.

Materials/ Proportions	Tepe-A mix	Tepe-B mix	El Fuerte mix	Combined mix
Pumice	1	1	1	1
Cacahuatillo	1	1	1	1
Lime residue	1	1	–	–
Black clay	1/3	–	–	1/3
Industrial lime	–	–	1/6	1/6
Sand	–	–	5/6	5/6

Table 2. Compression tests results synthesis.

Mixture	Volume dosage	Simple compression resistance (kgN/cm^2)
Tepe- A mix P: C: LR: BC	3: 3: 3: 1	31.17
Tepe- B mix P: C: LR	1: 1: 1	21.2
El Fuerte mix P: C: IL: S	6: 6: 1: 5	20.2
Combined mix P: C: BC: IL: S	6: 6: 2: 1: 5	34.49

P: Pumice, C: *Cacahuatillo* LR: Lime residue, BC: Black clay, IL: Industrial lime, S: Sand.

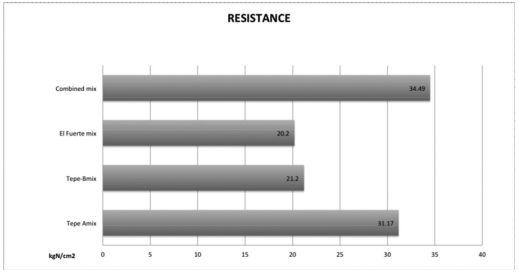


Figure 10. Compression resistance comparative graph.

and their proportions; results will be compared with "trade reality", that is to say, with information gathered orally from builders during the fieldwork (Figs 11, 12).

The test cubes were left to dry for 28 days, under with well controlled temperature and humidity conditions, and were then subjected to compression tests using a manual-digital ELVEC press, E 657-1 model (ASTM C39; AASHTO T22) (Fig. 13). In total, three test cubes were used for each mixture. Average results for each are shown in the following table, and in Fig. 10:

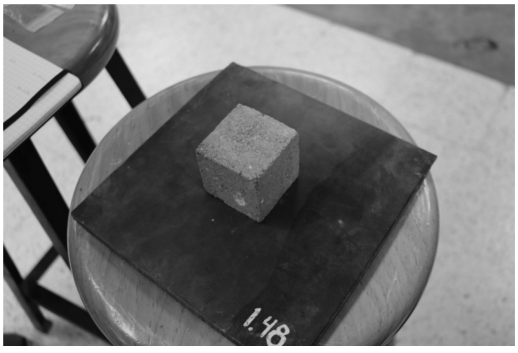


Figure 11. Test cube before testing.



Figure 12. Test cube after testing.



Figure 13. Testing process. ELVEC press, E 657-1 model ASTM C39; AASHTO T22.

4.2 *Discussion*

These initial results show that mixtures including clay have greater resistance (with similar range of values) than those without clay. In the future, new tests are planned with an increased proportion of

clay, along with tests using different types of clay and earth in order to find out whether this building system is transferrable to other regions with similar materials.

These preliminary results offer a promising panorama, because the samples resist 75% better than ordinary rammed earth walls. It is important to bear in mind that Tepeyahualco's rammed walls have an average thickness (25 cm) half that of ordinary rammed earth walls (50 cm).

The combination of the different materials in the mixture generates a chemical reaction during the hardening process which produces notable advantages in comparison with traditional rammed earth walls, allowing a reduction in wall thickness. This is because the lime residues still have active elements. Lime hardens on exposure to air (unlike cement, which reacts with water); this is why lime can be kept for years under water, without hardening and still suitable for use. Lime-based hydraulic mortars can be obtained by two methods: in the first place, mixing hydraulic lime with inert sands; in the second, mixing non-hydraulic lime (fat lime putty) with sand rich in silica and reactive alumina: for instance, pozzolanic ash or sands of volcanic origin, which include *tezontle* or pumice stone (Orea, 2013). This is what causes the reaction in presence of water. According to those interviewed, in wet weather or if water falls on the mixture, it hardens faster, so it is reasonable to think there is a pozzolanic reaction within the mixture, caused by the presence of lime hydroxide in the lime residues in contact with pumice stone, which contents silica.

This inference should be verified with new test samples with different hardening times (28, 84 and 164 days), and to confirm whether or not there is a correlation between hardening time and resistance.

The rammed system using pumice and lime residues optimizes materials and procedures, as compared with earlier similar building systems. The construction process is faster than the earlier ones, but at the same time it maintains the original simplicity and offers material savings, better mechanical performance, less maintenance and longer periods of useful life.

The analysis of this fusion in building traditions could be used to establish working methods in further project phases. The study has confirmed efficiency in the use of materials and respect for the environment. The system is a transitional one based on the earlier rammed earth tradition, but modifying it through the incorporation of pumice and lime. At the same time, it offers features that have evolved within the local building tradition that could render it competitive with architectural influences imported from urban contexts.

5 CONCLUSIONS

Rammed walls using pumice stone an lime residues as main materials, produce a wall 50% thinner than the usual compacted earth ones, this is a consequence of optimizing a raw material with greater density and internal cohesion, resulting in improved structural performance and reductions of the amount of material used and preparation time. This technique still uses local materials, a simple and traditional building process and, like its predecessors, does not require sophisticated tools.

These reflections have been partially verified thanks to experimental work, the first results and conclusions of which are exhibited in this paper. Further research phases will compare these results with modern building systems involving brick and concrete block masonry that have already made their appearance in Tepeyahualco.

Finally, we should mention the progressive disappearance of ancestral techniques and their spatial expressions. As we have tried to show with reference to this particular case, such techniques may have lessons to offer in the quest for a sustainable architecture. This is the main motive inspiring the study of such traditional methods: the hope that it may serve as a contribution to their preservation and, it is to be hoped, their improvement.

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Structural analysis of vernacular architecture



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Structural assessment of earthen walls using damage tests and models

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ABSTRACT: The study and understanding of the structural behavior of earth as a construction material are key to proposing compatible interventions that guarantee the durability and stability of earthen buildings, especially in seismic regions. Nonlinear calculation methods such as damage models are of great use in the mechanical assessment of earthen buildings. However, these procedures require accurate knowledge of the mechanical properties of the material, such as compression strength, tensile strength, modulus of elasticity, and fracture energy, if they are to provide truly precise results. This article details the process of characterizing a case of earthen construction using in situ and laboratory tests for the application of mechanical properties described in a nonlinear numerical model to produce accurate calibration of the behavior of the material both under gravity and seismic actions.

1 INTRODUCTION

Traditional earthen construction systems are currently in use in many parts of the world. Between 30% and 50% of the world population live in earthen constructions (Houben & Guillaud 1994) and there is also considerable historic-architectural heritage built using earth. That is why in recent years the discussion on criteria, procedures, and methods for its conservation, restoration, and rehabilitation has become increasingly important.

However, throughout the twentieth century social changes and demographic flow, particularly in Europe, have resulted in the progressive abandonment of these construction techniques and the associated know-how (VVAA 2011). As a result, there are currently few interventions in earthen architecture, especially in the case of vernacular architecture, and these are often carried out by the owners themselves or by specialists with no specific training in restoration. Therefore, these interventions employ modern materials and techniques which are not suited to the properties and behavior of earth and can cause constructive and structural incompatibilities to appear.

To tackle this problem it is essential to research the material and structural conservation of earthen architecture in order to bring about and promote true understanding of the behavior of the material, increasing awareness in society of the importance of preserving earthen built heritage and providing specialists with the necessary tools for efficient and compatible interventions.

2 OBJECTIVES

Analysis of the structural behavior of earth as a constructive material is simple in terms of calculation, when taking into account only the effects of loads on the structure, but the difficulty is noticeable when examining the potential dynamic effects of seismic action on the structure. However, as earthen constructions are often found in areas affected by severe or moderate seismic action, the study of the behavior and reinforcement of these constructions in the event of an earthquake must be a priority (Gallego & Arto 2015; Vargas 2010).

This article therefore analyzes the structural behavior of a traditional rammed earth construction applying a damage model based on the results obtained from nondestructive tests on a lime-enriched rammed earth wall.

The use of nonlinear numerical models (Oñate et al. 1996) makes it possible to accurately calculate the response of a specific structure to both gravity and seismic actions. However, this model requires a suitable knowledge of the mechanical properties of the material used in the structure for the calculation parameters to calibrate its behavior accurately.

3 METHODOLOGY

The present study has been structured in two phases, tests for the material characterization of a real case of earthen construction and the application of the results of these tests on a typical case of vernacular construction to which the damage model has been applied.

This article therefore analyzes the structural behavior of a traditional rammed earth construction by applying the damage model based on the results obtained from the analysis of nondestructive tests on an actual lime-enriched rammed earth wall.

3.1 *Characteristics of the element tested*

The nondestructive tests to obtain the material characterization used to calibrate the damage model were developed in Aguiló Castle in Petrés, in the province of Valencia (Spain).

Dating from the late fourteenth and early fifteenth centuries, and more residential than military, this construction was built using rammed earth walls with a mix of earth, lime, and large rounded stones poured and tamped in formwork, and with traces still visible in the walls (Fig. 1).

Despite numerous modifications and extensions over its long history, the castle was well conserved until its partial demolition in the mid-twentieth century (Vegas et al. 2017). As a result, the remaining walls are well conserved and can be used as a point of reference in the material characterization of a calculation model, although they are no longer part of a complete structure and only hold up their own weight.

3.2 *Description of tests*

To obtain the behavior parameters of the earthen and lime walls of the castle, two in situ tests were proposed using flat jacks (Lombillo 2010).

This procedure is habitually used to assess some of the mechanical and deformation properties in stone and brick walls, but its use in earthen walls opens up a whole range of possibilities, increasing understanding of the structural behavior of earth (Fig. 2). The use of this test for the structural analysis of earthen constructive systems is all



Figure 1. Interior view of the castle in Petrés.

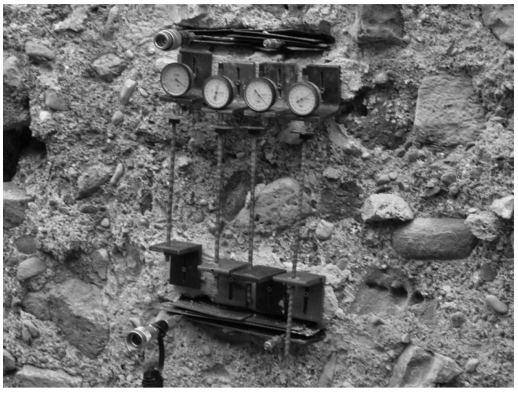


Figure 2. Test using double flat jack in Petrés castle.

the more interesting as it is a direct method that is practically nondestructive, and only requires the partial elimination of the mortar from the joint it is inserted in, taken from a band measuring approximately 30 cm.

The test consists of two phases: the state of compression stress in the construction is obtained in the first phase and the deformation parameters in the second. In order to obtain the stress state of the wall strain gauges are placed at a specific distance, with the flat jack inserted in a cut made halfway between both gauges.

When the cut is made the initial distance between the gauges is reduced due to the tensional adjustment produced by eliminating material from the joint. The jack is connected to a hydraulic pump which increases the pressure until the initial separation between gauges is recovered. Stress T in the wall is obtained using the formula:

$$T = K_m \cdot K_a \cdot p \tag{1}$$

where p is the pressure of the jack in Kp/cm^2; K_m is the nondimensional coefficient of the flat jack specified by the manufacturer and K_a is the ratio between the surface of the flat jack and the mean surface of the cut made in the construction.

In order to establish the deformation parameters two cuts are made in the wall and two flat jacks are positioned to define a portion of the element. This fragment acts as a test tube with no need for extraction. Subsequently, the flat jacks are subjected to pressure steps using a hydraulic pump. The deformations are measured using the expression:

$$E_i = (d - d_i) \cdot K_e \tag{2}$$

where E is the deformation obtained in pressure step i; d is the initial distance between points of

reference; d_i is the distance between points of reference in the pressure step *i* and K_e is the deformation coefficient of the gauge.

Based on the test values a stress-deformation graph can be made for each pressure step *i*, allowing the modulus of elasticity of the material to be determined.

In the case of the walls of Petrés castle the random positioning of numerous large elements in the mix of lime, earth, and large rounded stones in the walls made it difficult to identify the points where two flat jacks could be inserted in a position that would guarantee valid results. Therefore, in order to avoid unnecessary damage to the building, a single test with a flat jack was carried out and complemented with compression strength tests in the laboratory using samples extracted from the sections of wall demolished in the mid-twentieth century.

3.3 *Description of the calculation model*

As mentioned earlier, the partial demolition of the castle in the mid-twentieth century created a rather unusual situation in which the fine state of conservation of the constructive elements still standing contrasts with the overall ruin of the construction and with the lack of a loadbearing structure to allow material behavior to be assessed.

For this reason, a theoretical model of the construction was adopted, based on one of the most common typologies of traditional architecture in the region, to which the strength parameters of the material tested were applied. The type of rammed earth used in the castle is not the most common in the vernacular constructions in the region, where less reinforced earthen mixes were often used, but it is possible to find similar mixes in cases in which traditional architecture was starting to be built by the wealthier classes.

This model is to be used to study the mechanical validity of the technique tested, associating it with a common structural system in the region. The results obtained are expected to be easier to use as reference for the assessment of other nearby constructions.

This model, comparable to that of a rural dwelling in the Spanish Levant, has a structure made up of three bays of wood floors supported by walls that are 0.50 m thick, simultaneously defining the living spaces. The first two bays create a spacious first floor, with a central column holding up a wooden beam and gabled roof (Fig. 3).

The numerical model analyzed using the Finite Element Method has 6,090 hexahedral solid elements and 9,192 nodes, with a total of 25,896 degrees of freedom. Linear and nonlinear analyses were carried out in order to assess the building's response to the oscillation of gravity loads. In addition, a modal dynamic analysis was carried out on the structure in order to determine its vulnerability in the event of an earthquake, taking into consideration its implementation in regions with different seismic risk (Asteris et al. 2014).

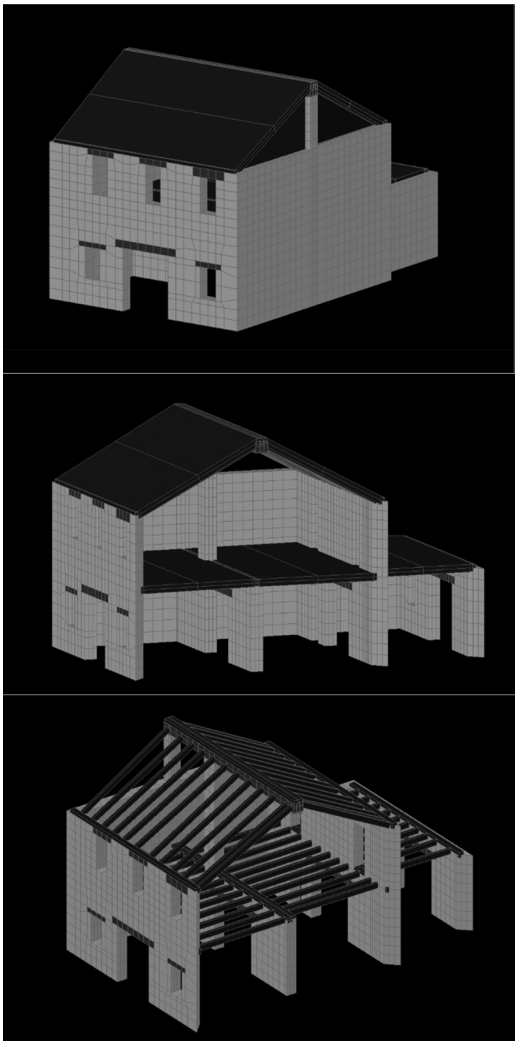


Figure 3. Calculation model analyzed.

4 RESULTS

4.1 *Test on the constructions of Petrés Castle*

In order to determine the deformation parameters of the walls of Petrés Castle, a flat jack test was

carried out inserting two 30 × 10 cm flat jacks covering a section of wall 60 cm thick (Fig. 4). The selection of the test point was based on the state of conservation of the wall, the absence of surrounding unstable elements, and sufficient remaining height above the test point, to ensure that the reaction allowed the sample tested to be studied.

The load steps started from an initial stress of 0.160 N/mm^2 and an average strain of 13 ·10^{-5} under initial load, reaching a maximum stress of 0.732 N/mm^2 for a strain of 10^{-5} under maximum load (Fig. 5).

A deformation module of 4,830 N/mm^2 was obtained from these results. It should be noted that under 8.6 Kg/cm^2 stress a fissure occurred in the lower part of the sample of the earthen wall.

Given the difficulty in identifying suitable points for the repetition of the test, the data obtained were completed with compression strength tests carried out in a laboratory on samples extracted from fragments of wall which had fallen off during the demolition in the mid-twentieth century.

Three samples between 44 and 50 cm thick were tested under compression, and the density and strength results are shown in Table 1.

Due to the scattering obtained in the sample test results, the values obtained in the analysis were rejected. The stress-deformation results obtained after eliminating the data for M2 are shown in Figure 6.

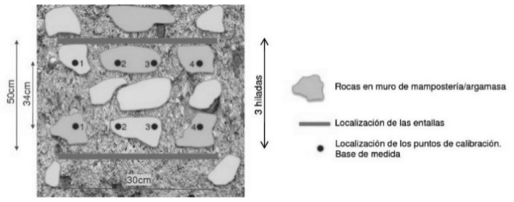


Figure 4. Position of flat jacks.



Figure 5. Stress-deformation graph for the sample tested using a flat jack.

Table 1. Results of compression tests.

Sample	Density (g/cm^3)	Strength (Kg/cm^2)
M1	1930	20.9
M2	1930	5.6
M3	1927	18.2

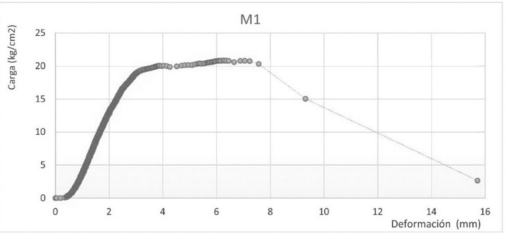


Figure 6. Stress-deformation graph for the sample tested under compression in laboratory.

4.2 *Application of laboratory results to the numerical calculation model*

After obtaining the results from the laboratory tests, strength parameters similar to those of the wall under study are applied to the walls of the calculation model. Considering a density of 1,930 g/cm^3, a deformation module of 4,830 N/mm^2 and a compression strength of 19.5 Kg/cm^2, it is observed that the structural response is optimum, that the deformations suffered by the building are admissible (Fig. 7a), and that the value of compression stress is far lower than the strength of the construction (Fig. 7b).

It is therefore clear that the material tested combines satisfactorily with the local architectural typology selected to generate a stable system in the event of non accidental actions.

Calculation to assess vulnerability in the event of seismic phenomena is carried out through the pushover method (Marques & Lourenço 2013). This procedure entails a nonlinear load calculation, simulating and progressively applying seismic action until the structure collapses in order to ascertain its strength capacity (Fig. 8). The degree of vulnerability of the structure is obtained by comparing this load curve with the seismic demand (Figs. 9 and 10).

The risk levels have been considered taking into account the seismic risk map found in Spanish earthquake-resistant construction standard, NCSE-02, referring to the basic acceleration for each zone: low risk for areas with $0.05 \cdot g \leq a_b \geq 0.12 \cdot g$; medium risk for areas with $0.12 \cdot g \leq a_b \geq 0.18 \cdot g$, and high risk for areas with $0.18 \cdot g \leq a_b$.

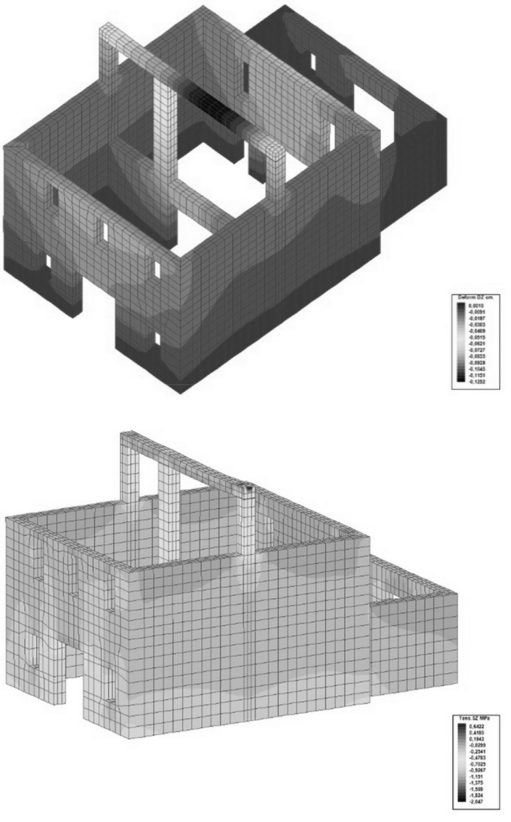


Figure 7. State of deformations (a) and stresses (b) of the calculation model compared to action of gravity.

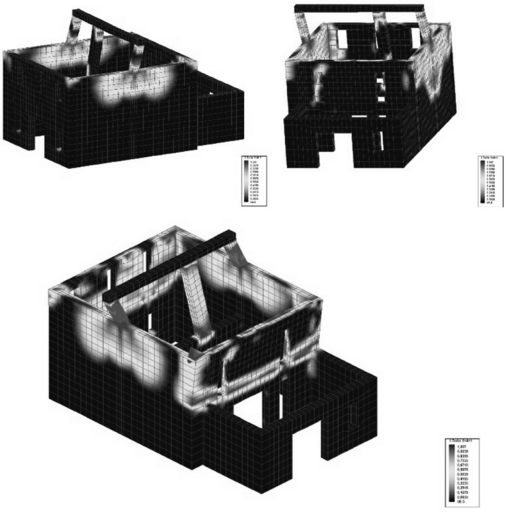


Figure 8. Analysis of the model using the pushover method. Load state prior to collapse (a) and after collapse (b).

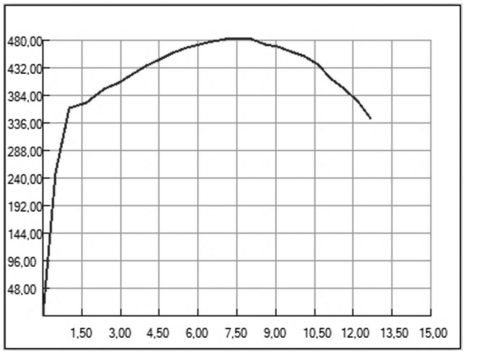


Figure 9. Basal-deformation shear capacity curve at the roof.

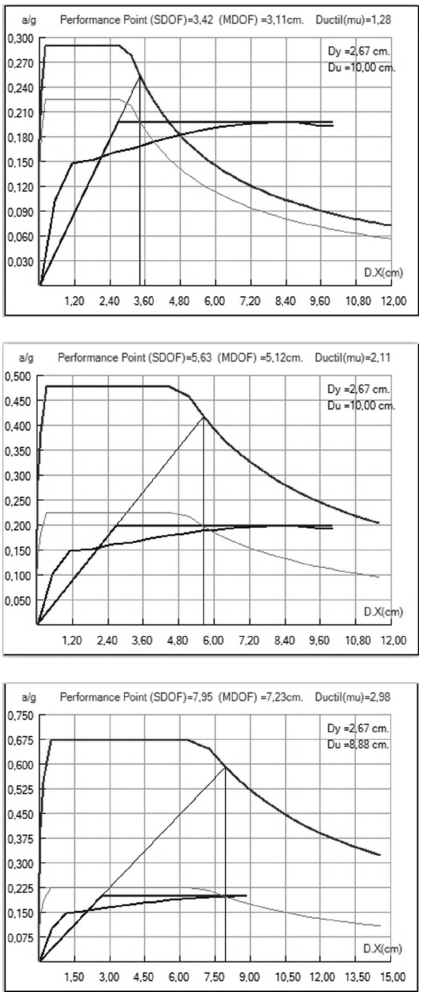


Figure 10. Performance point for low (a), medium (b), and high (c) seismic risk.

From the results obtained it can be observed that for an area with low seismic risk such as the province of Valencia, the structure presents a low degree of seismic vulnerability. However, the risk of collapse in the event of an earthquake increases considerably in the case of buildings in areas of medium or high seismic risk.

5 CONCLUSION

This article demonstrates how nondestructive tests such as flat jack can be used for the mechanical characterization of earthen walls, providing that the characteristics of the building studied allow this, and that wall composition is suited to the insertion of testing devices.

The flat jack method provides results that are accurate enough to carry out simulations for the structural response of earthen elements and are sufficiently reliable to assess real behavior.

The analysis model using the Finite Element Method with a damage model has proved to be a valid procedure for the analysis of this type of structure, which requires a specific approach given its constructive and material characteristics.

NOTE

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Planning for acceptable contemporary earth construction in South Africa

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ABSTRACT: Sustainable living solutions, using natural materials such as earth construction has been proven to be successful for many centuries. In South Africa there is a variety of sustainable buildings, but not enough of these utilize earth construction techniques while claiming green building status. The use of earth construction methods can be positioned at the core of sustainable building. The challenge is the acceptability of upgraded earth building techniques utilised within contemporary public buildings. This paper reflects on green building that incorporated earth materials in contemporary construction. Several contemporary buildings illustrate skills transfer and public education as a holistic approach to earth constructed green building. It can be expected that more examples of this contemporary design approach will continue to set the bar for truly green buildings in South Africa.

1 INTRODUCTION

Different well-known earth construction or building techniques around the world is still widely utilized in South Africa. These techniques are not limited to traditional methods or restricted to rural areas. However, suppliers of building products and systems are often criticised for not being truly sustainable. According to architect and critic Peter Buchanan (2005: 7) politicians and corporations often claim to be acting sustainably based on irrelevant cynical reasons that achieve only seductive advertising that result in scepticism.

Green building containing earth construction can be considered as a core component with-in sustainable building. Figure 1 shows how earth building fits with-in the bigger field of sustainable systems. Although it is not as simple as can be explained in a single diagram, this helps to organize it visually. According to Buchanan (2005: 7) sustainability implies long-term viability that "involve a new respect for and learning from the past" but "can only be achieved by also moving forward". Thus using upgraded traditional earth building techniques often makes sense.

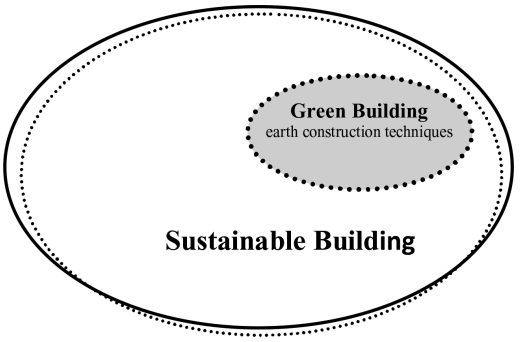


Figure 1. A diagram that explains the position of green building within sustainable building.

2 VERNACULAR LESSONS LEARNT FOR CONTEMPORARY APPLICATIONS

Early South Africa examples of earth constructed houses illustrate the movement towards sustainable building with green building that include earth construction techniques. This approach has gained a lot of popularity the last 15 years in contemporary South Africa (Bosman 2015). These techniques have proven to be relevant where the design team address the needs of the client to accommodate job creation possibilities, building skills, training or public education. The techniques used are conceptualised as part of the planning process of the project.

The earth constructed works of Etienne Bruwer of Greenhouse Architects and of Andy Horn from Eco Design Architects illustrated the positive outcomes of green building 15 years ago. These buildings are substantial and were celebrated both in South Africa and abroad. Both architects often act as consultants and are involved in the design development and training of earth builders in cob, straw bale and stone construction.

Ten houses constructed by Bruwer since 2000 in Barrydale in the Western Cape Province (Fig. 2) have illustrated how green building can influence contemporary earth building in the country. These modest designs were well planned to give the clients sculptured houses from the site, using natural materials, while giving new skills to small builders from the area.

This continuous process as a learned experience and relationship between natural materials, site and available skills is also reflected in other low technology buildings, as seen in the Greenshops Financial Service Centre (GFSC) in Cetane in the Eastern Cape Province in South Africa (Fig. 3).

This project was designed by Anna Cohen, who also trained local builders in the application of earth building techniques. Since the acceptability of traditional earth constructed buildings still proves to be a significant challenge in South Africa more efforts are made to show case upgraded earth construction techniques (Bosman 2015).

The high technology contemporary applications can be seen in the Sishen Iron Ore Community (SOIC) office building (see Fig. 4) designed by Katie Salzmann of Cube Architects.

Earth building techniques such as sods, adobe, and wattle and cob in combination with local stone masonry work, is well known from the last three centuries (Frescura 1989, Edwards 2011). Techniques, such as rammed earth were only introduced by French missionaries early in the twentieth century in some parts of South Africa and Zimbabwe (Archibald et al. 1948:3–4). Contemporary buildings in soil cement techniques as the Sishen Iron Ore Community (SOIC) office building (see Fig. 5) illustrate the usefulness of contemporary soil cement. The mentioned older and traditional



Figure 2. Private earth house in cob, straw bale and stone in Barrydale by Etienne Bruwer (Steenkamp 2012).



Figure 3. GFSC's Chief's Hall with wattle and daube walls and site-sourced timber together with the use of natural light and contemporary innovative design (Steenkamp 2012).



Figure 4. Contemporary soil cement utilized in the Kathu SIOC office building (Bosman & Salzmann-McDonald 2015).

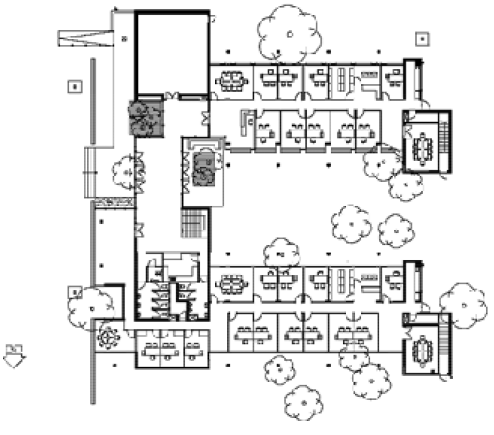


Figure 5. Plan of the Kathu SIOC office building (Bosman & Salzmann-McDonald 2015).

South African techniques are combined with more conventional materials and techniques, which have received good exposure and resulted in its growing popularity.

Contemporary earth constructed buildings as hybrid buildings illustrate the support for a sustainable building culture in South Africa. The following two built projects highlight the contribution that environmental awareness and adult education contribute to sustainable building. The built projects from architect and instructor Andy Horn, from Eco Design Architects & Consultants, highlight some lessons learned. The Nieuwoudtville Caravan Site in the Northern Cape Province, an internationally awarded and celebrated example, will be used for this purpose. This will be followed by a discussion of the recently completed OR Tambo Narrative & Enviro Centre near Johannesburg by principal architect Thunde Oluwa in collaboration with Newtown Landscape Architects and Andy Horn.

2.1 *Nieuwoudtville Caravan Site, Karoo, Northern Cape: Eco Design Architects & Consultants*

Nieuwoudtville is a small town situated 350 km north from Cape Town. This area is famous among tourists for flower viewing in spring. In 2005 the Nieuwoudtville Caravan Site was upgraded for the Hantam Municipality by architect Andy Horn.

By making use of local stone and earth construction techniques within the design, costs were drastically minimized. The construction included a full palette of local natural building methods, utilizing a mix of sandstone and straw bale construction with natural plasters, pole structures harvested locally and eco-friendly, treating it with moon phase harvesting and boron based preservative methods (Eco Design Architects & Consultants, 2016).

The project also made use of rubble trench foundations (Figs. 6 and 7) from the nearby

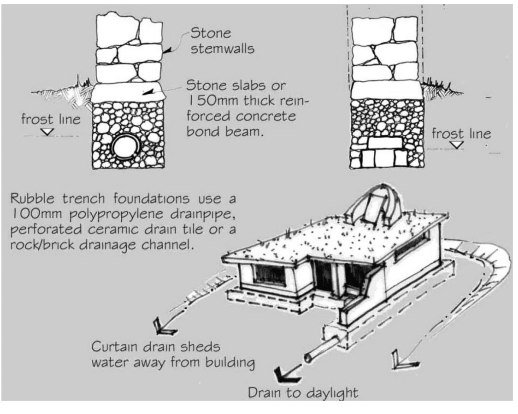


Figure 6. Foundation detail and 3D-sketch of Gate house (Eco Design Architects & Consultants 2016).



Figure 7. Dry stacking of straw bales during wall construction of the gatehouse, Nieuwoudtville Caravan Site (Eco Design Architects & Consultants 2016).



Figure 8. Completed gatehouse, Nieuwoudtville Caravan Site (Eco Design Architects & Consultants 2016).

dumping site, and a planted roof show casing the local succulents and bulbs. This minimized the environmental impact and maximised the involvement of the community for job creation.

The rubble foundations used reduced the use of concrete within the foundations with 75%, of the total cost. The gate house and the slab of the adjacent new ablution block was completed (Fig. 8), together with some landscaping components, before the project management ran into difficulties. The chalets, altered ablutions and the new ablutions were not completed. The upgrade of the Nieuwoudtville Caravan Site was awarded a silver medal for sustainable construction for Africa and the Middle East during 2006 at the Global Holcim Awards (Eco Design Architects & Consultants 2016).



Figure 9. View of partial completed straw bale walls with wetlands in background. (Eco Design Architects & Consultants 2016).

2.2 *OR tambo Narrative & Enviro Centre, Benoni, Johannesburg: Newtown Landscape Architects*

The OR Tambo Narrative & Enviro Centre situated next to Leeupan, in Wattville, Benoni, is a project that served as a social and environmental learning curve for the client which was the Ekurhuleni Metropolitan Municipality (Momberg 2014). The design team received a brief from the client to rehabilitate the Leeupan Wetlands area (Figure 9), while the environmental education centre would act as an educational experiment to demonstrate green building practices (Eco Design Architects 2016).

Its development on the bank of the Leeupan has been welcomed by residents from the surrounding communities who identified a chance to improve their lives by creating small businesses. In exchange they were to teach the local children about environmental protection, since the pan was over-fished, abused, contaminated by acidic mine water, and had become the local dumping ground.

The project aimed to educate the surrounding community, in order for the wetlands to be cleaned (Momberg 2014). Straw bale walls, cob and adobe were combined with soil cement earth walls. Nearby stone and urbanite (recycled concrete) from a local factory was also incorporated in the material palette. Harvested rain water is used for the gardens and flushing of the toilets (Eco Design Architects 2016).

The building's location in the Highveld landscape meant that the nearby wetlands became a design influence, and the use of natural materials and traditional construction methods would ideally support the design. Viable alternative methods could be determined, to serve as a point of reference regarding the green architecture industry in South Africa. Reeds from the wetlands were abstracted and reflected within the timber and steel pole design. Geothermic earth tube technology



Figure 10. Construction of The OR Tambo Narrative & Enviro Centre with complete stone and straw bale walls (Momberg 2014).

is used to draw air into tubes to create ducts (Eco Design Architects 2016). These ducts were installed in the structure, allowing for a cool breeze to enter during the day and warmth to be retained once they are closed. Furthermore, it makes use of heat-insulating polycarbonate cladding and aluminum louvers for winter and summer months respectively (Momberg 2014).

Apart from the museum, outdoor amphitheater and five multi-purpose artist workshops, cob earth floors (Fig. 10), steel columns and straw bale walls support the upside-down steel roof trusses (Fig. 12) and sloping balconies of the five pavilions also contained within the Centre (Figs. 11 to 13). Cow dung and mud was used to plaster the walls, for which local women were recruited to ensure high quality finishes (Momberg 2014).

Further sustainable features include the use of recycled timber, steel and stone from industries close by. Urbanite slab off-cuts from a local factory were used for the garden and the amphitheater seating (Momberg 2014). There are also recreational facilities such as multi-purpose arts



Figure 11. OR Tambo Narrative & Enviro Centre with straw bale wall with first dung layer during construction, (Eco Design Architects & Consultants 2016).



Figure 12. The five completed pavilions (workshops) of the OR Tambo Narrative & Enviro Centre (Momberg 2014).



Figure 13. The OR Tambo Narrative & Enviro Centre with complete stone and straw bale walls (Momberg 2014).

and crafts workshops, an outdoor amphitheatre and the caretaker's cottage (Eco Design Architects 2016). Although the Centre was built at a higher building cost than anticipated, it remains a good example of responsible construction. Green, sustainable materials and traditional construction techniques were used to promote overall sustainability and energy efficient building in South Africa (Momberg 2014).

3 CONCLUSION

The interaction of vernacular methods with newly induced building methods is not new. Since before 2000 South African architects designed and constructed some of these hybrid buildings that slowly started this contemporary tradition. Although the low technology Nieuwoudtville Caravan Site was not completed, the international recognition it received, set the scene in 2006 for more South African "green" buildings to be constructed in earth building techniques. Since then the South African building industry has joined the global effort in reducing its carbon footprint. But more importantly it has highlighted South Africa's rich vernacular architecture and traditional earth building techniques.

Further, the high technology OR Tambo Narrative & Enviro Centre stands as a suitable example to highlight the knowledge gaps regarding the sustainable building industry in South Africa. According to Momberg (2014) the contractor and client had to "write the recipe book…it has worked out more expensive for them, because there were no recipes for mud bricks, or the correct combinations of lime and cow dung to make the perfect plaster or compressed earth walls." South Africa is yet to maintain a steady developmental growth in terms of sustainable urbanization methods with optimum energy efficiency and the technology needed to execute it. The celebration of vernacular and ethnical traditional building influences in South Africa will help to reduce problems with the acceptability of the use of earthen materials, often to be exchanged for more robust conventional methods. These examples show community engagement with the design and construction process followed. The buildings might have to address future management and maintenance problems, as is often the case with South African public buildings, but it shows high levels of acceptability with the materials and building techniques used. Today the South African contemporary built environment with upgraded earth construction techniques provide a hopeful future in which architects and building professionals have a better understanding of green buildings and environmental design than two decades ago. South African building professionals now have a larger perspective on environmental and sustainability issues within the global community. However superficial 'green washing' of systems and materials should make way for greater efforts to make the South African building industry truly sustainable. Planning for green projects starts with using acceptable earth construction techniques as core component to address environmental, economic and social issues that include the culture and the identity of individuals involved.

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Main church of the Cartuja de Vall de Christ, Altura (Spain). Analysis of the interventions

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ABSTRACT: In 2007–2008 the consolidation of the main church walls of "La Cartuja de Vall de Christ" was undertaken. This paper will analyse the reconstruction of the upper section of the main walls and all of the back part of the sanctum walls and the back wall behind the apse. The walls were made of concrete masonry and had deteriorated over time, so first it had to be consolidated before the reconstruction started. The project team decided to do it according to the original, so it was necessary to look for the clues that told how to do it. The conclusions will try to explain that although it is amazing to work on a very special building it is a big responsibility to do it properly.

1 HISTORICAL BACKGROUND

The Cartuja de Vall de Christ is a monastery of the Order of Carthusian monks, founded in the 14th century, 1386, by the infant Don Martin of Aragon, who would later be King Martin the Human. It was one of the most important ecclesiastical centers of the Valencian Community. At present almost all the buildings have been lost, but it was a monastery of great magnitude, formed by the Church of San Martín Obispo, the Church of Nuestra Señora de los Angeles and its atrium, a minor cloister, a major cloister, refectory, hostelry and other minor dependencies, besides those dedicated to the exploitation of the lands and, above all, cattle raising.

The Order of the Carthusians is a contemplative and prayer order, it is the order that professes more austerity and throughout history they have remained in poverty. It was founded in 1084 by San Bruno.

The Nuestra Señora de Los Angeles Church belongs to "La Cartuja de Valldechrist", the second church that was built at the monastery and it became the most important because of its dimensions. The first building was the S. Martín Obispo church, built during the 1390s. The major cloister and the Church's construction works began in 1399 and like for all constructions under this religious order, they formed the main part of the monastery. The monastery was designed according to the orientation of the greater church, which always had the presbytery facing towards the east. The roof plan shows an internal length of 41.75 m long × 9.10 m wide, surrounded by rammed earth walls of 1.8 m width all around its perimeter. The roof is a ribbed vault with a maximum 14 m high ridge draining rainwater through stone gargoyles. During construction, a downpipe and a broken gargoyle were identified in the back wall behind the apse.

The gothic church's main door led to the Cartuja access patio. Before the atrium was built, the church facade had a big Gothic rose window built during the early part of the fifteenth century. This rose window was almost buried and partially destroyed when the atrium was constructed, probably during the second part of the seventeenth century. During this century, the use of baroque style construction started and it was known as "modern construction". The ribbed vault was completely demolished and so were the arc corbels and the presbytery enclosure wall.

The church floor plan almost remained the same, modifications were limited to the construction of the back part of the sanctum, which had 60 cm thick walls and the construction of a new access door to the cisterna's cloister.

Demolition of the ribbed vault was due to certain orthodox criteria that followed the architectural archetypes of that period. The cornice height reaches 18.30 m on the ridge and the wall elevation was made with an external concrete masonry wall of 0.45 m thick and an interior arcade gallery constructed the same way. This led to the space that was generated, between the barrel vault's upper face and the building's roof, leaving a corridor between wall and gallery that was probably used for maintenance purposes. The south wall allowed sun light penetration through nine elliptical oculus, located just underneath the cornice, providing the vault with proper illumination and ventilation.



Figure 1. Picture took in 1919, there is a serious state of deterioration. The oculus in the south wall are still visible.



Figure 2. Drawing representing the baroque period.

Initially the roof was built with a barrel vault, probably without thinking about the dome and the central tower that would rise years later (1655).

A three-pane roof covered the church, two of them sloping sideways and third one to the back part of the roof. The structure had to be made of wooden trusses resting on the arcade gallery.

The central tower rested on the two 1.80 m width walls that constituted the church sides, and over the half point arches; with a distance, one from another, of around 9.10 m, forming pendentives at the four angles to round the hole were the octagonal dome vault would rise.

In 1835 the monastery was bought under the *desamortizatión* or confiscation law. This law existed from the end of the eighteenth century to the twentieth century. The state expropriated the goods of the Catholic Church and sold them or destined them to different uses, military and sanitary among others. The purpose was to pay the public debt and increase the national wealth, creating a bourgeoisie that permitted the state to collect more and better taxes.

By not keeping it in use, it deteriorated very quickly because of the atmospheric conditions and the continuous despoiling and misuse. It was then used as quarry and for agricultural purposes. Movable and immovable properties were taken, some of the pieces can now be found in Segorbe and Altura, but there are even pieces in Paris and USA.

The Regional Administration bought "La Cartuja" and in 1994 commissioned Enrique Martin Gimeno, Cartuja's conservative architect, to prepare a study to both document and to see how to proceed in the conservation and reconstruction of the monastery.

2 INTERVENTION

Some interventions were carried out after the Regional Administration bought the monastery. This paper analyses the one carried out between August 2007 and February 2008. The Project, by Enrique Martín Gimeno, "Consolidation of the walls of Ntra. Sra. de los Ángeles church in La Cartuja de Vall de Christ", was ordered by the Ministry of Culture, Education and Sports, with a grant of the 1% from the Ministry of Development. The contract for the work was won by Edycon company in a public contest. The project team was formed by Enrique Martín and Agustín Pastor. The intervention was carried-out on the stone block walls and concrete masonry walls, and other consolidation work was applied to the wall's finishing layer. The upper area of the concrete masonry has been affected a lot. The walls were made with wood formworks, you can see the holes of the connectors and marks of the wood, composed of stone masonry between 20 and 40 cm. wide. Although the mortars were not analysed, the concrete seems to be made of lime, sand and gravel of different particle sizes. In the book





Figures 3 and 4. Before and after the intervention.



Figure 5. Seen here is the oculus conserved in the south wall.



Figure 6. The erosion of the wall and the trace of the wooden table.

"La Restauración de la Tapia en la Península Ibérica" Vegas & Mileto (2014), one can see in the distribution maps of types of rammed earth, that this construction system is used in the monastery area, they even give two examples of existing constructions in Castellón. The finish layer probably contained gypsum.

To find a place in the wall where the marks of the wood could be seeing, it was necessary first to find the clues of the wooden table of the rammed earth and did it the same way. It wasn't easy because of the serious state of deterioration of the walls, the erosion and loss of mass. The loss of the roof meant that this pathology was present in the top of the wall, the crowning was the worst as it directly received the rain and it was more exposed to the wind. The concrete in the top was almost lost, so the clue was found 2.00 or 2.50 m. below. The baroque walls were gone, just one oculus, three very uneven arcades and a few little parts of the walls were left.

The top of the walls were full of shrubs and earth, so first of all it was necessary to clean it carefully so that no architectural elements were lost. The clues of the arcade pillars and of the walls were searched and found.

The next step was the consolidation of the masonries, the method employed was:

1. Cleaning prior to removing the plants and remnants of mortar, sand and concrete, which didn't allow the adhesion of the new concrete.
2. Injections of hydraulic lime with vinyl resin, in increasing proportions, adding gravel in big volumes. This was necessary in the lintel of the big Gothic rose window of the main facade, since it had lost the integrity of its volume.

3. Three different ways to consolidate the surface of the walls were used, depending on the loss of mass suffered:
   3.1. Minimum loss due to wind and erosion: it was just cleaned it, leaving it alone otherwise.
   3.2. High loss of concrete: this meant the stone of the masonry wasn't stuck to most of the surface, but without sufficient thickness for formwork. The holes were filled with mortar, with different particle sizes depending on the volume to recover.
   3.3. Complete concrete loss: the stone was free or nearly free, but there was enough thickness for formwork, so the work was carried out on each side of the wall, filling with concrete and stones when it was possible to be done.



Figure 7. Consolidation process of the walls. The bottom layer is already done, the medium level is clean but not consolidated yet. The top didn't need to be consolidated, just a few points needed to be filled.



Figure 8. Concrete masonry walls.





Figures 9 and 10. Before and after the intervention.



Figure 11. Formwork for the arcs.



Figure 12. Formwork for the oculus.



Figures 13 and 14. Before and after the intervention of the presbytery enclosure and back part of the sanctum.

When the consolidation was finished, the rebuilding of the lost walls and arcs started. The board used for the formwork had the same size as the original, the mixture of concrete was made with white cement, lime, sand and gravel (1:3:15), used in the construction.

Then the stones were placed, more concrete added and then more stones again, layer by layer until the end of the formwork. Some stones were left with part of them projecting out of the concrete, to ensure the join between the levels of the formwork.

There was a special formwork for the oculus and the arcs, in order to achieve the correct curvature. In the case of the arcs a steel plate was used, formed with a shoring system of metal and wood. For the oculus, a handmade wood structure was put inside the formwork of the wall.

After these, work started on the remaining element, the base of the presbytery enclosure and the back part of the sanctum walls. Here a complete rebuild was carried-out. The base was cleaned



Figure 15. Eaves detail.

and the walls reconstructed with the same method as the others. To ensure the integrity of the join between the south and north walls with the new one, stainless steel corrugated rods were placed and fixed with epoxy resin during the reconstruction of the wall.

On the top of the walls and for the arcs a reinforced strap was employed, joined by a slab between the south and the north walls. Metal drawers which worked as anchor plate were embedded in the slab, these were designed to locate the beams for the new roof, in a subsequent intervention. The eave was rebuilt with solid handmade brick, following the original piece that was preserved in a small area.

3 CONCLUSIONS

It is a privilege to work in such a special place, the ruins of a monastery in the middle of a wonderful landscape, a sacred land. There are few words to describe what one feels when one steps on the top of the walls, where nobody has been for centuries.

But that privilege translates into a huge responsibility. Now, ten years later, you can reflect on the criteria. Does it make sense to rebuild a ruin? Wouldn't it have been more appropriate to have consolidated and then maintained the ruins? Where is the limit? How far should this type of work go? These are the eternal controversial questions of heritage restoration and conservation. If the architect decides to recover the space to use it, there are different options for this. It could be rebuilt as done so in this Project, but a new building could also have been built within the present

ruins, having consolidated these first, and therefore allowing for the ruins to be enjoyed as they are without altering them.

In order to make this decision, it is necessary to consider the restoration theories and it is also very important to take the feelings opinions and expectations of the people who live around the construction into consideration.

Never forget that our generation is neither the first nor the last to work on this building and that should give us another perspective, it makes us more respectful of the heritage, because it belongs to everyone.

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Thermal orthophotos and vernacular architecture: Surveying half-timber walls in Béjar, Spain

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ABSTRACT: Recent diffusion, simplification and subsequent reduction in cost of new technologies, expanded their field of application to vernacular architecture. One of these techniques is infrared thermal imaging, one of the most practical and completely non-destructive methods to assess and study traditional buildings. This paper aims to demonstrate the effectiveness and convenience of combining thermal imaging with photogrammetric techniques, in order to be able to trace plans, elevations and sections from orthophotos that contain thermal information with the final objective of obtaining a deeper knowledge of the construction. The study was carried out on a traditional building in the old town of Béjar, Spain, which over the centuries had suffered from a number of changes and reparations. The text will focus on the analysis of the half-timber walls that, being hidden behind the renderings, would have remained undetected by a conventional survey without the thermal images.

1 INTRODUCTION

When studying historic architecture, several complications can arise, but one of the most recurring impediments is the lack of accessibility and visibility of structures and construction elements. Frequently, especially in Spanish vernacular architecture, structural components are hidden behind other features and materials. A clear example of this issue is the horizontal timber structure that very often is not detectable to the eye of the architect or engineer because it lies behind suspended ceilings.

The lack of visibility is a concern if a survey of the structure and the constructive elements of a building is needed as well as if a detailed assessment of the active degradation processes is needed. Both these scenarios can have an impact on the restoration projects because the lack of knowledge of either the structural configuration or the conservation status entails a degree of uncertainty that negatively influences the decision-making processes in the project and its budget.

There are several techniques and technologies that can help with the analysis of buildings in order to collect detailed information and reduce such uncertainty. In the case of important historic architectures, as a first resort, it is advisable to use non-destructive techniques because, even if the collection of information is essential, the preservation concern must always have the preference. Returning to the example of the horizontal timber structure, the removal of the suspended ceiling, if on the one hand it has the result of achieving a more detailed knowledge of the construction and making the survey of the structure possible, on the other hand it requires the destruction of a construction element, the suspended ceiling, that even if it does not have load bearing capacity, it is relevant from a historical and artistic point of view.

Traditionally, in order not to harm the appearance and materiality of the building, one of the most commonly used procedures is carrying out trial removals and excavations involving a small amount of material sacrificed to the study of the historic building so that a deeper understanding of it can be achieved.

Although the small trial removals and excavations are carried out carefully, there are cases, like monumental architecture, in which the smallest elimination is counterproductive when the final objective is the integral preservation of the building and all its features. In these cases, non-destructive techniques are preferred even if, as a general rule, they have a greater degree of sophistication and consequently a greater cost. Thanks to the advancement and dissemination of technology, these techniques, formerly used only for monumental architecture, have begun to spread also to the analysis of smaller and vernacular architecture due to their affordable cost and convenience.

Infrared thermographic imaging is one of the non-destructive techniques that are increasingly being used in the study of historic non monumental buildings. Since it does not require direct contact with the examined objects, thermography is an

ideal research method. On the one hand, it enables the detection of hidden clues corresponding to different construction phases and on the other hand, thermal images highlight latent pathological processes and make possible to assess the severity of the degradation and establish intervention guidelines.

2 OBJECTIVES

The objective of this paper is to investigate the potential of combining infrared thermographic imaging with photogrammetric techniques in order to, not only discover hidden structures and elements but also survey them with some degree of precision.

Thanks to the thermal camera it is possible to obtain images that can detect non-visible changes of material; however, having those images attributes similar to traditional photos, photogrammetric techniques can be used to rectify them. These rectified images can be finally combined to obtain an orthophoto with thermal information that can be traced, in order to incorporate more information to the survey of the building.

In order to complete this objective, a traditional building in Béjar, Spain, was selected as case study.

3 MATERIAL AND METHODS

For the study described in this text, a FLIR E60bx 1.3 thermal imaging camera was used; it has a FOL 18 mm lens, a range of temperatures between –20 and 120°C and a thermal sensitivity lower than 45 mK NETD.

The produced thermal images, that have a resolution of 320 × 240 pixels, were processed with the FLIR Tools software, which allows to vary the thermal field, the palette of visualization and other parameters such as emissivity, distance, overall temperature and reflected temperature, as well as to calculate the maximum, minimum and average values of a certain area of the image.

The capture process required the choice of a suitable range of temperatures and the proper optical focus of the object. Although initially the automatic temperature scale (thermal field) was chosen, the temperatures range and the colour palette were set up to be consistent in all the images capturing the same area making the subsequent merging of the photos possible.

After calibrating the camera and measuring the distances between the targets strategically placed on the studied surfaces, the thermal images were processed with ASRix, version 2, in order to rectify them. ASRix is a veteran software, specifically designed for the field of architecture, used for years to rectify images and create orthophotos.

Once obtained the rectified thermal images, Photoshop was used to combine the numerous individual images into a single orthophoto, also erasing the presence of the targets used for rectification.

Finally, the orthophoto was inserted in AutoCAD in order to trace the structures visible in the image and obtain actual measures from the thermal information detected.

3.1 *An overview of infrared thermography*

The thermography is a technique that focuses on the portion of the electromagnetic spectrum that corresponds to wavelengths between 8 and 14 μm, (long wave, LW), far beyond the range visible to the human eye (between 0.4 and 0.7 μm) (Tormo-Esteve et al. 2016).

Infrared thermography is based on the two basic laws of thermodynamics and on Planck's law, which states that all bodies whose temperature is above 0°K (–273°C, absolute zero) are capable of emitting infrared radiation; as a consequence, higher temperatures correspond to higher radiation emission. The intensity of this thermal radiation is the one that is captured by thermal imaging cameras. The total radiation emitted by a body is given by the Stefan-Boltzmann law:

$$WCR = \varepsilon \sigma T^4 \quad (1)$$

where WCR = radiation emitted by the body (W/m^2); ε = emissivity of the material, a constant reflecting its effectiveness in emitting energy; σ = Stefan-Boltzmann constant ($5{,}67 \cdot 10^{-8}$ $W/(m^2 \cdot K^4)$); T = temperature of the body (°K).

The term "thermography" can be mistakenly interpreted, since the thermal images do not detect temperatures but the radiation emitted by the surface of the object. Therefore, the image will describe the behaviour of the thermal energy conducted, reflected or radiated by the surface. Only considering the parameters of the object, the thermal camera will translate the detected energy to a temperature scale and finally to a palette of colours visible to the human eye (VVAA 2011).

In the thermal camera, the data collection system consists of an objective, a sensor and a computer processor. The normal objective of a thermal imaging camera is made of several individual lenses that define the visual field and capture the infrared radiation and transfer it to the sensor. The thermal sensor captures this radiation and converts it into electrical signals while the computer processor assigns a value of thermal energy to each pixel of the image. This image is further processed by

assigning a colour to each value of thermal energy making it intelligible.

As a result, the image obtained by thermal cameras can reveal information about temperature variations existing in the studied body, i.e., its thermal gradient, showing the direction of heat flow.

In addition to the thermal radiation emitted by the studied object, the camera also record indirect radiation from other sources; for this reason, the understanding of the characteristics of the device, of the studied object and the environment are critical to correctly interpret thermal images. Moreover, even if the images should be preferably captured with the camera perpendicular to the studied object, among the possible errors that may occur during the data collection, the reflection of the operator body heat can appear, according to the surface characteristics, interfering with the actual radiation from the object.

Since the beginning of its development at the end of the sixties, the thermographic techniques allowed to analyse and measure the transfer and distribution of the heat in a wide variety of scientific fields. However, the application of these techniques to the study of architectural heritage is fairly recent.

Thermographic analysis in the field of architectural heritage does not usually require accurate temperature values, but only seeks to detect possible sources of degradation or hidden structures and elements. In this case, the study begins using a qualitative method, which allows to locate areas of thermal contrast on the surfaces of the building for its subsequent evaluation, with no need of temperature data.

The thermal contrast in the images is based on passive thermography since solar radiation, night cooling and the heating inside the building are sufficient to detect thermal gradients, whereas active thermography would use a source of heating to accelerate the thermal behaviour of the materials and to highlight the thermal contrast (Royo 2015).

Data collection is usually done at the beginning of the day or the night because of the significant variation of temperature and its impact on the ability of materials to store and release thermal energy. In this sense, it is necessary to consider the orientation of the studied façades as well as the elements and other buildings that may cause shadows on the surface, since the amount and intensity of the solar radiation received will be variable.

3.2 *An overview of photogrammetry*

Photogrammetry is a discipline that allows to make 3D models from 2D photographs relying primarily on the mathematical relations of projective geometry and stereoscopic vision. It is an indirect technique since measurements are not carried out on the object, but on images. As photographs are conical projections of an object while the plans of a building are orthogonal projections, photogrammetry can be considered as reverse perspective (Tabares Esteban 1999).

One of the products of photogrammetry are raster datasets (orthophotos and rectified images) that can help to directly obtain plans or maps from a series of photographs, without creating a 3D model, resulting in a very cost-effective analysis technique.

An orthophoto is a digital image that has been processed to correct the alterations due to both the perspective and the aberration of the lenses. All images taken with a conventional camera, as well as in the case of a thermal imaging camera, have some sort of distortions that will deform the represented object. Even if these distortions often go unnoticed, for example in the case of telephoto lenses, when a wide angle is used straight lines appear bended.

Apart from the focal length, the focus distance is another factor that will influence the distortion, however, focus distance is generally a secondary concern in the field of architecture because the façades of buildings are usually photographed form a certain distance and the camera is generally focusing the infinity. Nevertheless with thermal cameras is still difficult to precisely know the focus distance, especially in interiors. In any case the best way to correct the distortion is the calibration of the camera hence ensuring a more than acceptable accuracy. After calibrating the camera and knowing the parameters needed, the rectification of the images is a simple transformation so that the original conical projection captured becomes an orthogonal projection provided that the coordinates of a number of targets or identifiable points on the object are known.

Finally, the orthophoto can be analysed, scaled and used to actually measure what it represents in the reference system of a CAD software.

As for the rectification of the images, the software ASRix, version 2, was used. This software includes an internal process that can be followed in order to obtain information concerning the calibration of the camera, i.e. lens distortion parameters.

The mentioned process uses photographs of a 10×13 grid with numbered targets of known coordinates to provide the distortion parameters for a specific camera and focal distance. These parameters are later applied as the first step of the rectification processed of images taken with the same camera.

In the case of the thermal imaging camera, the targets employed both in the grid for the calibration of the camera and in the real life building

to survey, are aluminium targets which could be clearly identified in the thermal photos as they have completely different emissivity compared to traditional materials used in architecture.

4 DISCUSSION AND RESULTS

4.1 *The case study*

The case study analysed in the text is a 18th century building in the historic centre of Béjar, Spain, located in the Plaza Mayor behind the El Salvador parish church. The main façade looks toward the square; it is made of a stone masonry wall two stories high whose openings are surrounded by ashlars.

The posterior façade looks northward toward the small valley of the river Cuerpo de Hombre. It has four stories and the walls of the two lower floors are built with stone masonry and openings are surrounded by ashlars, like the main façade except that in this case the wall is not completely rendered. The difference in height between the two façades is due to the fact that the building rests on a slope of the hill where the historic centre of the town is located (Hernández Díaz 2012).

The most interesting part of the building and the one that is relevant to the study is the structure of the two upper stories of the posterior façade and the interior structure of the building.

Although the interior structure consists of chestnut pillars, beams and planks, as it can be seen inside the two lower levels (Fig. 1a), only a small section of the framework is visible and it reveals the half-timber constructive technique of timber posts and adobe infill (Fig. 1b).

The rest of the structure, namely the two higher levels of the rear façade, the interior walls and floors are all completely hidden from sight because the walls are plastered and the horizontal structure lies behind suspended ceilings. These are the hidden structures that have been studied through thermal imaging and photogrammetry considering portions of internal and external walls as flat surfaces whose photos, once rectified and combined, can reveal useful information.



Figure 1. a. Chestnut pillars and beams structure. b. Visible half-timber with adobe infill.

4.2 *Findings*

The thermal camera was calibrated as indicated in the previous chapter and a series of images were recorded and individually rectified with ASRix. However, before taking the thermal images, aluminium targets were placed on the surface of the interior walls (Fig. 2) and the relative distance of each target was measured in order to have the necessary reference information for the rectification of the images which would contain at least four targets each.

Large groups of rectified images were put together into mosaic orthophotos which were inserted in AutoCAD and finally scaled and traced in order to extrapolate information to be added to the pre-existing survey of the building.

It was possible to clearly detect the framework behind the plaster thanks to the thermal characteristics of the different materials highlighted by the contrast between the cold winter air ant the heated areas of the building. Thanks to the information contained in these thermal orthophotos it was possible to detect the intricate layout of the framework as well as to have an indication about the dimensions and spacing of the studs and rails.

The thickness of the studs and rails seems to be approximately 8–9 cm although it is possible for this value to be greater. In fact, the panels around the timber structure emit more heat radiation and



Figure 2. Interior wall corresponding to the section A (see Fig. 7) in which the difference between the thermal and normal image can be appreciated. Note also the presence of aluminium targets.

it is possible that the conduction and refraction in the plaster produces an enlarged image of them.

The distance between the posts and studs varies greatly and the presence of rails is not uniform, however it is clear that the half-timber frameworks that constitute the interior partitions are more articulated then those that belong to the rear façade. In the latter, there is not almost any rail and the posts cover the entire height of the story while their distance is also more regular, as can be seen in section E and the rear façade (Figs. 4, 8).

An important feature that was discovered with the thermographic analysis is the presence of a sealed door in section B (Fig. 5) which, due to its size, was a point of access to the adjacent space that, in the past, must have been part of the unit and was later acquired by the neighbours. As a confirmation of this, it is possible to see how the outline of the area on the top floor does not correspond to the lower floor (Fig. 3).

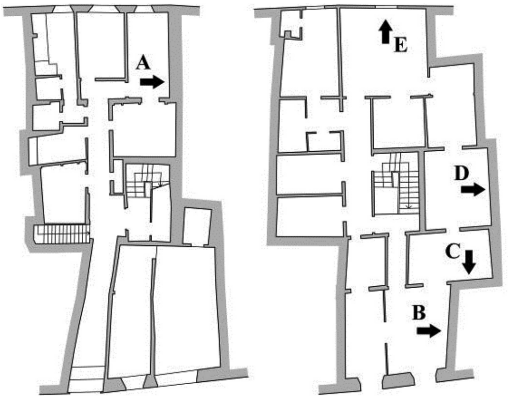


Figure 3. Plans of the last two storeys of the building.



Figure 4. Rear façade with the detected half-timber overlapped.

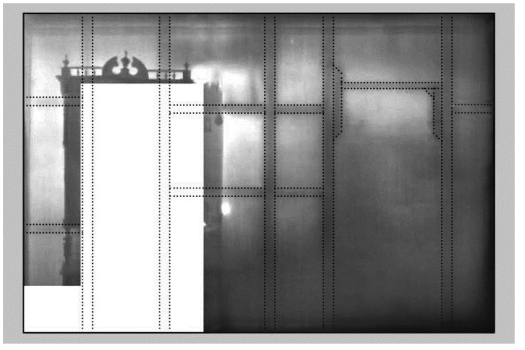


Figure 5. Thermal orthophoto of section B with the detected half-timber overlapped. Note the sealed door on the right. The white parts are pieces of furniture that could not be moved (Mosaic of 22 separate images).

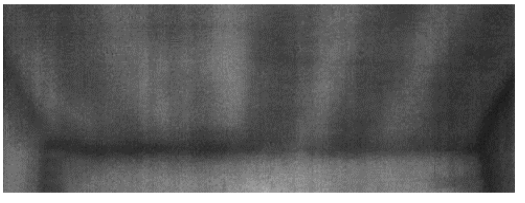


Figure 6. Thermal image of the beams in the room corresponding to section C.

It is also possible that other smaller points of connection between the units existed; in fact, it was very common that, during the centuries, adjacent neighbours traded parts of their properties resulting in a changing interior layout that would not ever influence the façade.

Furthermore, thanks to the thermal images, the presence of different materials used as infill could be detected. For example, in Figure 7, it was possible to identify the areas where adobes or bricks were used as well as the areas where it was not possible to distinguish the presence of any specific construction element. In these cases, the infill could be made of a homogeneous earth mixture, rammed earth or cob for example, however, it is also possible, that the infill material cannot be recognized because of a thicker layer of plaster just dedicated to cover the panels that would prevent even thermal images to show the actual composition. Figure 7 also shows a great variation of the distance between studs; the half-timber with adobe infill has a very regular appearance while the rest of the timber structure is more dense and articulated. This could mean that the partition walls may have been executed not only with different techniques, but also in different moments.

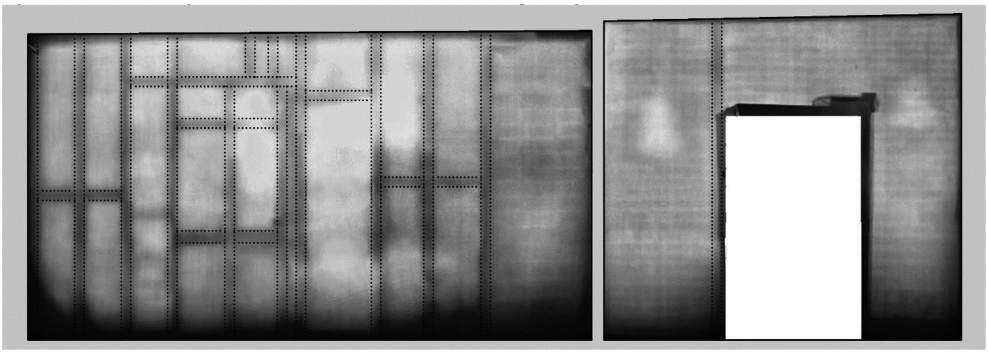


Figure 7. Thermal orthophoto of section A with the detected half-timber overlapped (Mosaic of 53 separate images).



Figure 8. Thermal orthophoto of section C, D, E with the detected half-timber overlapped. Section E can be compared to its corresponding exterior view in Figure 4 (Mosaic of respectively 8, 16 and 20 separate images).

Finally it was possible to detect the beams of the horizontal structure corresponding to sections B and C (Fig. 6) possibly because, in these cases, the suspended ceiling was in direct contact with the timber. These were the only rooms where the horizontal structure was visible in the thermal images because generally the suspended ceiling hangs separated from the beams.

After having obtained very promising and interesting results in the detection of half-timber, the question to ask is why they cannot always be seen. The reasons are different, for example, the lack of a good thermal contrast or thick renderings can reduce the quality of the images but also the wallpaper with its small separation from the substrate prevents the transmission of heat making it very difficult to detect hidden structures with a thermal imaging camera.

5 CONCLUSIONS

Thermal imaging is usually employed in architecture for diagnostic purposes like the detection of

moisture in walls and timber structures as well as the identification of hidden elements. This study was able to get more information out of this powerful technique implementing the combination of thermal images and photogrammetric techniques in order to obtain orthophotos that can greatly improve the survey of a building, in particular when half-timber are completely hidden behind the renderings.

This process was applied to the case study of a vernacular building in the historic centre of Béjar, where the half-timber of the interior walls and part of the posterior façade are completely hidden.

Thanks to the mentioned techniques, not only was possible to discover the constructive features of the half-timber like the adobe, brick and earth infills, but also to obtain orthophotos of interior sections where the distance between studs and rails could be measured. While the procedure for obtaining the orthophotos was rigorous and careful, the lack of definition of the thermal images caused a fairly high degree of uncertainty in the measurement. The uncertainty is not so much due to the reduced number of pixels of the photos, but to the dispersion and diffraction of heat in the rendering between the observer and the studied structure.

Even considering the degree of fluctuation of the measurements, the information uncovered with this technique was extremely useful and otherwise impossible to obtain.

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The influence of ambient conditions into rammed earth compressive strength

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ABSTRACT: Nowadays, there are several research lines regarding how to improve rammed earth properties. Due to the lack of regulation for this material in Spain, the standard used as reference is related to fresh concrete. However, concrete and earth are completely different building materials. This paper presents the results obtained in earth samples that have been manufactured with the same percentage of initial water but they were hygroscopically stabilized at different relative humidities. Moreover, two types of rammed earth were studied using (1) lime water and (2) only water. The aim of this research is to evaluate how ambient conditions can influence compressive strength results of these two types of rammed earth.

1 INTRODUCTION

1.1 *Justification*

Traditionally, earth was used as building material for centuries in the Iberian Peninsula (Mileto et al. 2014). Lately, this practice was replaced by new and modern materials (as concrete, steel, clay bricks, etc.) and people began to consider earth buildings as a synonymous of poverty and low social status. However, most of the Iberian building heritage is constructed with earth that still need advances in research for conservation, rehabilitation and restoration.

From the construction point of view, one of the most relevant topics that arises earth constructions is its resistance. The maximum distributed load that can be withstood by an earth element depends on several factors as the constructive technique used, the properties of the material, the improvements made by the incorporation of stabilizers or additives, the method of preparation and compaction, among others. For this reason, compressive strength of earth elements with structural function must be known for both, rehabilitation and new structures purposes (Bestraten et al. 2012, Miccoli et al. 2014).

Nowadays, there are several research lines regarding how to improve rammed earth properties. Some examples are the study of the effect of particle size distribution, plasticity, compaction, particles degree cohesion, the use of additives, the evaluation of shrinkage during the drying process, durability, compressive strength, etc. (Fontaine et al. 2009 and Houben et al. 2006). However, due to the lack of regulation for this material in Spain, the most commonly used standard is related to fresh concrete, although concrete and earth as a building material are completely different (González 2016).

One of the most relevant properties of the earth is hygroscopicity. Nevertheless, authors found that available publications do not provide information of ambient conditions. Therefore, relevant parameters as relative humidity during curing process are not controlled making the comparison of results very difficult.

1.2 *Objectives*

The objective of this paper is to evaluate the influence of ambient conditions (relative humidity) into rammed earth samples produced using the same percentage of initial water but hygroscopically stabilized at different relative humidities. Furthermore, the influence of using lime water instead of only water is also assessed to evaluate the influence of pH on compressive strength of rammed earth.

2 MATERIALS AND METHODOLOGY

2.1 *Earth physical characterization*

The soil used during the experimentation was characterized using a standardized particle size test (UNE 103101: 1995). Moreover, the Atterberg limit (UNE 103103: 1994 and UNE 103104: 1993), soluble salts (UNE 103205: 2006) and clay size fraction by X-ray diffraction analysis were also determined.

2.2 *Rammed earth mechanical characterization*

The first step to determine the mechanical behaviour of a construction system of a soil element

starts with the determination of the optimum compaction related to the humidity content using the Standard Proctor test (UNE 103500: 1994). This method is used instead of Modified Proctor test (UNE 103501: 1994) because the compaction energy used is similar to the compaction used in traditional construction techniques (modified Proctor test uses compaction energy too high).

After the hygroscopic stabilization of the samples, the second step is to determine simple compressive strength (UNE 103400: 1993) and the real (initial and final) humidity of samples (UNE 103300: 1993).

2.3 *Manufacture of samples*

Once the particle size distribution and the optimum humidity were defined, 35 samples of rammed earth with the same composition and the same percentage of water (in vol.) were made (Fig. 1). The 35 samples were tested following the Standard Proctor test. This test is an easily reproducible method that guarantees the maximum density of the soil. Samples have cylindrical shape with dimensions of Ø 101.5 mm × 116.0 mm height.

Following this methodology, 20 rammed earth samples were made adding water and 15 samples adding lime water. The lime added into water is corresponds to a calcium hydroxide with a concentration of 1.7 g/l. This concentration is remarkably lower than the concentration generally used to stabilize rammed earth with lime. Ranges of 5 to 8 wt% of lime in relation with the mass of earth are usually employed in stabilization. In our case the introduced lime corresponds to 0.02 wt% of the earth weight.

Immediately after the manufacturing of process of each sample, they were kept in the climatic chamber till the hygroscopic stability is achieved (Fig. 2).

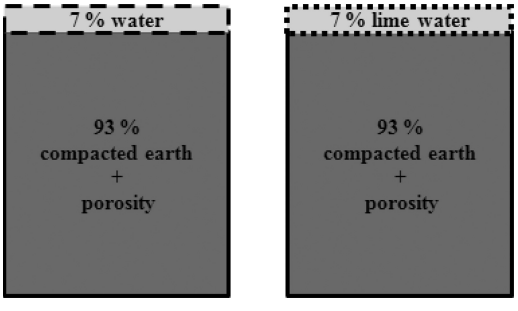


Figure 1. Samples composition scheme. Left: only water, Right: lime water.



Figure 2. Rammed earth samples in the climatic chamber.

2.4 *Hygroscopic stability*

The ambient conditions where the samples were kept until their hygroscopic stabilization corresponds to an air temperature of 20 ± 5ºC with 4 different relative humidities (RH):

- Environment "A": 30% RH
- Environment "B": 50% RH
- Environment "C": 85% RH
- Environment "D": 100% RH

In one hand, 5 samples produced with water were stabilised into each relative humidity (A: 30%, B: 50%, C: 85% and D: 100%). On the other hand, 5 samples produced adding lime water were stabilised in two environments (B: 50% and D: 100%).

The time that takes the stabilization of samples fluctuated according to the relative humidity of the environment where they are exposed. The hygroscopic stabilisation is considered to have finished once the weight variation is 0.1% or less.

Samples were made adding 7% of water (in vol.), obtaining an apparent average Proctor density of: 2.30 ± 0.01 g/cm^3 for the samples made with water and 2.31 ± 0.01 g/cm^3 for the samples made with lime water.

3 RESULTS

3.1 *Earth characterization*

The soil used for the experimentation corresponds to a clayey cohesive soil with medium plasticity.

The soil contains 28% of clay and silt (particle size less than 0.063 mm) with a liquid limit of 36% and a plastic limit of 24%. In addition, a comparative study has been carried out in order to test the plastic behaviour of the clays in relation to the type of water added (water or lime water). Figure 4 shows the variation that occurs when we replace the kneading water with lime water.

The plasticity index of clays mixed with water is 11.94. However, this value strongly decreases when adding lime water (1.92). This variation will

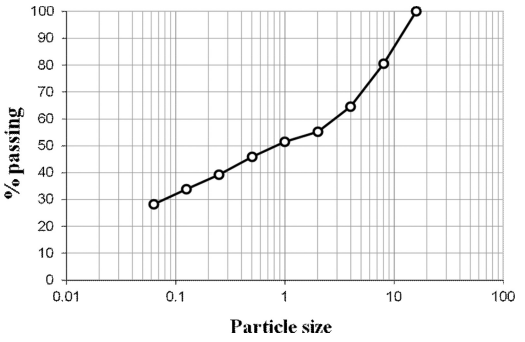


Figure 3. Particle size distribution.

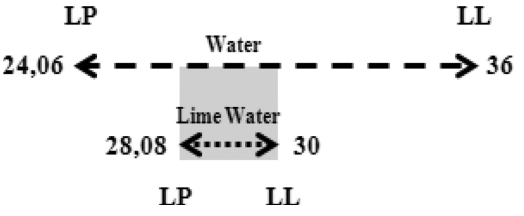


Figure 4. Variation of clay plasticity.



Figure 5. Compressive strength test.

condition the water required by the samples produced using lime water, which will be higher so as to achieve plastic workability.

3.2 *Compressive strength test*

After the hygroscopic stabilisation, standardised compressive strength tests were performed (UNE 103400: 1993) (Fig. 5).

Figure 6 shows the results obtained in all samples tested and Figure 7 compares the average values of the samples (made with only water and lime water, under each relative humidity) as well as the final average densities. It can be seen that behaviours can be classified in three different zones as follows:

Zone A corresponds to the values obtained in samples made with water and stabilised in 30% RH and 50% RH. The average compressive strength is 1.43 ± 0.3 N/mm^2. The apparent average density of samples once stabilized in both RH is lower (2.15 ± 0.1 g/cm^3) and has decreased by 7 ± 1% if results are compared with Proctor density results (2.30 ± 0.01 g/cm^3).

Zone B corresponds to the values obtained in samples made with water and stabilised in 85% RH, and samples made with lime water and stabilized in 50% RH. It can be noticed that the values of compressive strength obtained are 0.78 ± 0.05 N/mm^2, that means that compressive strength is halved if results are compared to Zone A. The density of these specimens (2.17 ± 0.01 g/cm^3) are very close to the densities obtained in Zone A samples, but still lower than the specimens themselves before being tested.

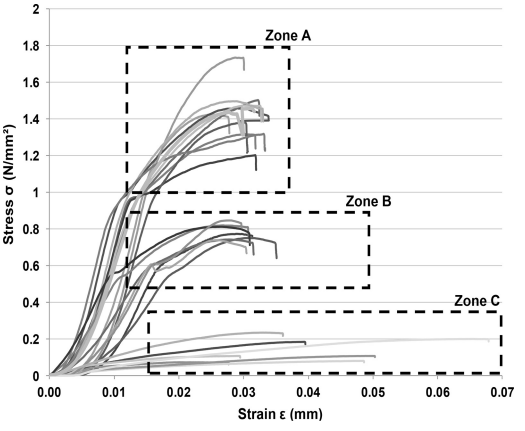


Figure 6. Stress vs strain of all samples.

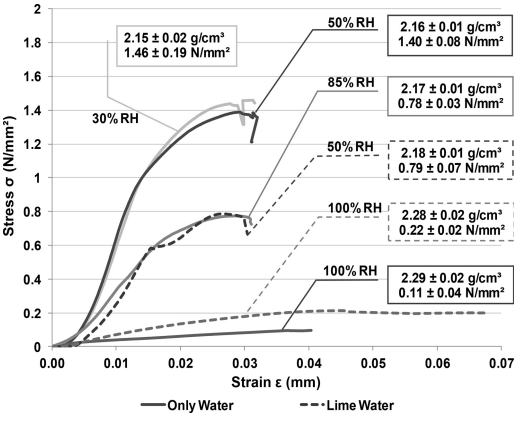


Figure 7. Average stress vs strain of samples.

Zone C corresponds to the values obtained in samples stabilized in the environment at 100% RH, for both water and lime water types. Compressive strength value obtained is 0.1 ± 0.1 N/mm^2. Compressive strength of samples in zone C is reduced to 1/12 of compressive strength obtained in water samples stabilised in 35% and 50% RH. Apparent average density of samples in zone C is very close to density proctor (2.29 ± 0.02 g/cm^3).

4 CONCLUSIONS

Results clearly showed a direct relation between the environmental conditions (relative humidity) where the samples were cured and their compressive strength. Moreover, apparent density was also affected by environmental conditions if results are compared to the initial Proctor apparent density. This parameter control is not new in building materials. For example, standards of wood, plasters and even natural stone takes into account this parameter during the manufacturing process of samples (UNE-EN 408: 2003, UNE-EN 14146: 2004 and UNE-EN 102042: 2013).

For this reason, authors consider extremely important to let know the initial humidity content of samples and also the relative humidity of the environment where samples are placed during the curing process. These two parameters will condition the final values of apparent density due to the hygroscopic behaviour of earth and, therefore, compressive strength.

Compressive strength results of the same sample composition vary more than 900% between dry environment (35 to 50% RH) and very humid environment (100% RH). Variation between 200% and 400% were observed between dry environment and humid environment (85% RH). Therefore, authors highly recommend relative humidities below 50% so as to hygroscopically stabilise rammed earth samples and also to achieve the best compressive strength results.

It is also important to remark that when relative humidity is close to 100%, compressive strength strongly decreases (between 0.4–0.5 N/mm^2), therefore, this materials will be not able to be used as a building material.

Finally, authors have been able to verify that the behaviour of water samples and lime water samples is very different although they were placed in the same environmental conditions: lime water earth samples achieved lower compressive strength values than water earth samples when they were stabilized in high relative humidity conditions.

Samples made with lime water (pH 12) archived lower values of compressive strength than samples prepared with water (pH 7). This can be explained by the reduction in the plasticity index of the clay fraction induced by the alkaline pH. In these conditions the clay acts as a mud. The amount of lime used in this work is 4000 times lower than the lime used to stabilize rammed earth.

ACKNOWLEDGMENTS

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Acoustic test on adobe and rammed earth walls

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ABSTRACT: The text presents the tests realized in the field of the acoustic transmission of the earth architecture, within a larger project in which multiple standardized assays of different types were carried out on samples from two different origins of the region and the need for a regulatory regulation for professionals in the sector was questioned. In addition to the scientific results obtained and presented here, it is important to highlight the problems experienced in carrying out the tests. On the one hand, there was evidenced that standard tests seldom facilitate their use when the element is tested. On the other, it was verified how the administrative processes can become an obstacle for the obtaining of samples in spite of being the earth an abundant material and of easy extraction.

1 INTRODUCTION

1.1 *The lost balance*

Despite years of structural evolution in which millions have been invested in research, development and the application of new technologies and materials which have cornered markets, and have been applied in all kinds of housing, the problems in the everyday housing scenario have not disappeared: dampness, noises, cracks, smells, cold temperatures in winter, excessive heat during summer... All kinds of serious and different-natured pathologies that keep appearing in more modernised constructions. The benefits that the new construction materials can offer are undeniable in comparison to other older ones. Nevertheless, the carbon footprint of their production, the energy cost of extraction and transport, the results of their life cycle analysis and carbon footprint of their industrialisation represent a big drawback. These disadavantages, together with the current trend towards a more harmonic, common sense, even bioclimatic construction, using indirect systems to take the most from natural elements such as the sun, vegetation, wind, water, shade, orientation etc., perhaps there has come the time to consolidate earth architecture as another structural option to consider at the time of designing and investing in the realisation of new housing.

1.2 *Context of the research*

The whole research has included the following tests and studies:

1. a study and simulation of seismic resistance
2. a resistance test against fire and calorific radiation
3. a reaction test against fire
4. a study of capacity, conductivity and thermal transmittance
5. a study, simulation, and simulation of acoustic transmission
6. a study of the steam effect
7. a study of structural resistance

The development and test simulations were possible thanks to a collaboration with the entities AIDICO and the Universitat Politècnica de València, although all tests could not be carried out due to problems concerning time and logistics. Perhaps the most interesting tests among those mentioned are the ones regarding acoustics, as there is less information available on them. With regard to the acoustic tests, there are three that turned out to be of greater interest:

- Airborne noise insulation
- Analysis of impact sound insulation
- Acoustic absorption

2 METHODOLOGY

2.1 *Origin of the samples*

Two samples of earth were taken from representative places in areas of Valencia and Alicante, where there is evidence of earth architecture in the past.

2.1.1 *Valencia*

The earth was obtained from the area of Bétera where the Islamic tower called Bofilla (Vegas & Mileto 2012) still stands today. The appropriate legal procedures were undertaken in order to extract the earth from an authorised area, a small

publicly-owned space in the vicinity of the tower that is under the responsibility of the 'Junta de Montes de Bétera' institution, which authorised the access permits. The SEPRONA (Nature Protection Service) unit was also informed, and permission was requested to avoid any incidents.

2.1.2 *Alicante*

In this case, the earth was obtained from the municipality of Carrícola in the Vall d'Albaida, a town situated very near the province of Alicante, at the foot of the Islamic tower called Carrícola. Due to the same reasons in the previous case, the earth had to be extracted from a public access area that was accessed by a nearby forest trail, very close to the tower, but never within the archaeological area.

2.2 *Making of the samples*

The samples of adobe and rammed earth were made in the laboratory of the School of Building Engineering at the Universitat Politècnica de València.

2.2.1 *Rammed earth*

The formwork was built in a traditional way for this research.

The dimensions of each block are:

Height: 33 cm / Depth: 22 cm / Length: 100 cm

Volume of earth required for each sample of rammed earth:

Volume of 1 block: $0.33 \times 0.22 \times 1$ m = 72.6 dm^3

Total = 72.6 litres or 0.0726 m^3 of earth.

2.2.2 *Adobe*

The adobe samples were adjusted so that their configuration as a sample of a bonded wall would have the same volume as the rammed earth blocks. Upon revising current documentation on the adobes, several authors agree that they should have some proportional measurements with regard to their length and density (ratio 1:2). In this way, the adobes had a measurement of $22 \times 11 \times 7.5$ cm, to which a joint of 0.5 cm had to be added between each horizontal and vertical row, as well as a thickness of 0.5 cm corresponding to the layer of clay rendering. The final sample consisted of 21 bonded adobes, with the same dimensions as the rammed earth.



Figure 1. All samples exposed. From left to right: Rammed earth sample from Carricola, adobe wall sample from Carricola, rammed earth sample from Betera, adobe wall sample from Betera.

2.3 *Calculation of the weight of the adobe wall sample*

The Bétera adobe wall sample weights:

Weight of 21 adobes = 21×2.80 kg = 58.80 kg (being 2.8 kg the weight of a single adobe of Valencian earth checked on weighing scale)

Weight of clay in joints: 17.56 kg

Total weight = 17.56 + 58.80 = 76.36 kg

The Carrícola adobe wall sample weights:

Weight of 21 adobes = 21×2.3 kg = 48.30 kg (being 2.3 kg the weight of a single adobe of Carricola earth checked on weighing scale)

Weight of clay in joints: 14.42 kg

Total weight = 14.42 + 48.30 = 62.72 kg

The weight of the Bétera rammed earth sample:

d = m / v -> m = d × v ->; m = 1877.55 × 0.0495 = 92.94 kg

The weight of the Carrícola sample:

d = m / v -> m = d × v -> m = 1795.54 × 0.0495 = 88.88 kg

2.4 *Acoustic transmission study*

2.4.1 *Airborne noise insulation*

A partition wall or wall is required to be built in a transmission chamber to carry out a standardised airborne noise test. Nevertheless, It was decided not to carry out this kind of test due to the difficulties of availability and the impossibility of constructing a properly closed wall.

Since this is uniform and heavy material, the most convenient way to calculate or approach the value of its airborne noise insulation is by means of the density.

		Valencia	Alicante
Single adobe sample	Mass	2,8	2,3
	Density	1.542,69	1.267,21
Adobe wall sample	Mass	73,36	62,72
	Density	1.542,69	1.267,21
Rammed earth sample	Mass	92,93	88,87
	Density	1.877,55	1.795,54

Figure 2. Samples characteristics summary.

VALENCIA (Bétera)	Dimensions (l x h x d)m	Volume m3	Mass (kg)	Density (d = m / v) kg/m3
Single adobe sample	0,22 x 0,11 x 0,075	0,001815	2,8	1542,69
Adobe wall sample	1 x 0,22 x 0,225	0,0495	76,36	1542,69
Rammed earth sample	0,11 x 0,22 x 0,225	0,0495	92,93	1877,55

Figure 3. Samples characteristics from Bétera (Valencia).

ALICANTE (Carrícola)	Dimensions (l x h x d)m	Volume m3	Mass (kg)	Density (d = m / v) kg/m3
Single adobe sample	0,22 x 0,11 x 0,07	0,001815	2,3	1267,21
Adobe wall sample	1 x 0,22 x 0,225	0,0495	62,72	1267,21
Rammed earth sample	0,11 x 0,22 x 0,225	0,0495	88,87	1795,54

Figure 4. Samples characteristics from Carrícola (Alicante).

	Rammed Earth sample from Carrícola						
	Frequency (Hz)	Emission	Reception (Hz)			Average reception	Gross isolation
			1	2	3		
Bass	100	84,2	68,3	68,1	68	68,1	16,1
	125	92	71,7	71,5	71,4	71,5	20,5
	160	96,2	75,6	75,4	75,3	75,4	20,8
	200	99,9	74,8	74,6	74,5	74,6	25,3
	250	94,9	74,5	74,3	74,2	74,3	20,6
Mid	315	93,6	74,1	73,9	73,8	73,9	19,7
	400	90,7	71,0	70,8	70,7	70,8	19,9
	500	91,4	66,3	66,1	66	66,1	25,3
	630	88,5	61,9	61,7	61,6	61,7	26,8
	800	88,9	56,5	56,3	56,2	56,3	32,6
	1000	88,6	53,1	52,9	52,8	52,9	35,7
Treble	1250	89,9	51,5	51,3	51,2	51,3	38,6
	1600	91,8	48,5	48,3	48,2	48,3	43,5
	2000	87,8	44,4	44,2	44,1	44,2	43,6
	2500	88	42,5	42,3	42,2	42,3	45,7
	3150	86,6	38,4	38,2	38,1	38,2	48,4

Figure 5. Airborne noise insulation test for rammed earth sample from Carrícola.

To find out the sample's reaction against the impact of the sound wave, some aluminium, steel and lead sheets were inserted inside the sample. A signal was emitted to one of the sides, and was received at the opposite side.

During the first attempt, this was tested using the traditional equipment of the omni-directional speaker and microphone, but the results could not be processed, as the signal that echoed throughout the laboratory is greater than the direct transmission.

	Adobe sample from Carrícola						
	Frequency (Hz)	Emission	Reception (Hz)			Average reception	Gross isolation
			1	2	3		
Bass	100	83,9	64,8	64,7	65,1	64,8	19,1
	125	91,6	78,4	78,3	78,7	78,4	13,2
	160	95,9	81,8	81,7	82,1	81,8	14,1
	200	95,4	81,0	80,9	81,3	81,0	14,4
	250	92,8	76,4	76,3	76,7	76,4	16,4
Mid	315	89,7	72,4	72,3	72,7	72,4	17,3
	400	87,7	69,6	69,5	69,9	69,6	18,1
	500	88,9	65,4	65,3	65,7	65,4	23,5
	630	85,7	59,4	59,3	59,7	59,4	26,3
	800	85,2	57,1	57	57,4	57,1	28,1
	1000	83,6	54,2	54,1	54,5	54,2	29,4
Treble	1250	86,4	53,7	53,6	54	53,7	32,7
	1600	86,3	52,5	52,4	52,8	52,5	33,8
	2000	84,2	47,9	47,8	48,2	47,9	36,3
	2500	83,8	44,4	44,3	44,7	44,4	39,4
	3150	81,7	39,3	39,2	39,6	39,3	42,4

Figure 6. Airborne noise insulation test for adobe wall sample from Carrícola.

We decided to change this and emit a signal to measure three different receptions with all of them being at the same height and width of the transmitter, that is to say, the transmitter and the receiver exactly opposite one another. In this way, and despite not having an insulation calculation that we can use, we are able to test how the material reacts in relation to all frequencies, and this is the known spectrum.

By comparing the transmission with the reception, it is clear that certain points experience high or low levels of insulation. Therefore, it is important to compare the raw insulation graphs and try to detect the points that do not follow an ascending line. The values that do not form a lineal insulation curve are marked softly.

The spectra of the transmission and the reception, are shown in the tables, which were measured using a uni-directional microphone and speaker. You can also see the average of the receptions and the gross insulation, but we must not trust the result of the insulation in this case, but the linearity of the result instead.

2.4.2 *Impact sound insulation*

Like all mechanical waves, sound causes a vibration upon making impact on an object. The standardised vibration test consists of emitting or causing a controlled vibration, to measure the initial impact and the receptions at different points, in order to be able to study its propagation through the mass. Such propagation will be defined by the constant K value for vibration.

The reaction of the vibration is studied in all frequencies to see if there is a frequency where it is visibly more or less absorbed.

In this case, an automatic piston was first of all tested as a transmitter, and the response on the accelerometer was non-existent. This may have been due to when the exterior layer of the sample (clay plastering) was made, or in an intermediate layer, which left a small cavity wall that prevented the vibration reaching the receiver. After several attempts, the best solution for obtaining the results, or at least with which we obtained consistent values, was to use a hammer that was cushioned with a piece of wood as a transmitter, and some small pieces of wood with a metal needle as an interior receiver. The accelerometer received vibration which was fading while it moved away from the source.

We divided this test into two parts:

1. A study of the modes of vibration.
   The reaction of the vibration is studied in all frequencies to see if there is a frequency where it is visibly more or less absorbed.

   To do this, the two spectrums were placed and compared with only taking their inclinations into account, not the difference in values. It could be seen that it works practically the same in all frequencies. As the emission and reception spectra were very similar in the four samples, we set up an average of both.
2. Dissipation or evolution of the vibration in each one of the samples.

	Rammed Earth sample from Bétera						
	Frequency (Hz)	Emission	Reception (Hz)			Average reception	Gross isolation
			1	2	3		
Bass	100	90,4	67,6	67,4	67,3	**67,4**	**23,0**
	125	95,5	67,1	66,9	66,8	**66,9**	**28,6**
	160	98,2	71,1	70,9	70,8	**70,9**	**27,3**
	200	97,1	73,3	73,1	73	**73,1**	24,0
	250	94,9	67,1	66,9	66,8	**66,9**	28,0
Mid	315	88,4	62,9	62,7	62,6	**62,7**	25,7
	400	89,3	62,4	62,2	62,1	**62,2**	27,1
	500	90,7	58,2	58	57,9	**58,0**	**32,7**
	630	88,5	55,9	55,7	55,6	**55,7**	**32,8**
	800	88,4	52,0	51,8	51,7	**51,8**	**36,6**
	1000	86,7	46,8	46,6	46,5	**46,6**	**40,1**
Treble	1250	88,3	46,2	46	45,9	**46,0**	**42,3**
	1600	88,8	46,4	46,2	46,1	**46,2**	**42,6**
	2000	86,9	45,1	44,9	44,8	**44,9**	42,0
	2500	86,9	45,7	45,5	45,4	**45,5**	41,4
	3150	85,5	43,9	43,7	43,6	**43,7**	**41,8**

Figure 7. Airborne noise insulation test for rammed earth sample from Bétera.

	Adobe sample from Bétera						
	Frequency (Hz)	Emission	Reception (Hz)			Average reception	Gross isolation
			1	2	3		
Bass	100	84,8	67,8	67,6	67,5	**67,6**	**17,2**
	125	90,9	66,6	66,4	66,3	**66,4**	**24,5**
	160	93	68,7	68,5	68,4	**68,5**	**24,5**
	200	92,4	65,4	65,2	65,1	**65,2**	**27,2**
	250	94,2	65,8	65,6	65,5	**65,6**	28,6
Mid	315	89,7	60,1	59,9	59,8	**59,9**	29,8
	400	90,1	57,4	57,2	57,1	**57,2**	32,9
	500	91,6	53,7	53,5	53,4	**53,5**	**38,1**
	630	89,7	48,7	48,5	48,4	**48,5**	**41,2**
	800	87	44,9	44,7	44,6	**44,7**	**42,3**
	1000	85,7	42,0	41,8	41,7	**41,8**	**43,9**
Treble	1250	86,3	51,2	51	50,9	**51,0**	**35,3**
	1600	87	45,0	44,8	44,7	**44,8**	**42,2**
	2000	85,8	41,2	41	40,9	**41,0**	**44,8**
	2500	86,5	38,3	38,1	38	**38,1**	**48,4**
	3150	84,3	33,4	33,2	33,1	**33,2**	**51,1**

Figure 8. Airborne noise insulation test for adobe sample from Bétera.

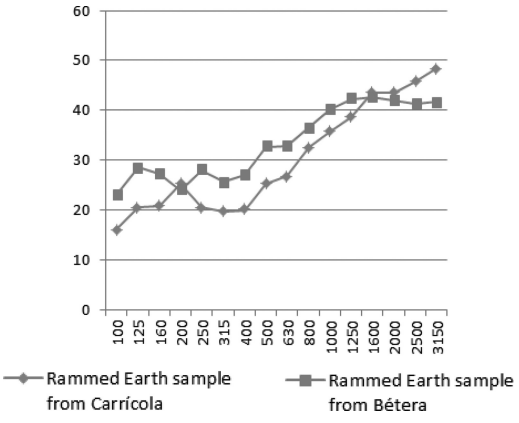


Figure 9. Airborne noise insulation. Rammed earth comparison.

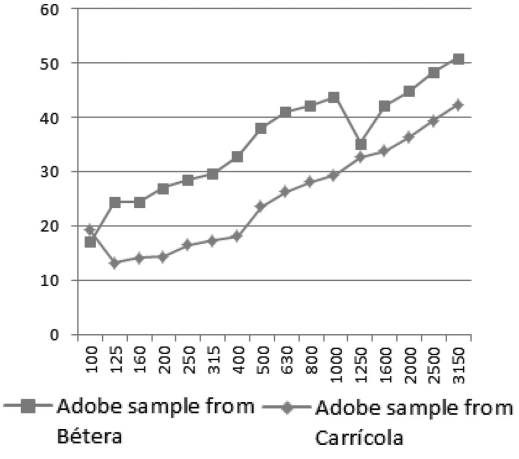


Figure 10. Airborne noise insulation. Adobe brick comparison.

Emission spectrum	
100	77,4
125	80,1
160	80,5
200	77,5
250	73,8
315	76,9
400	78,4
500	71,6
630	72,5
800	80,1
1000	75,1
1250	79,2
1600	73,3
2000	74,3
2500	77
3150	71,9

Receiving spectrum	
100	26,7
125	28,1
160	28,5
200	26
250	25,8
315	28,7
400	28,9
500	27,4
630	25
800	28,5
1000	25,1
1250	28,1
1600	28,1
2000	28,3
2500	29
3150	25,7

Figure 11. Emission and receiving spectrum graphic representation.

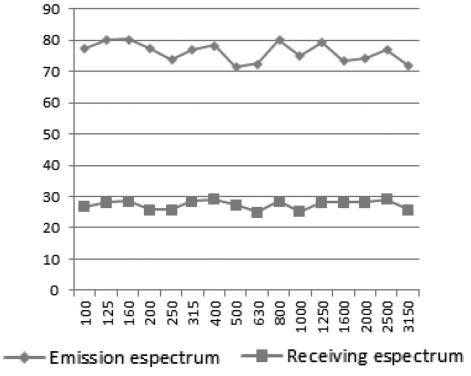


Figure 12. Emission and receiving spectrum graphic representation.

Emission	Rammed earth Sample from Carricola	
76dB	Height 1	Height 2
Point 1	3	2
Point 2	4	3
Point 3	9	9
Point 4	19	16
Point 5	22	28

Emission	Rammed earth Sample from Betera	
78dB	Height 1	Height 2
Point 1	4	3
Point 2	6	3
Point 3	13	12
Point 4	20	19
Point 5	28	27

Emission	Adobe sample from Carricola	
88dB	Height 1	Height 2
Point 1	4	2
Point 2	5	4
Point 3	10	11
Point 4	16	16
Point 5	26	23

Emission	Adobe sample from Betera	
78dB	Height 1	Height 2
Point 1	2	1
Point 2	5	5
Point 3	10	12
Point 4	16	18
Point 5	26	24

Figure 13. Results for dissipation of the vibration test.

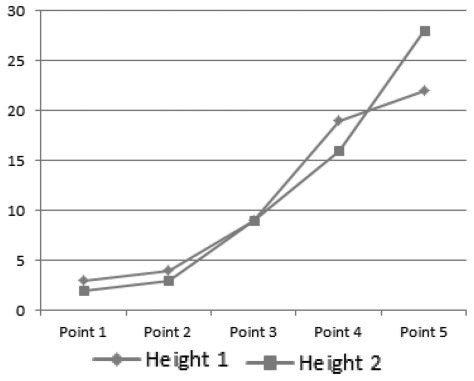


Figure 14. Dissipation of the vibration: Rammed earth sample from Carricola.

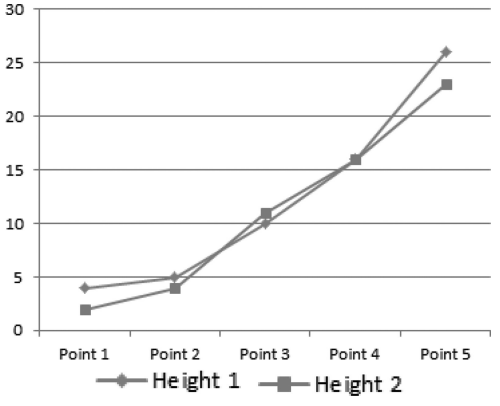


Figure 15. Dissipation of the vibration: Adobe sample from Carricola.

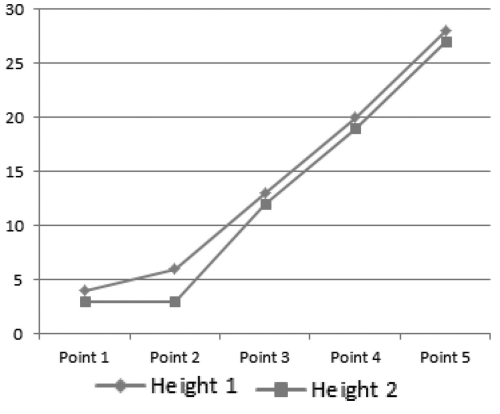


Figure 16. Dissipation of the vibration: Rammed earth sample from Betera.

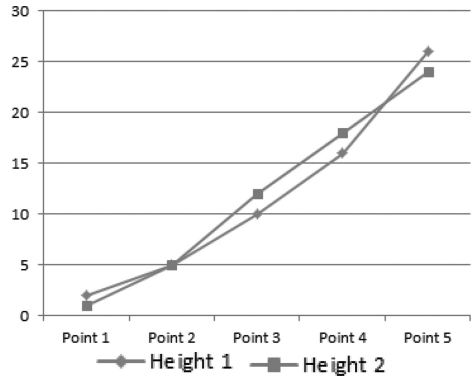


Figure 17. Dissipation of the vibration: Adobe sample from Betera.

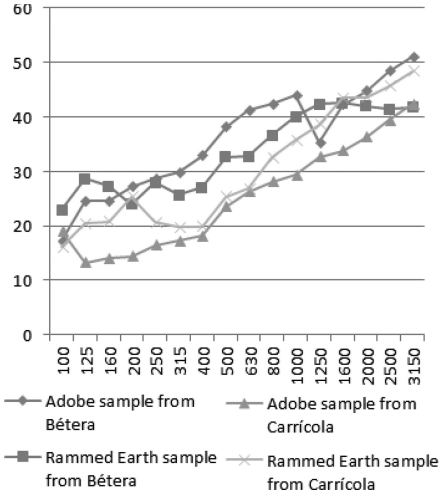


Figure 18. Airborne noise insulation. All samples comparison.

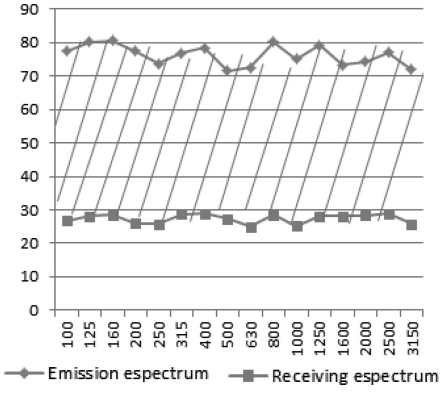


Figure 19. Shaded area: Vibration absorption average.

	Rammed earth sample from Carrícola	Adobe sample from Carrícola	Rammed earth sample from Bétera	Adobe sample from Bétera
	76dB	88dB	78dB	78dB
Point 1	1	2	1	1
Point 2	1	1	3	0
Point 3	0	-1	1	-2
Point 4	3	0	1	-2
Point 5	-6	3	1	2

Figure 20. Difference in the height value for each of the samples at the different test points.

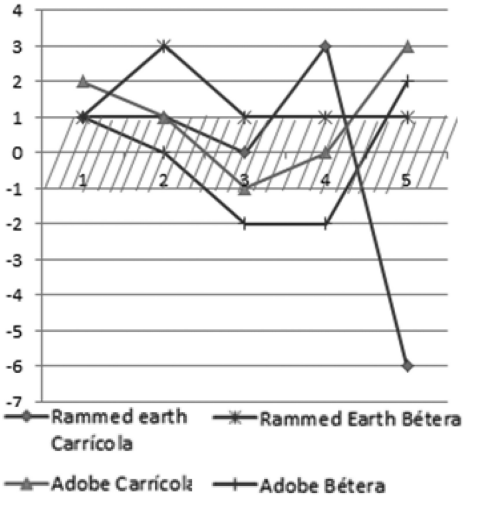


Figure 21. Graphic representation for value difference in height for each of the samples in the different test.

A diagram was made for each sample using the table showing the 10 points measured for each sample with 5 points at each height. To find in each of them the strongest variation, so that the more variation there is, the worse it has worked, because we have two elements one up and one down with a difference of about 10–15 cm.

For each value, the resultant was subtracted from all the values, which is an average value of vibration. To the top-left, we find the transmission value that was obtained in the impact.

3 CONCLUSIONS

3.1 *Airborne noise insulation*

From the data on the graphs made as a result of the findings, it has been proved that the earth from

Bétera offers a better result in relation to airborne noise in both adobe and rammed earth, and this is perhaps due to its density and high content of clay. It has been simultaneously confirmed that the adobe from Bétera is the sample that offers better quality as regards gross soundproofing, followed by the rammed earth from Bétera, Carrícola and finally the adobe from Carrícola.

3.2 *Impact sound insulation*

The analysis of the graph of behaviour to vibration shows that they are practically parallel, and that means there are no problems in the vibration, since it responds similarly on all frequencies.

The entire shaded area will correspond to the vibration absorption that the element studied presents, placing it at the level of good insulators to vibration, like elastic materials, but taking into account that it is a thickness of 33 cm.

3.3 *Dissipation or evolution of the vibration in each one of the samples*

In this test, it is proved how vibration advances through the sample, or rather how it does not advance, as the majority of rules do not take into account values under 20. It has to be taken into account that a metal tube was inserted into the samples, in order to obtain the findings, as this always produces higher results.

All the results obtained in the fracture –1 to 1 are considered correct results, that is to say those values indicate the good behavior of the material before the vibration. In this way it was determined that the rammed earth of Betera presents a better behavior to vibration, that is to say, it transmits less vibration. The more variation there is, the worse it has worked.

It is observed that rammed earth sample from Carrícola works worse in the last two modes of frequency. Rammed earth sample from Betera works worst at low frequencies with a difference of 3 units.

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Experimental study of adobe walls with geogrid reinforced mud plaster

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ABSTRACT: The paper describes the results obtained from an experimental campaign performed to assess the feasibility of an innovative strengthening technique for earthen constructions, which improves the seismic performance. The retrofitting technique is based on the application of geogrids on both sides of the earthen wall. The geogrid is inserted in the mud plaster which is applied to the wall surface in two steps. No additional connections are adopted, and the connection between the geogrid and the wall is granted exclusively by the mud plaster. Almost twenty small walls were built with different types of geogrids available in the market or without any of them. The walls were tested in laboratory under simple compression, diagonal shear, and three-point bending. In addition, some other walls were built to check the durability of the system with respect to environmental conditions. Some samples were also created applying the geogrids on an existing building.

1 INTRODUCTION

The earthen buildings, widely spread all over the world, are a "risky" heritage, especially in Italy, due to multiple factors.

The widespread use of materials and techniques that are frequently not compatible with the existing ones neither from a material point of view, nor from a structural point of view; the lack, except in few cases (Regione Piemonte 2006), of laws specifically targeting earthen heritage and promoting new constructions using this type of architecture; the need of specific standards for the selection of soils and the evaluation of performances of earthen products are some of the main threats to earthen buildings. Furthermore, in 2008, the issue of the Italian Technical Standards for Construction (Norme Tecniche per le costruzioni 2008) has determined a further tightening of anti-seismic regulations, making adaptation works mandatory together with structural improvements in case of interventions conducted on existing buildings.

Considering all these aspects, a research activity has been set up to test and assess the behavior of reinforced plaster on earthen buildings in order to identify a methodology of intervention designed to ensure the improvement of the construction performances against the seismic action.

2 SEISMIC RETROFITTING OF EARTHEN CONSTRUCTIONS

Since the seventies of the last century, after major earthquakes in Latin American countries that caused the loss of many lives, thanks to the collaboration between the Institute of Engineering of the National University of Mexico and the Catholic University of Peru, a wide range of studies started both to examine in depth the construction behaviour during earthquakes and to identify strategies able to mitigate the damage and the disastrous consequences in terms of loss of lives (Vargas Neumann et al. 1992).

Traditional adopted techniques were therefore analysed (Hurtado Valdez 2010). They normally recommend the insertion of reinforcing elements in different points of the building such as:

- Ring beam near the top of the building;
- wooden pieces located at the corners of the building;
- horizontal wooden elements placed along the walls;
- vertical wooden elements located at a distance of about 60 cm and connected to each other through pipes placed horizontally;
- tying wooden elements across the section of the wall (Leroy Tolles et al. 2000).

At the same time researches devoted both to analyse the modes of failure of traditional earthen architecture, and to develop strengthening systems, were set up (Vargas Neumann et al. 1986). Considering that earthen buildings are widely spread in developing countries, retrofitting structures and materials should be as much economic and locally available as possible. Therefore, experimentations have been carried out adopting retrofitting techniques able to fulfil these requirements (Meli et al. 1980, Mattsson 2015, Sathirapan et al. 2006, Webster 2006, Blondet et al. 2014).

3 MATERIALS

3.1 *Earthen plaster*

The experimentation involved the construction of little walls (64 × 64 cm), adopting earthen bricks (size 5,5 × 10 × 20 cm) produced industrially. The bricks are stabilized with hydraulic lime (about 5%) (Argilus®, Brique en terre crue).

The bricks were laid with clay mortar joints about 1 cm thick.

A layer of pre-mixed plaster made from clay, sand, flax fiber, cellulose and natural ochre pigment (Argilus®, Monocouche) was applied on the walls. The particle size analysis of the mixture is reported in Figure 1.

Subsequently, the application of the reinforcing meshes previously selected was carried out. The geogrids were chosen within the ones produced by the geotextile industry and primarily used in the construction of retaining walls. They have been applied without any fastening elements in order to make easier the building operation (Fig. 2). The walls were finally covered by a further layer of plaster on which a siloxanes coating product was applied (Primat® Prosilox-S-A.V.) to ensure greater durability against weathering.

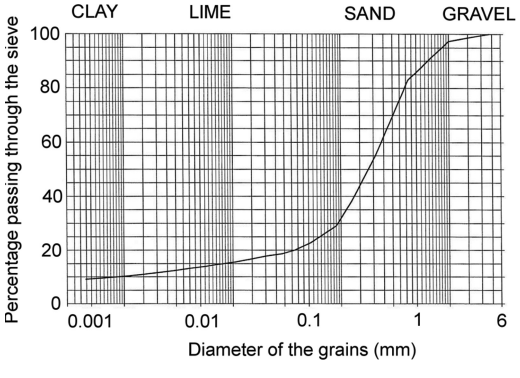


Figure 1. Particle-size distribution of the mixture adopted for the plaster.

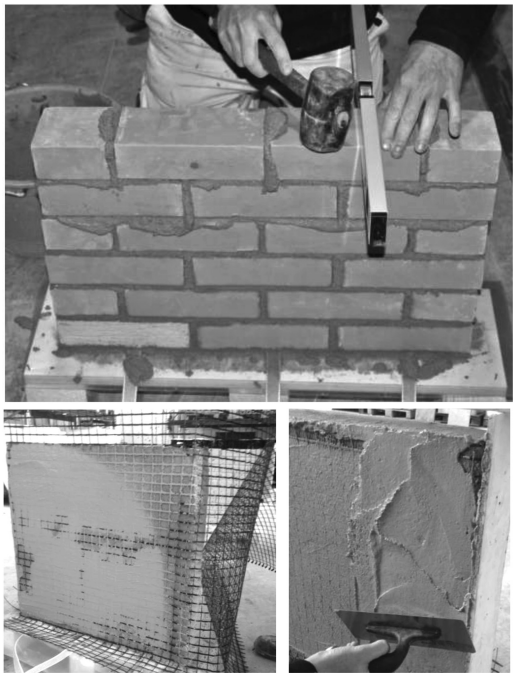


Figure 2. Construction phases of the adobe wall and set up of the reinforced plaster.

3.2 *Geogrids*

The reinforcement selection was carried out through a preliminary analysis of the scientific literature (Sathirapan et al. 2006, Mattsson 2015). From the consulted works emerged that solutions based on the use of linear elements (i.e. bands, cords, etc.) require a laborious and long-lasting application, since the mutual cooperation of the elements is often difficult and complex to achieve without adopting specific devices.

The use of meshes or fabrics directly embedded in the plaster seemed to be the best solution. Geogrids (open mesh, extruded or with welded ribbons) and geotextiles (knitted closed, fabric, knitted fabric or non-woven fabric) were considered. According to their characteristics three different types were identified (Figure 3):

1. Coarse polymeric resin net, without internal reinforcement (Tenax® 3D Grid S).
2. Fiberglass net reinforced with a spider web inside the main mesh (Alpeadria Textil® Arter GTS 31);
3. Polymeric resin net reinforced with a spider web inside the main mesh (Alpeadria Textil® Arter AG 50–50);

In the preliminary phase, samples with reinforcement of jute have also been realized.

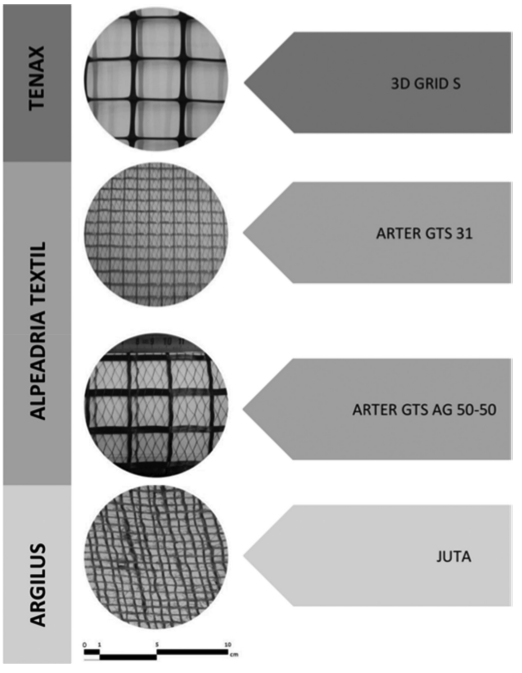


Figure 3. Adopted reinforcement solutions (Tenax®, Alpeadria Textil®, Argilus®).

Unfortunately, no mechanical characterization of the juta net was available, therefore this kind of reinforcement have no longer been adopted in the experimentation.

4 METHODS AND RESULTS

The mechanical tests to assess the efficiency of the reinforcement system proposed were carried out at the Laboratory of materials and structures (MASTRLAB) of the Department of Structural, Geotechnical and Building Engineering of the Politecnico di Torino, Italy. Nine walls, reinforced with different types of geogrid, and nine walls without any reinforcement, useful for evaluating the effectiveness of the proposed intervention methodology, were tested.

Simple compression tests, diagonal shear tests and three-point bending tests were conducted. The tests were carried out following, whenever possible, the ASTM test directives (ASTM 2002, ASTM 2003) and the information acquired through the examination of the literature (Miccoli et al. 2014). The samples were cured at least 28 days, taking care to detect temperature and humidity conditions during the seasoning and during the tests.

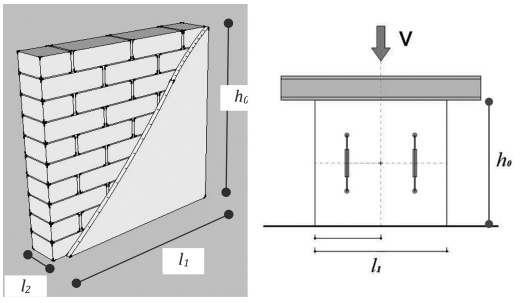


Figure 4. Geometry of the wall (unreinforced) and simple compression loading scheme.

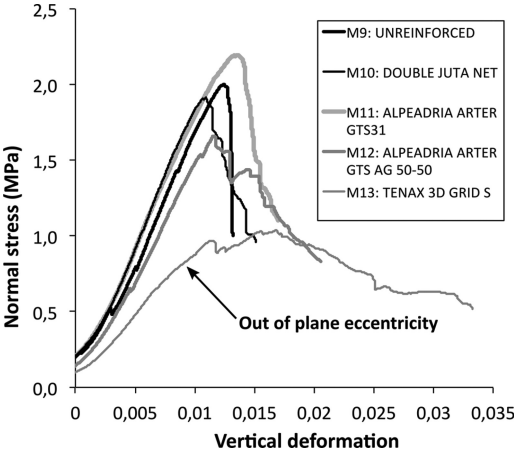


Figure 5. Simple compression tests: stress-strain diagram.

4.1 *Simple compression tests*

Tests were performed with a Baldwin-Zwick 500 kN-B-1058 universal machine. The geometry of the sample and loading scheme are shown in Figure 4. The load is applied through a spherical joint, allowing for minimization of bending stresses.

From the stress-strain diagrams (Fig. 5) can be observed that the mean compressive strength is about 2 MPa, and the Young's modulus about 170 MPa. The dispersion of results is quite limited, and independent from the presence of reinforcement.

Only one curve sensibly deviates from the common behavior, but this was due to a visible verticality imperfection of the wall.

The crack pattern of unreinforced samples is characterized by typical vertical splitting cracks and delamination of the outer plaster (Fig. 6a).

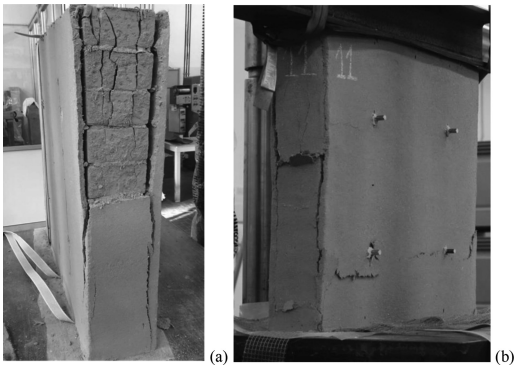


Figure 6. Crack patterns in unreinforced (a) and reinforced wall (b).

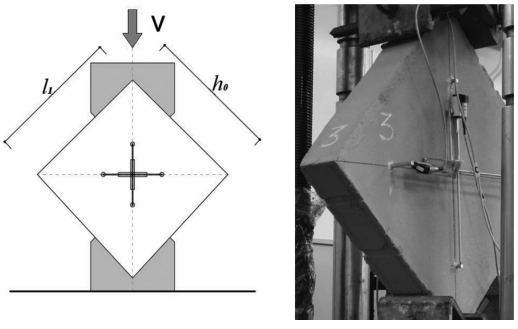


Figure 7. Diagonal compression test loading scheme.

The mechanical confinement of the reinforcement is limited, but delamination of the plaster is inhibited (Fig. 6b).

4.2 *Diagonal shear tests*

The effect of the reinforcement is more evident in the results of diagonal shear tests. The loading scheme, shown in Figure 7, was done according to the ASTM E 519-02 (ASTM 2002).

The shear strength of reinforced specimens reaches 0.1 MPa, almost the double of the unreinforced walls strength. In addition, due to the presence of reinforcement, the brittle behavior of unreinforced walls is replaced by a more ductile response, where the residual shear strength is about equal to the 50% of the peak strength and the ultimate deformation is dramatically increased (Figure 8).

Figure 9 shows how the brittle dominant splitting crack of unreinforced walls compares to smeared cracking of reinforced specimens.

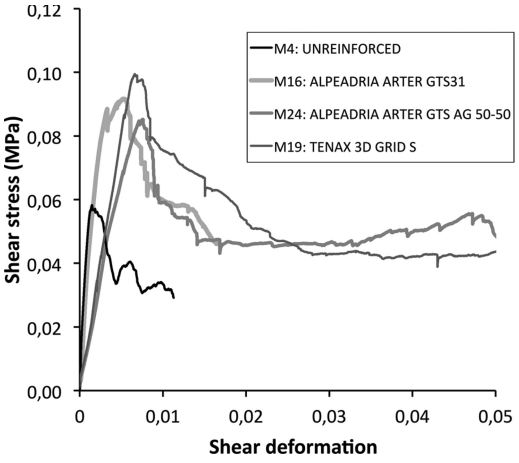


Figure 8. Diagonal compression test loading scheme.

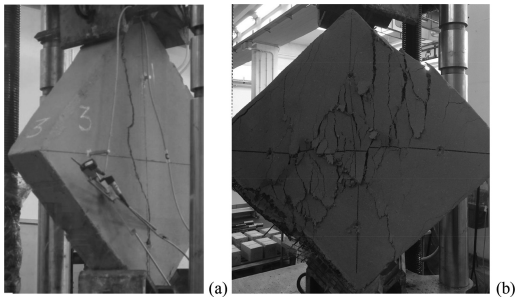


Figure 9. Dominant vertical splitting crack in unreinforced walls (a); smeared diagonal shear cracks in reinforced walls (b).

4.3 *Three-point bending tests*

The three-point bending tests were carried out on walls analogous to the ones used for simple compression and diagonal shear tests (Fig. 10a), contrarily to the beam geometry suggested in ASTM E 518-03 (ASTM 2003). In order to distribute the vertical load on the wall thickness, a stiff metallic beam was placed below the spherical hinge.

In this test as expected, the influence of the reinforcement becomes very evident.

The unreinforced specimens behave very brittle. The peak load is limited and followed by a quite steep softening branch (Fig. 11). The crack pattern (Fig. 12b) is characterized by a dominant flexural crack that starts from the intrados in correspondence of the maximum moment section below the line load.

The peak stress of reinforced wall is more than two times the strength of unreinforced samples,

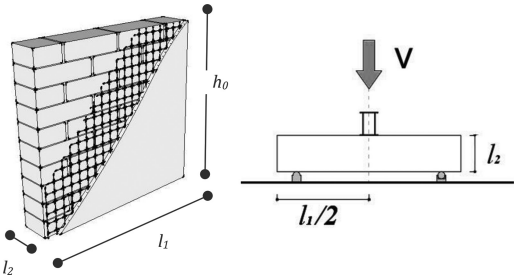


Figure 10. Three point bending tests geometry and loading scheme.

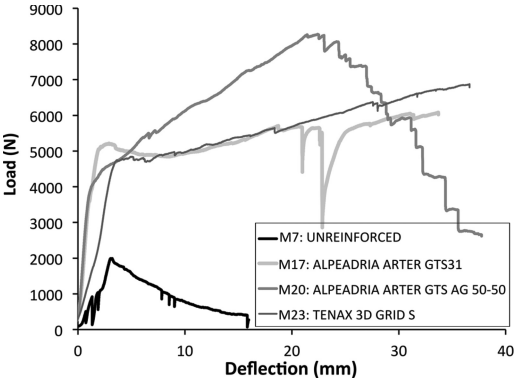


Figure 11. Three point bending tests: load-deflection diagrams.

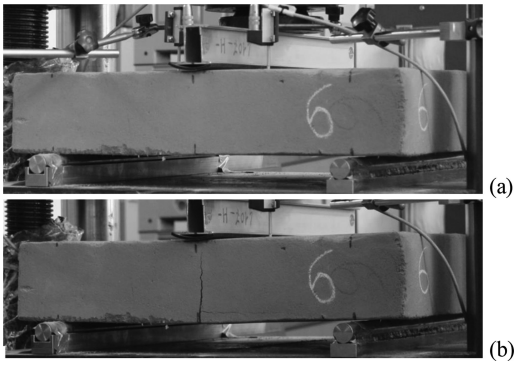


Figure 12. Three-point bending test of unreinforced walls: initial stage (a); final dominant bending crack (b).

and is followed by a strain-hardening regime over a quite wide interval of deflections (more than 0.2 m). The effect of the reinforcement is to redistribute the stresses, even when the whole central part of the wall appears widely cracked. In addition, arching mechanisms are activated in the final

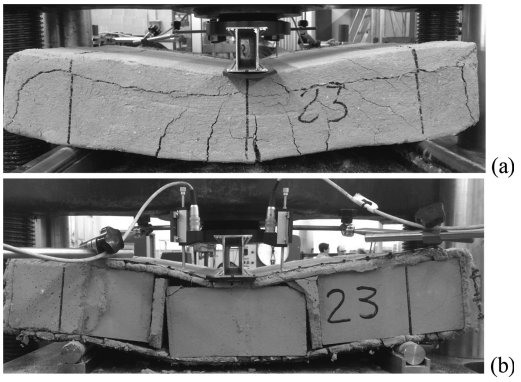


Figure 13. Smeared cracking of reinforced walls: plastered side (a), adobe bricks kinematics and geogrid binding effect (b).

part of the test (Fig. 13a). Figure 13b shows how the reinforcement literally braces the adobe blocks and how the frictional dissipation of energy is activated.

The dissipated energy corresponds to the area below the load-displacement diagrams of Figure 11. As a consequence, it is expected that the reinforcement is able to greatly improve the out of plane behavior of earthen walls subjected to horizontal actions.

4.4 *Durability test*

In order to assess the behavior of the proposed reinforcing technique with respect to external agents over time, some reinforced plaster samples were exposed to weathering. On the top of the walls it was placed a metal flashing with a projection of about 20 cm, to simulate the presence of the roof.

The walls were placed outdoors with North-South exposure. Monthly their conditions were monitored (Fig. 14).

Plaster samples (size 1 × 1 m) were also applied on the outside wall of a mud-brick farmhouse in Rivasecca (Torino, Italy).

The plaster applied on the sample walls showed a good state of preservation a year after their application. On the contrary, the samples of plaster applied on the exterior walls of the farmhouse, even if exposed to weathering during a smaller amount of time, showed erosion and detachment phenomena. The cause of this different behavior might be probably due to a greater protection guaranteed by the metal flashing when compared to the one of the roof of the farmhouse whose projection was very limited.



Figure 14. Durability tests: on the right side the plaster was treated with siloxanes coatings (Primat Prosilox-S-A.V®).



Figure 15. In situ durability tests: application of reinforced plaster.



Figure 16. In situ durability tests: state of conservation after fall rains: the thicker geogrid makes the plaster less durable.

5 CONCLUSIONS

The preliminary market analysis allowed us to select a set of geogrids, normally used in the field of earth containment, which could properly answer to the issue of compatibility, both from the technological and mechanical point of view, in the application of earthen walls reinforcement.

The experimentation has confirmed the feasibility of the application method of the geogrid, which can be incorporated into the plaster without substantial difficulties. The geogrid performs similarly to commonly used plaster-holding meshes.

The reinforced plaster does not tend to peel off from the support, and does not require specific anchor devices such as those provided by other reinforcement systems proposed in literature.

The mechanical tests have highlighted the performance improvement especially in plane shear behavior and out of plane bending, both crucial in case of seismic loads. In our opinion, this result is not only due to the good tensile strength of the geogrid, but also to its optimal stiffness in comparison to the stiffness of the earthen wall.

As far as economic sustainability is concerned, the geogrids could be considered too expensive in developing countries, however they look very promising in more developed contexts.

Geogrids confirmed to be the most compatible and effective reinforcement for adobe walls. None of grids tested showed superior mechanical performance with respect to the others. Since their bending flexibility and thickness are quite different, the grid should be chosen according to the plaster characteristics and thickness. The seismic reinforced earthen masonry could be considered such as a structural material, with wide potential use in the bio-architecture field. The results obtained during the experimentation will help to foster the renewed use of raw earth as a construction material, with strong impact as regards environmental and economic aspects. It should also be emphasized that the effects are not simply restricted to new buildings, but they are likely to concern the entire rich but fragile still existing earthen heritage, widespread in Italy and in many other countries of the world.

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A preliminary study of CIPS as a consolidant for earthen cultural materials

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ABSTRACT: This study investigates the suitability of the Calcite In Situ Precipitation System (CIPS) as a consolidant for treating clay-rich earthen cultural materials. CIPS works through in situ crystallisation of the mineral cement calcite ($CaCO_3$) from an initially non-particulate, water-based, non-toxic solution of low viscosity, features that make this product a potential alternative to current treatment options. The study will assess the treatment by using the archaeological site at Butchers Gully, Australia, as a case study where CIPS was used to treat two rammed earth Chinese miners' cottages.

1 INTRODUCTION

Despite the abundant research conducted in this area, there are still challenges involved with the conservation of earthen cultural materials given their diversity and complexity (Avrami et al. 2000). The lack of a scientific and technological base in this growing field concerned with the compatibility of materials and techniques currently hinders efforts in the conservation of these structures. Problematically, the most common methods used in the conservation of earthen architecture have been borrowed from other associated sub-disciplines such as masonry and stone conservation, which have proven to be unsuitable due to the very different natures of their material requirements. Moreover, the preservation of architectural ruins and earthen archaeological sites presents a series of complex issues for conservation, interpretation and management, mainly because of the difficulties and limitations in stabilising these fragile, exposed structures (Correia & Fernandes 2006). Current conservation treatments for earthen structures include: cleaning and desalination; the use of grouts; consolidants; adhesives; and surface coatings. Of these treatments, consolidation is the most widely discussed and studied treatment for non-decorated earthen materials and has been primarily used to treat issues of structural stability on archaeological sites and ruins, where physical interventions are often compromised or missing (Oliver 2008a). It is also perhaps the most controversial conservation intervention. Lopez Martinez (2012) described consolidation as more of a response to "wishful thinking than to a real possibility", and argued that the restoration of rammed earth architecture should only be made using techniques and materials that are coherent and compatible with the original. However, declining expertise in traditional building methods, the lack of regular maintenance, and poor management of resources has led to the rapid deterioration of earthen structures, particularly on archaeological and historic sites (Rainer 2008).

There are also current gaps in the literature with regards to the way in which consolidants age and fail in earthen materials, as well as a lack of investigation into the impact and effectiveness of retreatment using the same consolidant means that mistakes are still being repeated (Oliver 2008b, Correia et al. 2016).

According to Keefe (2005), the successful conservation of earthen structures requires the use of adequate intervention techniques. This means that the intervention techniques and materials must be sympathetic to the original (although this is not clearly defined), otherwise the intervention is more likely to cause damage and durability problems, rather than solve them. Thus, the ideal material will be applicable on a wide range of earth types; deeply penetrating; non-toxic; easy to handle and apply; non-coagulating; water-repelling; and will cause no discolouration, surface sheen or other

disfigurement (Warren 1999). Furthermore, it would ideally also repel insect and biological growth; be permanent; readily available; indestructible; and economically viable. To date, no such perfect material has been found.

In terms of the composition of materials, there are generally two parallel factors that affect the strength and stability of the final earth structure (Warren 1999): first, the presence of a setting agent, which through crystallisation or adhesion can significantly affect performance in dry and wet modes by restraining the earth particles; and second is the mixture of particle sizes coupled with the presence of natural surfactants that allow the particles to move during placing by reducing internal friction and thereby producing a modified finished product (Warren 1999). Of these factors, the first is of crucial importance in this study given that the Calcite In situ Precipitation System (CIPS) acts through crystallisation within the earthen structure.

2 THE CALCITE IN SITU PRECIPITATION SYSTEM (CIPS)

CIPS was developed at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia by Graham Price and his chemist Ed Kucharski (Price 2013) and is distributed by Lithic Technology Pty Ltd as "a new technology for the treatment of loose, weak materials, such as sands, soils, undersea sediments and weak and porous rocks and their transformation into strong 'rocks' with similar properties to natural rocks such as sandstones and limestones" (Lithic Australia 2016). The system works by in situ crystallisation of the mineral cement calcite ($CaCO_3$) from an initially non-particulate, water-based, non-toxic solution of low viscosity, effectively delivering calcite in a liquid form (Lithic Australia 2016). Originally intended for commercial applications on sands in civil engineering, these features make CIPS a potential alternative to the current synthetic consolidants in the conservation of earthen architecture.

A CIPS treatment begins by preparing two solutions, A and B, in advance of application and generally off-site in a laboratory or factory. Solutions A and B contain all the necessary chemical components already dissolved and ready to react, including dissociated calcium ions (Ca^{2+}) and a chemical phase that is a precursor to carbonate ions (CO_3^{2-}). This means that nothing is taken from the target material, which acts solely as a framework for cement deposition.

On-site application begins by mixing equal volumes of Solutions A and B and injecting this mixture (now called the CIPS Fluid), or otherwise permeating or soaking it into the target material (the substrate). Injection (or surface spraying, etc.) is done at low pressure and a slow flow rate so that the fluid flows into and fills the pore spaces between the particles and saturates the region that is to be treated. The site is then left undisturbed for at least six hours, and preferably up to 24 hours.

The first stage of cementation (shown schematically in Figure 1) begins as a sequence of time and temperature dependent chemical reactions slowly at first, but speeding up over time whereby free CO_3^{2-} ions are produced from the precursor. As these CO_3^{2-} ions are formed, they immediately combine with the dissolved Ca^{2+} ions in Solution A to create molecules of calcium carbonate ($CaCO_3$). Calcium carbonate has a low solubility in water and once sufficient $CaCO_3$ molecules have formed to exceed the saturation level, solid crystalline calcite begins to precipitate from the fluid. The surfaces of the particles/grains of the target material are attractive nucleation sites for the precipitating calcite so small crystals begin to nucleate and grow on these surfaces.

The CIPS chemical reactions continue for several hours after mixing Solutions A and B and its permeation into the target material. Within the CIPS Fluid inside pore spaces, calcium ions continue to combine with carbonate ions as they are produced from the precursor and solid calcite crystals continue to grow out from grain surfaces into the pore spaces. This process continues until the precursor chemical has been totally consumed and no more carbonate ions are produced, rendering the CIPS Fluid spent.

As the grains that make up the target material are packed tightly together, the rinds of fibrous calcite cement around neighbouring grains, which are relatively thick (around 6–10 μm), often meet and bond together. This intergrowth of fibrous calcite rinds is Stage 2 of CIPS cementation and is shown schematically in Figure 2. Effectively, these regions of interacting calcite cement rinds are crystalline bridges between neighbouring grains.

If the target material receives only one CIPS treatment, the rinds of calcite cement remain

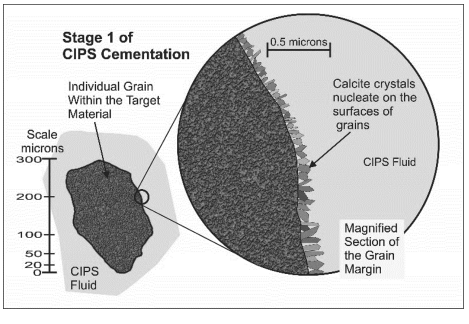


Figure 1. The outer surfaces of sand grains offer preferred nucleation sites for small calcite crystal nuclei (around 0.1–0.2 μm long) so they nucleate in many different crystal orientations.

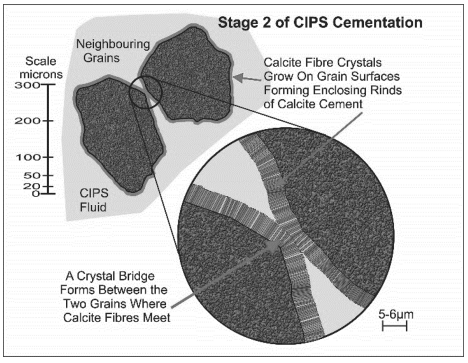


Figure 2. Calcite nuclei oriented perpendicular to the sand grain surface grow longer than those in other orientations (up to 4–6 µm long but only 0.1–0.2 µm thick) forming a rind of calcite cement around the grain.

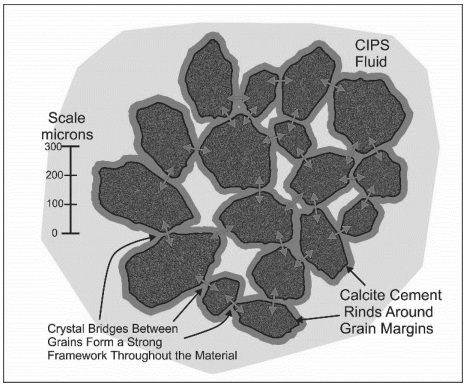


Figure 3. Repeated CIPS treatments deposit additional calcite around the grains making the rinds thicker. Crystal bridges between neighbouring grains become larger and stronger.

relatively thin and the number and size of crystal bridges between the grains remains relatively small. The bonding between the grains is notable, but is not large and in geological terms, the treated material is only slightly cemented. However, after CIPS treatment, when all chemical reactions have run to completion, the bulk of each pore space between the grains remains unfilled and contains only the spent CIPS Fluid, which is a solution of salts and water. Therefore, the CIPS treatment can be repeated, with a fresh batch of CIPS Fluid being applied so that a second round of calcite precipitation can occur. The calcite cement rind becomes thicker and the crystal bridges between the grains become larger and more numerous, which again increases the strength of the treated material.

CIPS treatment can be repeated a third, fourth or even more times (up to 10 times with a fine beach sand) with additional calcite cement being deposited and the bonding between grains increasing each time. The limit in the number of times a material can be treated is determined by its initial porosity and permeability, and the capacity to keep injecting CIPS Fluid into the material without fluid pressure becoming too high or application times becoming too long. The repetition of three CIPS treatments is shown schematically in Figure 3.

The result of multiple CIPS treatments is that a solid crystalline framework is developed throughout the entire treated material with an overall strength designed to meet the needs of the material, the structure or the site (Figure 4). Furthermore, as calcite can remain stable for very long periods of time (millions of years if not exposed to acidic waters) the overall cemented material will also remain stable.

Finer-grained materials that contain a proportion of clays and/or silts do not achieve the high strengths that can be reached by CIPS-treated clean quartz or carbonate sands. However, notable

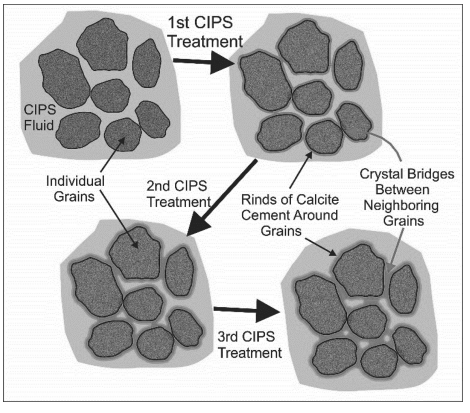


Figure 4. Calcite crystal bridges between grains form a strong bonded framework throughout the entire treated material. This is similar to cementation, which occurs in natural rocks such as limestone and sandstone.

strength increases for these materials can be achieved, depending on the proportion of clay/silt and which type of clay mineral is present.

Thus, this treatment approach addresses several conservation concerns when investigating new intervention methods for earthen materials.

First, it is sympathetic to the original material given that calcite is a naturally occurring mineral that acts as a cementing agent in nature. It can provide structural stability as it cements loose particles together and creates linkages between particles. It does not affect the surface finish, in either colour or texture as relatively small amounts of the calcite cement can provide surprisingly high strength. It is also non-toxic and be applied using a range of techniques to suit the individual site. These features, make it an excellent alternative treatment

option in the consolidation in the conservation of earthen materials.

2.1 *Case study: Butchers Gully, Castlemaine*

The archaeological site of Butchers Gully, Castlemaine (Heritage Victoria Place ID 7969, Heritage Inventory (HI) Number H7723-0303), where two Chinese miners' cottages were treated with CIPS in 2005 provides a rare opportunity to evaluate and assess the long-term effectiveness of CIPS treatment (Banner et al. 2008, unpubl.).

Butchers Gully is in the Mt Alexander Goldfields region, approximately 11.5 km south of the regional town of Castlemaine in Victoria. It is a dry stream line winding through low forested hills and is rich with the remains of small pits, adits and shafts from the 19th century and water channels and eroded creek banks from sluice mining for gold in the 1930s–1940s. Of special interest are the remains of three small huts composed of local stones and soil located less than one kilometre upstream of the confluence of Butchers Gully with the Lodden River. One of these huts is in poor condition, consisting mainly of a jumble of stones, but the other two are in better condition, consisting of the lower courses of hut walls of which some are composed of natural stones and others of packed mud and gravel (pisé). The huts lie at an elevation of around 310 m in hilly terrain covered with an open forest of box and ironbark eucalypt trees with sparse mixed scrubby undergrowth (Banner et al. 2008, unpubl.).

Understanding the construction of the walls was paramount in developing a conservation treatment plan. The wall remains are primarily composed of local stones and pisé, a mixture of local light-mid brown clay and gravel. Although most of the walls consist of moderately large stones (up to 50 cm across) bonded with a pisé mortar and plastered on the inside with a pisé coating, some walls are made entirely of packed pisé. Packed pisé mud was also used along the eastern side of the smaller hut and in other places where the walls were constructed without any stones.

The conservation treatment options at Butchers Gully focused on stabilising the pisé surface to reduce the rate of erosion; therefore, the conservation strategy was to specifically treat the clay matrix component of the pisé with CIPS Fluid. As strength could only be achieved if the CIPS Fluid penetrated into the target material, part of the treatment strategy was to ensure that the application methodology allowed the CIPS Fluid to penetrate at least 5–7 mm beneath the surface.

An application method was developed by Price (Bannear et al. 2008, unpubl.) where CIPS Fluid was sprayed onto the outside of the walls and sucked into the material via capillary action. This method was tested in the laboratory with satisfactory results (Bannear et al. 2008, unpubl.), but only worked well if the walls were very dry and absorbed the fluid at a reasonable rate. Therefore, a hand-held spray application of CIPS was conducted during a prolonged dry period in summer. The walls were sprayed with CIPS Fluid in March 2005 using a pre-prepared formulation that was transported to Butchers Gully in 25 L drums. Pre-set volumes of Solutions A and B were mixed in a tank onsite, and a small electric pump was used to draw from this tank and deliver the mixed CIPS Fluid to a hand-held spray wand. Once the two solutions were mixed, it was sprayed onto a section of the walls within 2–4 min. Given the fragile nature of the walls, a compromise had to be reached where the spray application was not so forceful that any original material from the walls washed off, but was sufficient to allow the fluid to penetrate the surface and saturate the underlying material. This meant that the fluid had to remain on vertical surfaces long enough for it to be sucked inside by capillary action. If too much fluid was applied too quickly, it simply ran off, so the only option was to wet the surface with a light spray of CIPS, allow that to be drawn inside before applying another light spray to re-wet the surface, and to keep repeating this procedure until no further CIPS Fluid penetrated the surface (Bannear et al. 2008, unpubl.).

CIPS Fluid was sprayed into all small cracks, including shrinkage cracks in the mud pisé wall coatings where it soaked into the pisé from either side and behind the cracks; beneath overhanging stones and inside cavities. Repeated spraying of each section of wall was continued for up to 30 min, or until there were signs that no further luid was being absorbed, before moving on to the next section. This application method allowed a large volume of the CIPS Fluid to be absorbed into the walls' surfaces. After spraying, the walls were left undisturbed and no further action was taken. Only one application of CIPS was sprayed onto the walls of the huts (Bannear et al. 2008, unpubl.).

Following CIPS treatment in 2005, the walls were left undisturbed for over a year and re-examined in May 2006. The most notable change was a superficial growth of green algae that had developed in a few places on the walls, most likely following an extended period of rain prior to the visit. A visual inspection indicated that only one small part of one wall showed clear evidence of post treatment erosion, where one of the loose siltstone blocks sitting on top of the wall had fallen off and left a sizeable hole in the siltstone block. Further inspection of the area where erosion tests had been undertaken prior to treatment showed no sign that there had been any further loss of material (Bannear et al. 2008, unpubl.).

The Butchers Gully huts were revisited in 2007 to check if any further deterioration could be

detected. The only visible change was in one section of the packed pisé wall where a 10 cm × 15 cm slab of pisé had fallen off the wall and left a scar. No other signs of erosion were detected.

2.2 *Erodibility Index*

As stated previously, the overall objective in treating the walls of the miners' huts was to reduce the rate of erosion of the pisé coatings and packed pisé walls. It was recognised that the most dramatic erosional change would be the physical loss of the clay matrix in the mud pisé, which would allow pebbles to fall out of the walls, remove pisé mortar from between stone blocks and reduce the thickness and extent of the pisé mud coatings on the walls. Therefore, quantitative measures were required to understand the susceptibility of the walls to erosion from rainfall before and after CIPS treatment.

To determine the Index of Erodibility, or the quantity of potentially erodible materials on the walls, a method to remove and collect material from the walls poised for erosion in the near future was required. There were several possibilities as to how to collect the debris, including scraping the walls with a metal scraper, scrubbing the surfaces with a brush, or sandblasting to remove material (Bannear et al. 2008, unpubl.). However, with these methods, it would be unclear as to whether or not only the potentially erodible material had been removed from the walls, or whether other more tightly bonded material had been disturbed by the forces involved in scraping, scrubbing or blasting. Furthermore, as different micromechanical deformation processes are used in the above-mentioned techniques, a method was required which had the same outcomes on the walls as a rain shower, an erosion process that involves water drops striking the wall, dislodging already loosened particles and washing them off the wall (Bannear et al. 2008, unpubl.). Thus, a simple evaluation method was developed by Price whereby an artificial rain event was simulated to measure the rate at which the clay matrix and pebbles were physically washed off the wall surfaces.

Eleven 'spots' on the walls of the huts had already been selected in December 2004, and covered either a section of packed mud pisé wall, pisé mortar between stones or mud pisé coating over a stone wall. The intent was to collect run-off water and debris in a catch pan held below the 'spots'. The artificial rain events were created using a hand-held spray wand attached to a portable garden spray tank filled with plain water. The sizes of the water droplets and flow rate were controlled by maintaining a constant pressure in the tank. The volume of water sprayed onto each 'spot' over a 10 s period was 80 mL. The spray pattern from the nozzle was circular in cross section and the circular areas where it struck the wall were kept at a constant size (78.5 cm^2) by positioning the spray nozzle 10 cm from the wall during spraying and oriented perpendicular to the wall.

The intensity of the artificial rain showers was equivalent to 1018.6 $mL/m^2/s$, or in normal terms for measuring precipitation, 8800 mm per day. These simulated rain events were unrealistically intense, but were necessary to erode a measurable amount of material from the very small wall areas in the extremely short time intervals of the tests. The water and debris washed off each 'spot' were collected and stored in jars for subsequent analysis in the laboratory. As expected, different amounts of debris were collected from the different 'spots', reflecting their different erosion potentials, so the results were combined to produce an average for all the 'spots'.

The erodibility of the hut walls (i.e., their ability to be eroded by the intense simulated rain event) was measured before treatment in 2005, and re-measured over a year later in May 2006 using a new set of 11 'spots' adjacent to the areas tested in 2005. These 11 'spots' were subjected to the same rain events using the same conditions (such as the same water volume, same pressure, flow rate and the same method was used to collect the debris washed off the walls) as those used in 2005.

The results from both series of erosion tests are presented in Table 1.

These erodibility measurements indicate that the CIPS treatment reduced the rate of erosion to

Table 1. Measured erodibility rates before and after CIPS treatment.

	Before CIPS Treatment (2005)	After CIPS Treatment (2006)
Average erodibility rate	18.5 $g/m^2/s$	6.8 $g/m^2/s$
Standard deviation in measured rates	12.9 $g/m^2/s$	5.2 $g/m^2/s$

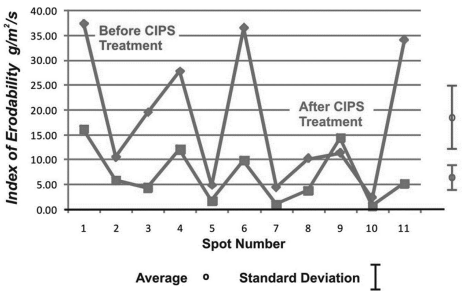


Figure 5. Chart comparing the 11 Index of Erodibility values prior to CIPS treatment, plus the average and standard deviation (blue line and symbols), with the 11 Index of Erodibility values afer CIPS treatment, plus average and standard deviation (red line and symbols).

approximately 36% of the rate that existed prior to treatment, from 18.5 g/m^2/s to 6.8 g/m^2/s. Treatment also reduced the standard deviation in erodibility among the selected test sites from 12.9 g/m^2/s to 5.2 g/m^2/s. This was a significant reduction in the erodibility rate and confirmation of the beneficial consolidation via CIPS.

Apart from the reduction in erodibility rate, and the dislodgement of a piece from a loose siltstone block, there were no other changes to the structure, size, appearance or texture of the hut walls. Further visual inspections carried out in 2007 and 2016 confirmed that no other changes had occurred and the walls had not undergone any significant erosion.

3 CONCLUSIONS AND FUTURE DIRECTIONS

This research aims to evaluate and assess the potential of CIPS as a consolidant for earthen cultural materials as it is more sympathetic to the original material and can provide structural stability by the creation of calcite bridges between soil particles. Observations based on the application of this treatment at the archaeological site of Butchers Gully indicates that its application has slowed down the rate erosion on the walls; however, this needs to be confirmed by further field and laboratory work, including detailed examination of CIPS-treated clay materials, identification of the grain-scale bonding mechanisms and evaluation of the changes in strength and/or abrasion resistance produced by CIPS treatment.

The key question of this research is whether CIPS can be used widely as an effective conservation treatment for clay-rich earthen materials. In order to investigate this hypothesis, a number of research objectives have been determined, including: (1) further quantification of the performance of the CIPS treatment at Butchers Gully, including whether addition CIPS treatments would be effective in further reducing the erodibility rate; (2) understanding the physical, chemical and biological effects of CIPS on various soil types; (3) evaluating the suitability of CIPS on other types of soil and earthen building materials; (4) investigating the most effective means of applying CIPS in situ; and (5) evaluating the effectiveness of different CIPS treatments over time.

The next stage of the research will focus on analysing soil samples that have been treated with CIPS to understand how its application has affected the soil matrix of the Butchers Gully archaeological site. Fieldwork and permission to collect treated samples from the Butchers Gully archaeological site will be required prior to undertaking the next stage of this research and is currently in progress. Furthermore, as CIPS was primarily designed to work with sands, experimental work will also be conducted to investigate its suitability for clay-rich soils. Soil samples will also be analysed using scanning electron microscopy (SEM) and optical microscopy (OM) to determine the crystalline structure of the soil types and to evaluate the calcite bridges formed post treatment.

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Low-cost adobe structures with bamboo additives and bamboo frames. Strength tests

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ABSTRACT: The research shows the possibility to improve the resistance of adobe constructions using products of bamboo processing waste, like the bamboo powder. It can be used as additive in the mixture of the adobe bricks and can increase their resistance. A parallel research has investigated the possibility of using bamboo canes to realize an external reinforcement to the adobe structures. Under normal operating conditions, the bamboo reinforcement does not collaborate with the adobe structure, but in case of strong exceptional events is able to avoid the collapse of adobe walls. The tested solutions suits to solve many problems in difficult contexts in Latin America. In fact, this system can be built as self-construction, in environmental extremely precarious conditions, and is also part of the traditional building knowledge of the populations to which it is addressed.

1 INTRODUCTION

1.1 *Raw earth architectures*

Vernacular architecture in its many forms is able to gather and witness traditional building techniques of any time. During the centuries, these traditions achieve high levels of adaptation to the context, with solutions of considerable interest from a structural, bioclimatic, economic and environmental point of view. Among them, earth constructions play a leading role, having demonstrated a high adaptability. In fact, they spread for thousands of years throughout the world, in areas with very different environmental and social contexts.

Many construction techniques rely on the use of raw earth. The best known are adobe and rammed earth (called also *pisé* or *tapia*). Very widespread are the techniques based on earth and straw, for example the wattle and daub (called *quincha*, *bahareque*, *embarrado*, *cuje* etc. in Latin America.), and methods based on earth and wood, like the cob wall constructions (*bague* or *freemason*).

In this paper we refer to the technique of adobe. It consists of sun-dried bricks made of a mixture of clay, water and organic fibers, pressed into an open timber frame. Adobe buildings are widespread in Latin America and the Middle Eastern countries, but also in the Mediterranean Europe.

The main property of adobe is the compression resistance, but no tension resistance. Therefore, one of the most critical points of adobe buildings, and in general of earthen structures, concerns their seismic behavior. In case of horizontal loads of a certain severity, the walls tend to crumble.

This material, often considered as weak, has been regularly replaced by materials considered "modern" and "safer". Nevertheless, understand and analyze the criticalities of raw earth should be the challenge to improve both the material and the techniques, in order to design innovative solutions.

1.2 *The research on the bamboo structures*

The research analyzes the possibility of delaying the collapse of the structures of adobe using bamboo as a completion.

This material has very peculiar botanical, anatomical, physical and mechanical properties. It grows in different climates, and many species are also invasive; moreover, it is easy to work, lightweight to carry and it has an optimal tensile strength. The plant grows under the ground with a complex root

system that forms a single body with the stems that protrude from the ground. The control of the cutting of the culms does not involve the death of the plant, that every year regenerates, in contrast with what happens with trees. Despite its peculiarities, the bamboo is often known as the "poor man's timber", the symbol of the precariousness in which the most disadvantaged sections of the population live. However, it is used for the construction of traditional buildings, and in various branches of the industry.

The research is divided into two parallel fronts. The first research analyzes the possibility to increase the tension resistance of earth bricks using bamboo powder and fibers from the waste of industrial processing as additive in the mixture of adobe. The second research designed an external frame of bamboo to be applied to the existing and new adobe walls, which is able to provide reinforcement in case of earthquake.

2 UNIAXIAL COMPRESSION TESTS ON ADOBE WITH BAMBOO POWDER ADDITIVE

2.1 *Materials and methods*

The bamboo species used in research is the *Phyllostachys edulis*, a type of giant bamboo that grows in different parts of the world at temperate latitudes. It is native of Taiwan and China, where it is called *moso bamboo* or *mao bamboo*, where is one of the most common species used in the textile industry. The used powder is a waste of production from an Italian company that produces accessories for the fashion industry.

For the tests, 12 specimens of adobe with bamboo powder addictive from the "bamboo burr" were prepared. The specimens are $8 \times 8 \times 8$ cm. The number of test specimens is reported in Table 1.

In the Table 1 are also reported the tests from Gigliotti & Malara (2012). Those tests were conducted on earth specimens with different origin, but similar size and comparable characteristics, kneaded with calcined gypsum powder additive. The calcined gypsum (*calcium sulphate dihydrate*) reacts chemically with the clay contained in the ground of mixture, and is commonly used to stabilize earthen structures. These tests were performed in the laboratory of Materials and Structures Testing of DIDA (Unifi).

Table 1. Test specimens.

Specimen	N°	Water percentage [%]	Additive	Additive percentage content*
T	3	20%	none	0%
GR	9	20%	bamboo powder	3%
TGC**	5	19%	calcined gypsum	15%

* dry weight percentage.
** Gigliotti & Malara, 2012.

For the realization of the specimens was employed earth dried in oven at 60°C for about 24 h, minced with mechanical grinder and passed through a sieve of diameter φ = 4.75 mm (corresponding to ASTM sieve n°4). The sieve n°4 was also employed to sift the bamboo powder. The earth was kneaded with bamboo powder in proportions equal to 3% of the weight of the earth, and mixed with water at 20%.

The mixture was manually processed and pressed into a timber mould, and removed after 2–3 days of drying. Therefore, for about a month, the specimens were seasoned with air on a wooden panel. Slow drying reduces cracking.

The test machine (Fig. 1) is composed of a hydraulic jack able to move axially, controlled by a desktop computer. The performed tests in monoaxial compression were conducted in stress-controlled mode; here, the force is increased at a given rate, and the correspondent piston's displacement is measured. The test specimen is loaded with a rounded head on a thick plate positioned on the upper surface of the specimen. The data on the displacements of the specimen along the direction parallel to the load were recorded through four displacement transducers placed on the four corners of the load plate.

2.2 *Preliminary analysis on the raw earth*

The earth can have at the same time an inconsistent and monolithic texture. Therefore, in order to study earthen structures is necessary to investigate both the issues related to the soil mechanic and of the strength of materials.

In order to hypothesize the shrinkage and the behaviour during the tests, the main properties investigated (Table 2) are:

1. mineralogical composition of the soil;
2. physical properties of the soil;
3. strength of the material through mechanical properties.

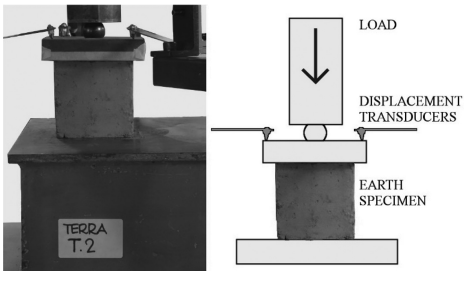


Figure 1. Loading scheme of the specimen.

Table 2. Physical characterization of the earth.

Property	Symbol	Value
Specific weight	Gs	2.4707 gr/cm^3
Water content	w	15.65%
Liquid limit	Ll	23.09%
Plastic limit	Lp	19.57%
Linear shrinkage	Rl	3.15%
Linear shrinkage at cold	Rl	2.02%

Table 3. Comparison of the tensions of failure for adobe specimens with different additives.

Specimen number	Additive	E [N/mm^2]	σr [N/mm^2]
T 3	none	163.10	2.07
GR 9	bamboo powder*	166.87	2.41
TGC 5	Calcinated gypsum**	129.09	2.40

* Bamboo powder obtained from industrial processing of briar.
** Gigliotti & Malara (2012).

The earth used for the research is from an excavation about 4 m deep in an area close to Florence.

2.3 *Results*

The specimens with bamboo powder additive show an increase of about 20% of the tension of failure σ_r, respect to the values obtained by the specimens without any additive. Furthermore, the specimens with the calcined gypsum additive show a similar σ_r as specimens with bamboo powder additive. The resume of the test results is proposed in Table 3.

2.4 *Conclusions*

The use of bamboo powder as well as the calcined gypsum additive increases the compressive strength of the adobe by 20%. Furthermore, the bamboo powder is a material recycled from the waste of the industrial processing. Therefore, the use of such additive is an ecological solution and does not affect the final cost of the adobe bricks.

3 BAMBOO FRAME FOR THE REINFORCEMENT OF ADOBE WALLS

A parallel line of research tested the effectiveness of a bamboo external frame for adobe walls, to install on existing and new structures. The designed reinforcement is formed by a grid of orthogonal bamboo canes, tied together by means of vegetal ropes. The frames, juxtaposed on both sides of the adobe wall are anchored each other by transversal

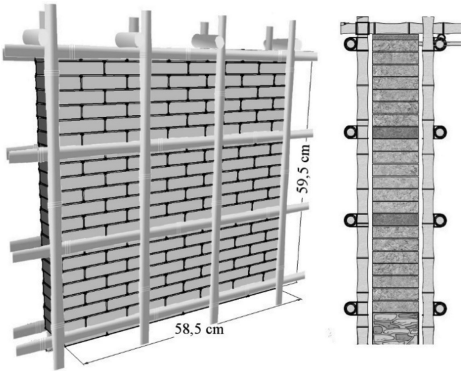


Figure 2. Scheme and section of the bamboo frame on the adobe wall.

elements, in order to form an external cage that stands on independent foundations (Fig. 2).

In service conditions, the bamboo grid does not collaborate with the bamboo wall, but the frame activates in case of earthquake, avoiding the risk of crumble of the wall; in fact, the elastic bamboo grid dissipates the seismic energy.

The reason why the reinforcement is installed on both sides of the wall is that the seismic force can have different directions. Nevertheless, the tests were performed considering the presence of the frame on only one side of the wall. In fact, the tests are aimed to evaluate the resistance of the canes and the lashed connections under the wall's self-weight on the most loaded side. If the wall were loaded on the opposite side, the second grid activates. The tests were performed considering the anchoring of the bamboo frame to the ground, and the rest of the highly resistant structure. This very complex aspect of the connection among the structural elements needs to be further investigated.

3.1 *Materials and methods*

In order to test the effectiveness of the proposed system, laboratory tests were done on the adobe panel, on the bamboo frame and the adobe wall reinforced with the frame. The structures (the adobe wall, the bamboo frame and composed structure) were tested in horizontal position (Fig. 3).

The tests performed are static tests, that do not intended to quantify the failure resistance of the structure, but only to assess the collaboration of the two materials in the situation in which the adobe panel is subjected to out of plane stresses.

The line of interaction of the load is perpendicular to the rows of bricks. The load was applied manually with the consecutive addition of weights of 5 kg each. The distributed load, perpendicular to the surface of the wall, is positioned along the central part of the same on a metal bar of 4 cm in

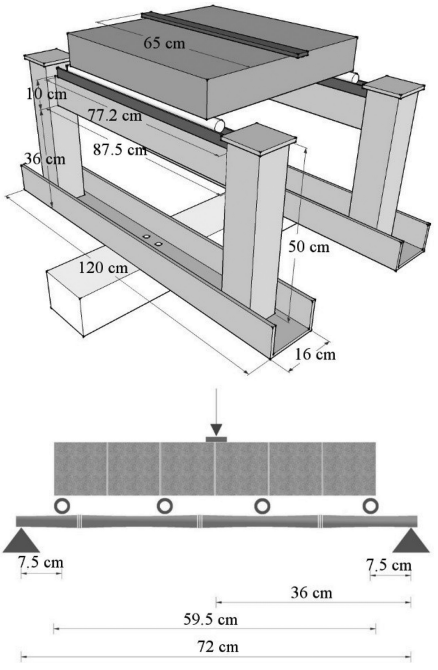


Figure 3. Scheme of the tests.

width. The surface of the metal bar on the panel side was coated with polyethylene to adapt to the surface irregularities of the adobe wall.

The measuring apparatus consists of graduated rulers integrated in the wall. The vertical displacement of the specimen at the point of application of the load is measured with respect to a fixed horizontal line, constituted by a nylon wire hold in tension between the two supports.

3.2 *Adobe wall*

To carry out the tests, 1,200 bricks of dimensions $10 \times 10 \times 2.5$ cm (scale 1:4) were made by hand. The procedure of the production of the adobe bricks is analogous to the one described in the paragraph 2.1. The bricks were left drying for 24–48 hours inside the moulds. After removing them from the mould, the bricks were left one more day in the air; finally, they were turned on edge to finish drying one last day. Then they were stored well aerated and non-overlapped for at least 15 days. The adobe bricks were completely dried and ready for use after about a month. The water content was measured in the mixture that presented limit characteristics (most particularly malleable or dry mixture) and varied between 19.6% and 22.8%. For the realization of the bricks, no additives were used in the mixture.

The bricks were afterwards assembled in scaled walls (scale 1:4) of dimensions $60 \times 60 \times 10$ cm. The bricks were in rows of 6 elements, fixed with mortar of sieved earth ASTM 10 ($\varphi = 2.00$ mm), mixed with water in proportion of 2.5 liters of water every 7 kg of earth. Each wall is composed of 22 rows and 132 blocks (including 22 special pieces and 111 bricks). After a few days, the formwork is disassembled, and the wall seasoned for a month.

3.3 *Bamboo frame*

The bamboo used is *Phyllostachys viridiglaucescens*, an Italian species that grows in Camaiore, Lucca. The preservative treatment is with the method of vertical diffusion for transpiration of the foliage, using a solution of borax and boric acid. The mechanical characterization of the bamboo culms is in Table 4.

Since the *guadua* (*Guadua angustifolia*) culms used for structural uses in Colombia have diameters between 8 and 12 cm, a scaled diameter comprised between 2 and 3 cm was chosen. The canes with less imperfections were chosen. The length of the canes is about 1 m.

The bamboo structure consists of 4 horizontal and 4 vertical canes joined together at 90 degrees angles. The spacing between the canes is about 19 cm, which corresponds to a real spacing of 75–80 cm (scale model 1:4). The lashing is made following the traditional technique of lashing with ropes (*uniones amarradas* in Hidalgo López 1980). In particular, the *square lashing*, optimal for joining two perpendicular elements was chosen. This type of joint, as it is completely external to the culm, avoids to drill the bamboo fiber; it is simple to perform, and is realized with readily available on-site materials.

The analysis of the mechanical behavior of the lashes showed that it has a static behavior similar

Table 4. Characterization of the culms of *Phyllostachys viridiglaucescens**.

Property	Unit	N° of specim. tested	Value
Diameter min	mm		46.0
Diameter max	mm		67.0
Thickness min	mm		4.1
Thickness max	mm		7.2
Area min	mm^2		578.2
Area max	mm^2		1,347.0
MC	% (dev.st.)	12	24.9 (5.8)
σc	Mpa (dev.st.)	12	56.8 (7.6)
Ec	Mpa (dev.st.)	12	3,100 (520)
σt	Mpa (dev.st.)	4	159.0 (13.0)
Et	Mpa (dev.st.)	4	22,500 (8,000)

* Mechanical characterization of bamboo culms carried out by Fabiani, M. (2014).

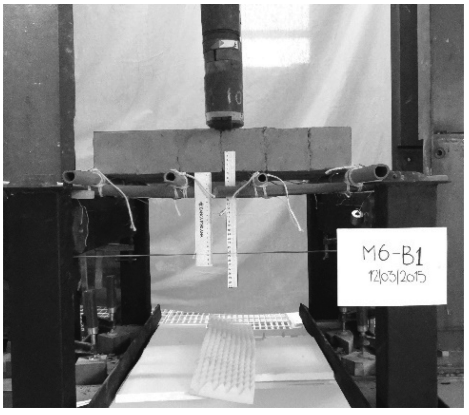


Figure 4. Bending tests on the adobe wall reinforced with bamboo frame.

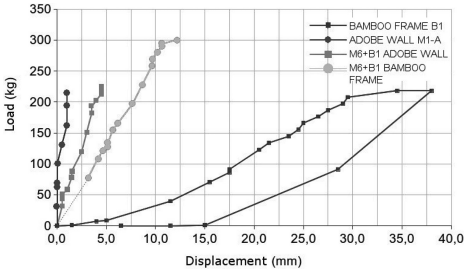


Figure 5. Load-displacement diagrams of the tests.

to that of a hinge. The resistance of this type of unions is linked to the mechanical characteristics of the material used for lashings. The rope used is the Cabuya, a processed product extracted from the fibers of *Furcraea Andean* plant, traditionally used in the *Eje cafetero* region (Colombia). The tension of failure in traction was measured of the order of about $\sigma r = 54$ Mpa.

3.4 *Tests on the flexural test on the adobe panel reinforced with bamboo frame*

The adobe walls were loaded until the collapse, that happened at a ultimate load of Fu = 220 kg. The test results are shown in the load – displacement (σ-ε) diagram in Figure 5.

The bamboo frame was not brought to rupture, as the available instrumentation for the test was not able to apply the adequate load for the failure. The tests showed that the bamboo is able to withstand without damage to loads that determine the collapse in the adobe structure. Besides, once the load is removed, the structure goes back to its initial configuration with minimum left deformation.

Concluding, the results verified that the presence of the bamboo frame improves the stability of the

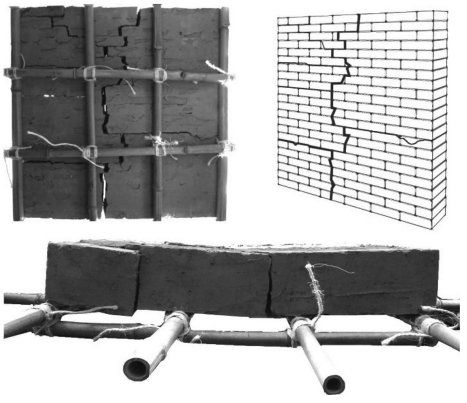


Figure 6. Failure of the test specimens.

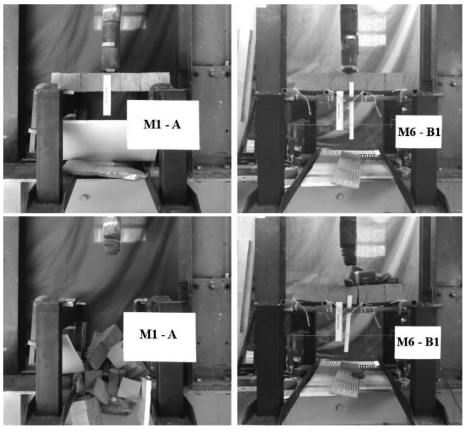


Figure 7. Comparison between the unreinforced wall (M1) and the wall reinforced with bamboo frame (M6-B1).

adobe panel, when the panel exceeds the tension of failure. The bamboo structure, which under normal conditions of use does not cooperate with the adobe wall, is triggered in case of horizontal loads, avoiding the collapse of the wall (Fig. 6 and Fig. 7).

3.5 *Conclusions*

In Figure 5 is shown the load-displacement diagram of the tests. Here, is possible to do a direct comparison among the bending tests of the different solutions (the adobe wall, the bamboo frame and composed structure). The adobe panel and the bamboo frame have a very different behavior. On one side, the adobe wall has not yield phase and reaches abruptly the collapse (see test M1, Figure 7), on the other side, the bamboo tends to significantly deform. The specimen B1 in Figure 7 is an example of the above described behaviour. Despite the different behavior of the two materials under loading, they have shown a good collaboration. In fact, as

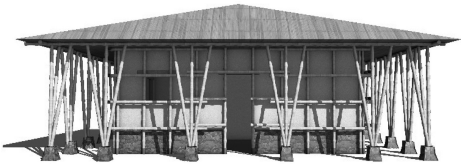


Figure 8. Prototype of building in adobe and bamboo.

shown by the test specimen M6-B1 in Figure 8, the tests on the reinforced adobe wall demonstrated the ability of the bamboo frame to support the adobe panel, and prevent its collapse. In fact, when the adobe structure exceeds the tension of failure and fails, the adjacent bamboo frame prevents the crumbling of the already damaged parts (Fig. 6). The efficiency of the proposed solution is also evident from the comparison of the test specimens with and without reinforcement, as shown in Figure 7.

4 CONCLUSIONS

The research has shown the ability to increase the resistance of the adobe structures using various products from the bamboo cane.

- The bamboo powder, waste of the industrial processing. Produced in large quantities, it can be used as additive in the mixture of the adobe bricks. In small percentage of weight (3% of the weight of the used earth) the tested specimens' compressive strength increases up to 20%.
- The bamboo frame. Bamboo canes for the realization of an external reinforcement in existing and new adobe structures. In presence of horizontal stresses that could cause the collapse of the adobe structure, the bamboo frame is crucial to prevent the collapse. Furthermore, the great flexibility of the element in bamboo absorbs seismic energy incident on the structure by reducing a further increasing of the deformation of the adjacent adobe wall.

The advantages of the use of such products are many. First of all, the bamboo is able to increase the resistance of existing and new construction to prevent their collapse in case of exceptional events; second, it is a renewable resource.

5 OUTLOOKS

Future research will concern the possibility of unifying the two researches presented in this paper. The resistance of the adobe constructions can be further improved by the use of walls built with adobe bricks with bamboo powder additive, and with the external bamboo three-dimensional frame.

A first development of the idea is the design of a home prototype in adobe and bamboo of one level (Fig. 8). The seismic risk to which the construction is subjected is also reduced thanks to the regularity of the structure in plan and in elevation, internal small spaces, and the positioning of openings far from the corners. Furthermore, in case of damage, the bamboo frame can be locally removed and the adobe brickwork can be fixed.

The strength of this solution is based primarily on the ease of execution, the low materials costs, and the use of renewable resources. Furthermore, the proposed building can be built as self-construction, in environmental extremely precarious conditions, and is also part of the traditional building knowledge of the populations to which it is addressed. Finally, it increases the resistance of these structures without changing the construction technique. Thus, it could help solve the precarious housing situation in large urban areas of many southern America's cities.

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Experimental analysis of compressive mechanical behavior of adobe masonry

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ABSTRACT: This paper is focused on the determination of the compressive constitutive law of adobe masonry from experimental tests. Compression tests of specimens of several shapes and size of adobe, as well as small adobe masonry wall panels were carried out. During the tests, the compressive load is monotonic until failure and it is applied through a testing machine. The compressive strength, Young modulus and the compressive stress-strain constitutive law are obtained from the tests. The paper analyzes the dispersion and consistency between different types of tests. The obtained results can be useful for the development of standards that define a methodology for the determination of the actual mechanical behavior of adobe masonry from simple tests, predict the actual behavior of adobe masonry for an adequate rehabilitation and retrofitting of existing buildings, or the design of new adobe constructions.

1 INTRODUCTION

Earth is a construction material widely used throughout the world since ancient times. It is estimated that approximately 30% of the world population lives in earth buildings and that in developing countries this percentage rises to approximately 50% (Grove 1980, Houben & Guillaud 1994). Besides, 10% World Heritage buildings and 57% World Heritage sites in risk of collapse are made of earth.

Because of the heterogeneity of earth properties, it is difficult to establish technical standards and methodologies for the mechanical characterization of adobe material. The development of knowledge about a compressive constitutive law of adobe, including, the inelastic zone, the analysis of damage pattern and crack propagation mechanisms are some of the challenges for the scientific community. This knowledge is required for the development of numerical models for the analysis of the structural behavior of adobe constructions.

This paper is aimed at contributing to this goal by providing experimental results from simple compression tests of different types of specimens (brick, cubic, prismatic and cylindrical) and adobe walls. The compressive strength, stress-strain relationship, Young modulus and damage patterns (crack propagation) are obtained and analyzed.

2 MATERIAL PROPERTIES AND MANUFACTURING PROCESS

2.1 *Material properties*

Adobe consists of a mixture of earth, straw and water molded and air dried. The content of sand and clay depends on earth properties and determines the cohesion of material. Usual weight proportions are about 40–70% for sand, 20–40% for silt and 10–25% for clay (Wu et al. 2012).

In this paper, the adobes were made with local materials selected from around the city of Seville and the specimens and wall panels were manufactured following traditional techniques.

In order to choose the suitable quantities of the components, several field and laboratory tests were carried out: sieve analysis, determination of plasticity, cohesion index, compressibility and sedimentation rate.

The finally selected earth composition was 40% of sand (2.20 mm), 30% silts and 30% clay. In order to improve the particle size distribution, the sand content of adobe was incremented up to 60% reducing the clay content to 20%.

2.2 *Manufacturing process*

The adobe specimens and adobe wall panels were manufactured in a laboratory environment.

The dimensions of the adobe bricks were $8 \times 16 \times 32$ cm (mean values) (Fig. 1), according to Peruvian standards (NTE E080 2005). Cubic (10 cm side) and cylindrical (30 cm high and 15 cm diameter) specimens were also molded. In addition, cubic (8 cm side) and prismatic ($16 \times 8 \times 8$ cm) specimens were obtained by cutting one eighth and one fourth of the adobe bricks, respectively, by using a dry disc cutter.

The adobe wall panels were manufactured following traditional techniques (Fig. 2). The dimensions were $60 \times 50 \times 16$ cm, which comply with CNS EN 1052-1 1999 Standard. These dimensions



Figure 1. Adobe bricks constructions.



Figure 2. Adobe wall panels.

correspond to one and a half adobes in the horizontal direction and to six rows of adobes in the vertical direction. For the joints, a mortar with the same composition of the adobe bricks was used.

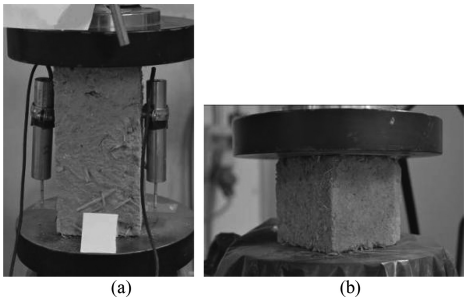
All bricks, specimens and wall panels were stored in laboratory conditions (temperature between 15 and 25ºC, and humidity around 50%) for 3 months approximately. A previous visual analysis was used to reject the samples that should not be tested due to cracks or absence of material.

3 COMPRESSION TESTS

3.1 *Test set-up*

During the tests, the compressive load is monotonic until failure. A universal hydraulic testing machine of 50 kN load capacity was used for testing the cubic, prismatic and cylindrical specimens whereas a load frame with a hydraulic actuator of 500 kN load capacity was used for the wall panels. The tests were displacement controlled and conducted following the indications of international standards (CNS EN 1052-1 1999, CNS EN 772-1 2011). During the tests, the rotation about any horizontal axis was relieved in order to diminish the bending effects or a non-uniform distribution of the load due to irregularities on the top surface of the specimens. For the wall panels, the top face of the wall was regularized by applying a thin lime layer to contribute to the uniform distribution of the load.

Strains were measured from the displacement of the actuator (global strain) and by using two LVDT type displacement sensors that measure the relative displacement between two intermediate points of the specimen (Figs. 3, 4 and 5). Sensors were fixed at opposite sides of the specimen so the average strain value is less contaminated by any bending effect. Because of the small size of the cubic specimens, no displacements sensors were installed on them (Fig. 3b). The sensors were fixed to the specimens by fixing screws.



(a) (b)

Figure 3. Simple compression test setup of (a) prismatic and (b) cubic specimens.



Figure 4. Simple compression test setup of cylindrical specimens.



Figure 5. Simple compression test setup of wall panels.

Below, details about the tests on each type of specimen are provided.

Cubes. 39 cubic specimens were tested in two different directions. One load direction (called *longitudinal* in this paper) coincides with the vertical direction during the molding and first stage of the drying process (the bricks are turned around to different positions during the drying process, following traditional procedures). This direction is also equivalent to the vertical load direction of the wall panels (usual compressive load of masonry). The other direction (called *transversal*) is a horizontal direction during the first stage of the drying process. The transversal load direction represents a horizontal compression of a wall panel. By considering both directions, some information about the material anisotropy can be obtained. The tests were conducted at 3 mm/min speed.

Prisms. 22 prismatic specimens were tested at 2 mm/min controlled speed. 9 specimens were instrumented with displacement sensors for measuring strains (Fig 3). Since these specimens were obtained by cutting one fourth of the brick, they were tested along the *transversal* direction.

Cylinders. 5 cylindrical specimens were tested with displacement controlled at 4 mm/min controlled speed. Strains were measured with displacement sensors in all tests (Fig. 4).

Wall panels. 6 wall panels were tested at 1 mm/min controlled speed. Four vertical strains (2 at each side of the panel) and 2 horizontal strains (1 at each side of the panel) were measured by using 6 displacement sensors.

3.2 *Test results*

The compressive strength (MPa), the axial strain at the peak strength, the stiffness (Young modulus) (MPa) and the stress-strain relationship are obtained from the tests. For the Young modulus, three different estimation procedures are considered: the chord modulus (the slope of the chord drawn between any two specified points on the stress-strain curve) between points at 1/3 and 2/3 of the compressive strength, and the secant modulus at 1/3 and 2/3 of the compressive strength. The mean values and the coefficient of variations *(CoV),* defined as the ratio between the standard deviation and the mean (in percentage) are obtained for each magnitude and type of test. For the computation of the normal stress due to compression, it is assumed that the cross-section remains undeformed and its area is constant.

Figures 6–9 show the stress-strain relationship obtained for all tests. They also show the mean stress-strain curve for each type of specimen. The shapes of the curves are qualitatively similar for all tests. They show a quasi linear behavior until the compressive strength is reached, and then a softening behavior is observed. However, the actual values of strength, stiffness and strains depend on the type of specimen and the method for measuring strains.

Table 1 shows the values of compressive strength and the corresponding peak strain. The table indicates if the specimens are tested in the transversal (T) or longitudinal (L) direction and it also indicates if strains are measured from the displace-

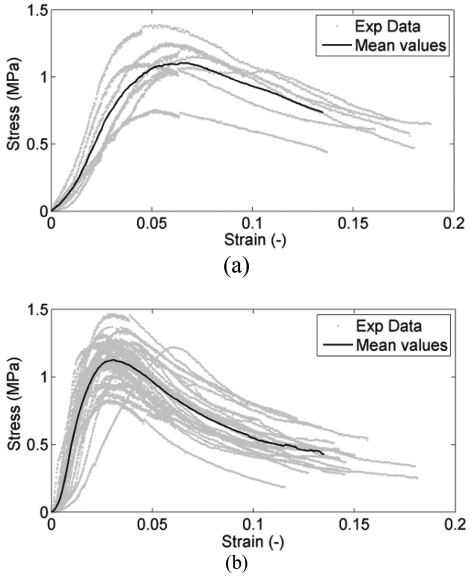


Figure 6. Stress-strain relationship for cubic specimens loaded on the (a) longitudinal direction and (b) transversal direction.

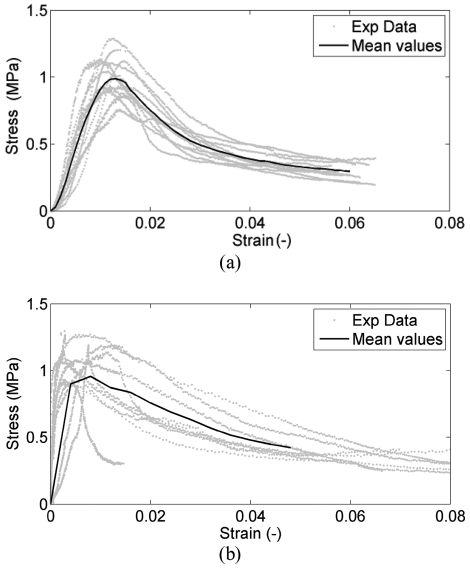


Figure 7. Characteristic stress-strain diagrams obtained from the compression tests and displacement measured (a) by machine testing sensor and (b) by LVDT sensors on prismatic specimens.

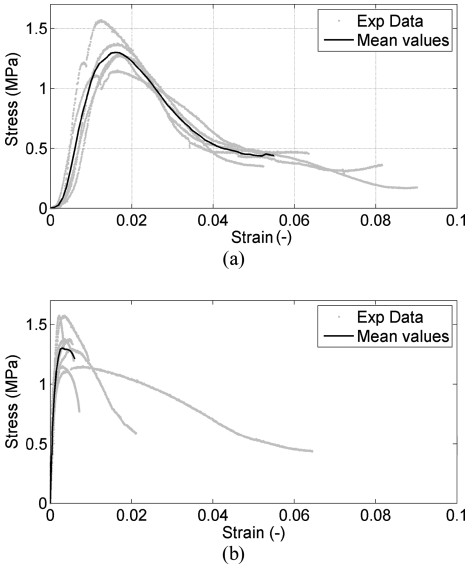


Figure 8. Characteristic stress-strain diagrams obtained from the compression tests and displacement measured (a) by machine testing sensor and (b) by LVDT sensors on cylindrical specimens.

ment of the platens (machine) or the displacement sensors (vertical or horizontal).

The compressive strength values cannot be directly compared from the different types of specimens. The size and shape of the specimen affects

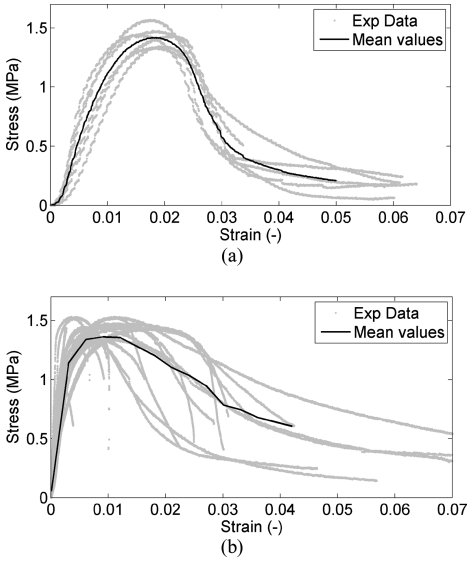


Figure 9. Characteristic stress-strain diagrams obtained from the compression tests and displacement measured (a) by machine testing sensor and (b) by LVDT sensors on wall panels.

Table 1. Compressive strength (f_{ck}, MPa) and corresponding peak strain (ε_k).

	f_{ck} (CoV)	ε_k (CoV) *machine*	ε_k (CoV) *sensors VERT.*	ε_k (CoV) *sensors HORIZ.*
Cubic(L)	1.13(17.3)	0.060(17.0)	–	–
Cubic(T)	1.17(11.8)	0.030(23.6)	–	–
Prism.(T)	1.06(15.9)	0.013(27.4)	0.006(59.6)	–
Cylind.(L)	1.33(12.2)	0.016(12.0)	0.004(47.5)	–
W.Panels	1.43(4.9)	0.018(12.2)	0.008(51.6)	0.006(28.3)

the way the load is distributed along the specimen and the level of confinement. A correction factor (Aubert et al 2016) based on an interpolation on the well-known Krefeld's correction factors is applied to the obtained values.

These factors depend on the aspect ratio of the specimen, defined as the ratio between the height and smallest dimension of its cross-section. Table 2 shows the experimental compressive strength (f_{ck}), the aspect ratio (*a.r.*), the correction factor (k_a) and the resulting modified compressive strength (f_c).

Table 3 shows the estimated values of the Young modulus from the chord modulus (E_m) and the secant modulus at 1/3 ($E_{1/3}$) and at 2/3 ($E_{2/3}$) of the compressive strength for each type of specimen. It is indicated the specimens tested in the transversal (T) or longitudinal (L) direction, and also if the strain is measured from the readings of the dis-

Table 2. Corrected values of compressive strength according to aspect ratios.

	f_{ck}	a.r.	k_a	f_c
Cubic(L)	1.13	1	0.7	0.79
Cubic(T)	1.17	1	0.7	0.81
Prism.(T)	1.06	2	0.78	0.82
Cylind.(L)	1.33	2	0.78	1.03
W.Panels	1.43	3.75	0.90	1.28

Table 3. Mean value of Young modulus for each type of specimen.

	$E_m\,(CoV)$	$E_{1/3}(CoV)$	$E_{2/3}(CoV)$
Cubic (L)	33 (33.5)	20 (29.4)	25 (30.8)
Cubic (T)	77 (37.8)	48 (39.6)	56 (30.8)
Prism (Maq)	132 (34.8)	77 (33.5)	95 (31.7)
Prism (Sens)	556 (58.9)	1080 (58.5)	721 (59.9)
Cylind. (Maq)	195 (28.4)	78 (28.1)	110 (27.1)
Cylind. (Sens)	801 (23.6)	1539 (51.5)	1005 (23.8)
W.Panels (Maq)	147 (24.8)	105 (27.8)	122 (24.9)
W.Panels (SensV)	540 (67.5)	668 (54.7)	550 (50.9)

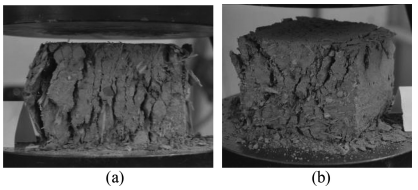


Figure 10. Typical modes of failure cubic specimens. (a) transversal and (b) longitudinal direction.



Figure 11. Typical modes of failure of prismatic specimens.

placement of the actuator of the testing machine (*mach.*) or from the displacement sensors (*sens.*).

The failure patterns depends on the size and form of specimens (Figs. 10–13). For cubic specimens, the failure modes are different for the longitudinal and transversal directions, due to the laminar microstructural



Figure 12. Typical modes of failure of cylindrical specimens.

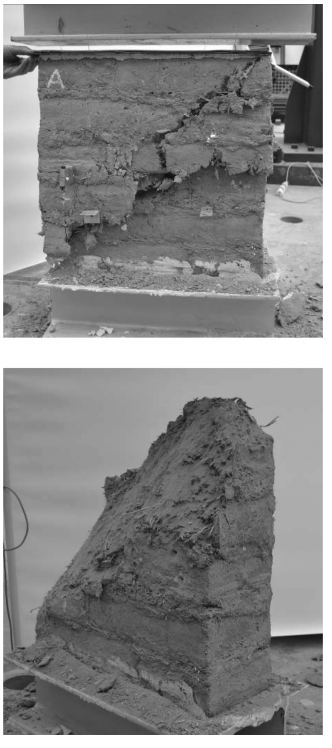


Figure 13. Typical modes of failure of wall panels.

scheme induced by clay during the drying process. The rest of the specimens show a damage pattern induced by shear forces in the vertical direction. Inclined fracture planes are induced by those shear strains.

4 ANALYSIS OF THE RESULTS

The obtained results show that compressive strength of the specimens is affected by the shape and aspect ratio. However, when the correction factor is applied, the strength for the prismatic and cubic specimens (transversal direction) are in agreement. On the other hand, no consistent values are obtained for the longitudinal direction between the cubic and cylindrical specimens. At this point, it must be mentioned that because of their slenderness, the cylindrical specimens where dried while being in the mould. Therefore, their drying process was significantly longer than for the rest of the specimens and mechanical properties can be affected. Cylindrical specimens did indeed provide the most similar values of strength to the wall panels. This can be due to the fact that, when building the wall panels, the addition of fresh mud for the joints can also enhance the mechanical properties of the masonry for allowing a new slow drying process. In addition, the cylindrical specimens exhibit the most similar damage pattern to masonry. However, the obtained results show that the strength of masonry cannot be determined from compression tests of any specimen of the same material.

It must be also noted that the masonry exhibits in this case higher strength than the single specimens. This may be due to the use of mud for the joints of the same composition as the adobes, including the addition of straw.

Regarding the Young modulus and stress-strain curves, it can be observed that the strain measured from the displacement of the testing machine platens is not reliable and lead to erratic values (see the higher dispersion through the coefficient of variation, CoV). This measuring procedure implicitly and erroneously takes into account the first stage of the compression of the specimen, when the platen is settled over the irregularities of the contact surfaces of the specimen and voids in the material are filled by compressive forces. Because of this, the secant modulus is also less representative of the actual stiffness of the material. The evaluated chord modulus provides a better approximation of the stiffness of the material during compression. However, the dispersion of the obtained values is high and no direct correlation exists between values from specimens and masonry. It must be also observed that cylindrical specimens also exhibited a higher stiffness. The aforementioned slow drying process may have also affected this property.

Regarding anisotropy, the tests on cubic specimens show that the strength is not affected by the load direction, but stiffness is significantly affected. The material is stiffer in the transversal direction, due to the horizontal microstructural layers formed by clay.

5 CONCLUSIONS

In this paper, the experimental results of compression tests on specimens of adobe material and adobe masonry for the analysis of their mechanical behavior have been presented. Laboratory tests revealed that the response of adobe in compression depends on the form and size of the specimen examined. However, the observed variability of results confirms that the inherent inhomogeneity and natural randomness of earth materials can lead to uncertain estimations of mechanical properties. The paper proposes the use of displacement sensors or any other measuring system that provide a reliable measurement of strain. The global strains measured from the displacements of the actuator should not be used for characterizing the stiffness or stress-strain relationship. For the determination of the compressive strength of material, existing correction factors that consider the aspect ratio of the specimen can be used for obtaining consistent values.

The experimental results also showed that the material is anisotropic in terms of stiffness but not in terms of strength. The vertical direction during drying process is less stiff than the horizontal one. Thus, the load direction must be taken into account when determining the material properties.

ACKNOWLEDGMENTS

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Stabilisation of earthen surfaces using carob (*Ceratonia siliqua L.*)

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ABSTRACT: Additives have been used in traditional construction throughout history. A significant body of literature endorses the potential and use of natural additives, establishing the suitability of these materials for construction purposes, contingent on the proper extraction, manufacture and application under certain conditions. In this paper we conclude that the *Ceratonia silique* or carob tree, common in Mediterranean area, contains the proper components to be used as consolidant for earthen surfaces. Biopolymers as tannins or polysaccharides contained in their pods are capable, in determinate medium conditions, of reacting in different ways with clay constituents improving mechanical properties of the colloid and endowing new possibilities to the earthen mortar.

1 INTRODUCTION

1.1 *Background*

Traditionally, additives have been used in construction in order to compensate for the mechanical weaknesses of low quality resources, usually in the form of residues or subproducts from related production areas such as blood, cheese, lung, animal hair and urine.

According to Lauren-Brook (2013), natural additives may be divided based on their animal, vegetable or mineral origin. He produced a detailed and complete taxonomy of the historic references of the use of these organic materials, various kinds of admixtures and their desired effects. For example:

Table 1. Effect obtained by organic additives.

Type of admixture	Desired effect	Organic material
Waterproof	Decrease permeability	Animal glue plus tannin Bitumen Wax emulsion
Water reducer	Reduce water required for given consistency	Sugar
Adhesive	Increases bond	Rosin Gelatin Animal glue Gluten Casein Blood Albumen

With the arrival of cement mortar, the view of additives changed, monopolizing the construction sector attention because of cements new possibilities. However, there were some authors still writing about them, such as (Vicat & Smith 2014) who explained how sugar could be used in small doses to make a mortar called *jaghery*.

There are several, sometimes contradictory opinions about the effectiveness of natural additives. In fact, some tests which compared the properties of renders containing the additive with others which did not, produced negative results with the additives making no improvement (Vargas Neuman et al. 1986).

On the other hand, several experiments with some of these products were performed with satisfactory results both in the construction of listed buildings and in new applications. Cedillo (1991), based on his observation and experience of the archaeological site of Balamkú, emphasises the importance of the urgent eradication of the use of synthetic polymers in archaeological rests and points out that a preliminary investigation of the case and a systematic study should be made.

In the same vein, Hoyle (1990) revealed that mucilages, are sulfuric acid esters (complex polysaccharide) contained in the vesicular cells of the parenchyma tissue from *Opuntia*, are insoluble in water, but are able to absorb and retain it; when in contact with it they form viscous solutions. This mucilage has conglomerating properties and also inhibits and selects germs, so its use brings material consolidation and avoids bacterium and lichen proliferation.

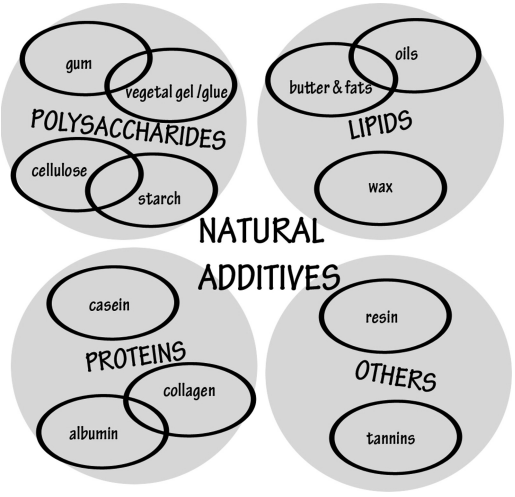


Figure 1. Grouping of additives according to their molecular components. Adapted from Vissac et al. (2013).

1.2 *Additive families*

Besides Sickel's classification in Vissac et al. (2013) a different grouping was proposed, based on molecular composition, as follows:

Proteins, important molecule for the animal and plant worlds, are biomolecules formed by lineal chains of amino acids, and are considered normally amphiphilic particles.

They are essential for organism growth, playing an important role in different areas, such as structure (collagen), protection (fibrinogen), sending signals (rhodopsin), enzymatic (sucrase) and transport molecules (casein).

There are two types of proteins: fibrous (collagen—normally insoluble in water) and globular (casein or albumin—normally soluble). The structure of each protein will determine its behaviour and interaction with clays.

According to Vissac et al. (2017), proteins create strong bonds with clays, linking their hydrophobic part (head) to the surface of the render, with the remainder of the hydrophilic part outside, creating an external water-repelling coat.

In the polysaccharides group we find sugars in different structures, as shown in figure 2. This is the largest group, which contains various structures: branched, linear, twisted, short or long, depending on the nature of the body from which the sugar was extracted. A key characteristic of these types of additives is that they carry a hydroxyl (OH) group.

The molecular structure is not necessarily available as a directly applicable additive and must be subjected to a predetermined previous transformation or extraction process such as grinding, decoction,

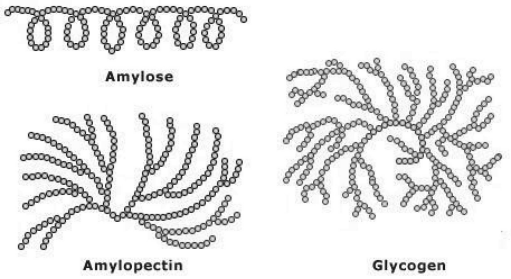


Figure 2. Polysaccharides' different molecular structures (Josh Scheerer).

maceration, etc. The extraction process can release those components susceptible to adsorption in the surface of the clay, which would allow the polysaccharides' chains to form micro networks with the clay particles in different mechanisms as we will see later.

A lipid is a molecule, either completely apolar (neutral lipid) or amphiphilic with a polar head linked strongly to an apolar chain (tail). The main biological functions of lipids include energy storage, signaling, and acting as structural components of cell membranes.

Temperature plays an important role in this group, as it modifies flexibility; depending on the origin of the fat, the substance will present a solid or liquid state: oils, waxes, fats (triglycerides), sterols, butters, among others.

According to Fontaine, Anger, Vissac, et al. (2013) the fatty acids, being small hydrophobic molecules, only allow weak interactions with the clays. Nevertheless, during the siccativation step of the unsaturated fatty substances, it is possible that new bonds are created, consolidating the coating.

In the others' group, we find the rest of the biomolecules. Most of them are phenolic compounds such as tannins. Most plants include high percentages of this component as a protection against herbivores or parasites.

Historically, tannin has been historically used to make black metallo-gallic ink, ground and mixed with iron sulphate forming iron tannate, an interesting product for earthen stabilization. We will explore his possibilities later.

1.3 *Extraction methods*

For the proper identification the most suitable extraction methods and in order to obtain the best possible yield with traditional methods, a thorough literature study was conducted in which many sources were consulted. Many of these sources lacked scientific rigour and produced contradictory results or conclusions. It is therefore important to highlight the relevance of the selection and

Table 2. Traditional extraction methods.

ALGARROBO (Ceratonia siliqua)	
Other names	Carob tree, kharuv, caroubier
Similar specimens	Locust tree, Clappertoniana, le néré (*Parkia biglobosa*), nitta (*Parkia filicoidea*)
Part used	Pods
Extract	Carob water
Extracting method A	Maceration
Once the pods were dried, they were collected and cut into pieces of 50 mm length. They are allowed to ferment in water and after 15 days the resulting liquid is stored (Manca et al. 2014)	
Part used	Pods
Extract	Carob water
Extracting method B	Decoction
Boil the *néré* pods in large pots, until obtaining a viscous liquid of red color. This water will be used for both kneading water and final protection (Pibot 2001)	
Part used	Pods
Extract	Carob water
Extracting method A	Maceration
The carob pods were cut into pieces approximately 20 mm in length and then boiled in water. The amount of material used was 10% by weight with respect to the water weight. This preparation boiled until 2/3 of its total volume was consumed. The remnants of the pods were then removed and the preparation allowed to settle. A liquid of slightly higher viscosity was obtained from the water, orange in color and containing sediments of brown color (Vargas Neuman et al. 1986)	
Part used	Pods
Extract	Carob water
Extracting method B	Decoction
40 g of pods were introduced into 1 liter of water taken at room temperature for 72 h. After filtration, the concentration of tannins in the decoction was estimated (6.33 ± 0.10) g/l. (Sorgho et al. 2016)	
Part used	Pods
Extract	Carob water
Extracting method B	Decoction
Soak dried carob pods in water for at least one night. The next day they were boiled and result in a hot water of very dark color between red and black to apply on the support (Taxil 2006)	
Part used	Seeds
Extract	Carob gel
Extracting method B	Boiling
It has been done by grinding only the seed of the carob tree was ground after being soaked in water for 15 days. Once crushed it was mixed with water. Subsequently, it was heated to 80°C resulting in a gel (Manca et al. 2014)	
Part used	Seeds
Extract	Carob rubber
Extracting method B	Boiling
The seeds were boned by treating the beans with heat-mechanical treatments. Then the peeled seeds were milled and sieved to obtain the endosperm. The gum of this pre-treated dry powder was extracted with distilled water (197: 1 water-endosperm), a water bath, temperature of 9°C for a time of 36 min. The solution and the solid phase were separated by centrifugation at (218°C, 1 h). The locust bean gum was precipitated with an excess volume of isopropanol. The formed white fibrous precipitate was collected by filtration with 45 µm sieve, and washed twice with isopropanol and acetone. After vacuum drying overnight at 30°C, the precipitate was triturated to a fine powder (El Batal et al. 2013)	
Part used	Pods
Extract	Carob powder
Extracting method B	Decoction
The shell was heated to 150°C for 3 h. It was then cut into pieces, crushed in a RETSCH blade grinder and passed through 2 mm and 0.125 mm sieves. The recovered powder was used as a binder to be mixed with the laterite soil. (Banakinao et al. 2016)	
Part used	Pods
Extract	Carob powder
Extracting method A	Maceration

(*Continued*)

Table 2. (*Continued*)

ALGARROBO (Ceratonia siliqua)	
The pods were crushed and reduced to grains. They were macerated with water in a container for several weeks. The juice was collected and sprayed onto the coating two to three times at one or two day intervals (Keré 1991)	
Part used	Seeds
Extract	Carob rubber
Extracting method B	Decoction
According to a recent patent Audibert, English Patent 241,186 (1925) the seed endosperm is first separated from its shell and sheath by rolling and crushing, roasting up to 150°C to a golden brown color, and then is extracted with boiling water in quantity 20 times its weight. The filtered clear liquid is evaporated and the dried slurry is sprayed. This powder mixed in water in different proportions gives us rubber with different viscosities (Hart 1930)	
Part used	Pods
Extract	Carob water
Extracting method A	Maceration
The pod of *Parkia biglobosa*, dried, was finely ground with the type of mill RETSCH SM 100 knives equipped with a 5 mm grid. The total phenolic compounds were extracted by decoction or maceration of these powders in distilled water for 60 min at temperatures ranging from 70 to 110°C and following a liquid/solid (L/S: mass/mass) ratio from 6 To 16. The obtained filtration is lyophilized (Nenonene 2009)	
Part used	Pods
Extract	Carob tannins
Extracting method A–B	Maceration & decoction
The shells were mechanically axed until a fine powder was obtained from which the tannin extraction was done. 1) Method: Before grinding the shells were dried for 3 h at 110°C. They were ground to a powder and passed through a sieve to obtain particles of 0.125 mm or less. The powder was left in water (powder/water ratio of 1/6 by weight) at room temperature for 5 days without any added additive. The suspension was filtered and the liquid obtained was concentrated by cooking in the open air without any temperature control. The extract obtained was a dark liquid solution of 50% solids content and high viscosity. 2) Industrial method: The powdered shells were placed in a beaker and water was added in a 1:6 powder: water weight ratio. The water had been pre-dissolved 2% sodium bisulfite and 0.5% sodium bicarbonate based on the weight of the powder to be extracted. The extraction was then carried out for 2 hours under continuous mechanical stirring at a temperature of 70–74°C. The mixture was then filtered and the tannin was recovered by spray-drying with a laboratory spray dryer (Buchi mini-spray dryer B-290), with and inlet temperature of 169°C and an outlet temperature of 70°C (Drovou et al. 2015)	
Part used	Pods
Extract	Carob tannins
Extracting method A	Maceration
The pods were pre-dried at 50°C, sliced and mixed with water (40 g pods per liter of water) at room temperature for 3 days. After filtration, the dry matter concentration in the solution was 9.6 g/l. The concentration of tannins was 6.3 g/l. (Keita et al. 2014)	

contrast the methods of extraction depending on the additive application.

For instance, Drovou et al. (2015) studied two different ways of extraction for *Parkia biglobosa*, a specimen similar to *Ceratonia siliqua*. The first is an artisanal and traditional maceration method, such as those presented in the following Table 2. below. The other method was akin to more commercial methods in presence of bisulfit, meaning that the results of the two methods were rather different. Mostly polyphenolic oligomers are present in the case of the more commercial extraction, while for artisanal maceration technique resulted in the unusual presence of long carbohydrate residues attached to the flavonoids.

These differences in the extracts obtained by different methods indicate that an extraction procedure needs to be chosen according to the purpose for which the tannin extract is to be used.

Table 3. Average composition of *Ceratonia siliqua* pulp.

Constituent	%
Total sugars	48–56
Sucrose	32–38
Glucose	5–6
Fructose	5–7
Pinitol	5–7
Condensed tannins	18–20
Non-starch polysaccharides	18
Ash	2–3
Fat	0.2–0.6

We framed our study in terms of only two of the additive groups in order to narrow the scope and focus of the research. We chose polysaccharides and tannin extracts, of which the applicable research

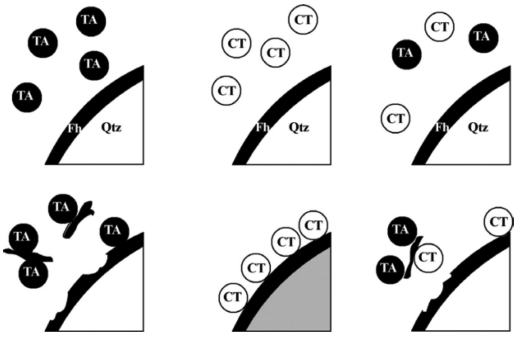


Figure 3. Proposed interaction between tannins and Qtz-Fh complexes. Kaal et al. (2005).

literature was more focused to the construction sector. These specimens included the *Ficus carica*, *Heuphorbia characias*, *Ceratonia siliqua, Agabe*, *Ficus indica* and the elm tree, among others.

Now we present some extraction methods from one of the selected specimens, the *Ceratonia siliqua*:

2 LOCAL APPLICATION

2.1 *Mediterranean specimens*

After the extraction method research, we focused our attention on *Ceratonia siliqua*, given that the literature review reveals the empirical reports and extrapolations from similar specimens from all over the world. Moreover, *Ceratonia siliqua* has components which may potentially work as soil stabilizers; polysaccharides and tannins.

According to Avallone et al. (1997) carob pod meal contained high levels of carbohydrates (45%) mainly sucrose, glucose, fructose and maltose, appreciable amounts of protein (3%), and low levels of fat (0.6%).

The chemical composition of the pulp depends on the cultivar, origin and time of harvest. The authors also proved that 70% of acetone was the most effective solvent for the extraction and recovery of tannins.

Carob pod contains a mean value of 19 mg of total polyphenols/g, 2.75 mg of condensed tannins (proanthocyanidins)/g, and 0.95 mg of hydrolysable tannins (gallo—and ellagitannins)/g. The germ contained higher concentration of total polyphenols (40.8 mg/g) and tannins (16.2 mg of condensed tannins/g and 2.98 mg of hydrolysable tannins/g) while only traces of these compounds were detected in carob seed. Puhan & Wielinga (1996) show a similar composition in his study the carob tree:

2.2 *Possible interactions*

As we showed previously, clays can interact with tannins and polysaccharides.

In order to obtain the correct interacting components, it is important to choose the proper extraction methods.

In the case of tannic use, when mixed with mineral phases tannins can act as dispersing agents for clays when pH and ionic forces are controlled, and change the rheology and plasticity of mixtures. Tannins are also able to form chemical bonds with active sites on mineral surfaces, leading to the change of macroscopic behavior (Kaal et al. 2005).

According to Vissac (2013) tannins are formed in several structures of hydroxyl groups, that in certain conditions of pH are able to trap a cation, effect known as chelation.

According to Kaal et al. (2007), tannic acid (TA) and condensed tannin (CT) are strongly retained by mineral phases consisting of quartz with or without coatings of either goethite or ferrihydrite,confirming that TA and the CTs used are efficient Fe, Al and Si mobilising agents. In natural soil, the fate of tannins after entering the mineral soil is probably affected by the soil's moisture regime and especially by the abundance and type of Fe (oxy)(hydr)oxides. Also, in quartzitic soil poor in secondary oxides, tannins may be tightly bound to Qtz surfaces. The mineral soil is probably affected by the soil's moisture regime and especially by the abundance and type of Fe (oxy)(hydr)oxides.

It seems obvious that not only the medium conditions will be determinant, but that the type of soil will also have an important role in this interaction. In Banakinao et al. (2016), the researchers

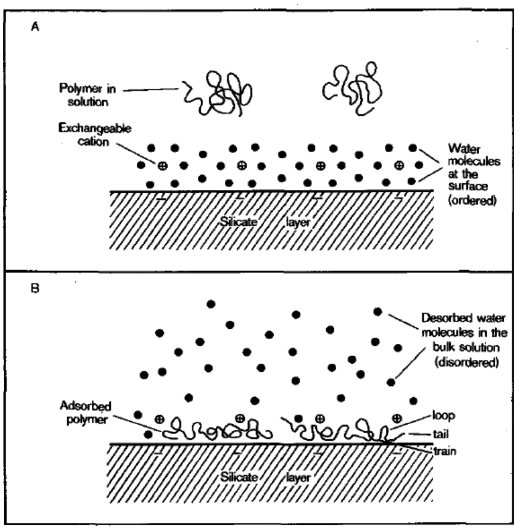


Figure 4. Diagram illustrating the desorption of numerous water molecules from a clay surface during the adsorption of an uncharged linear polymer, leading to a net gain in entropy by the system. (Theng 1982).

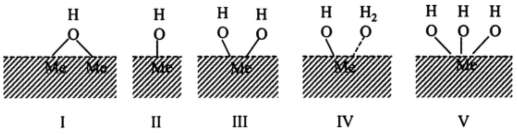


Figure 5. Mechanism of adsorption of a dextrin on the surface of a mineral by acid-base interaction. Case of a basic surface: Complexation. Liu et al. (2000).

mixed *Parkia biglobosa* husk powder with a lateritic soil, achieving positive results. On the other hand, *Ceratonia siliqua* has a very good percentage of polysaccharides which have an important potential as consolidants. This interaction is different from the one with tannins, since now we speak of adsorption (Figure 4.) of polysaccharide macromolecules into the clay surface.

Adsorption of natural biopolymers have been used and thoroughly researched in the soil and mineral industry for several uses, such as the biostability of soil organic matter (Schloesing 1874).

There are several kind of forces related to adsorption effect. Oliveira (1997) explains the most important of these: attractive Van der Waals forces, hydrogen bonds, electrostatic double-layer forces, hydrophobic interactions, short-range repulsive forces, steric interactions, ion bridging and hydration pressure.

Natural polysaccharides, such as starches, dextrins and guar gums that are widely used in mineral flotation adsorb through the interaction with mineral surface metal-hy-droxylated species. Based on the fact that the surface metal hydroxyl groups with a lower acidity exhibit stronger interaction with the natural polysaccharides, the nature of the interaction is likely an acid/base interaction. The extent of the acid/base interaction probably determines whether the adsorption is hydrogen bonding or chemical complexation (Liu et al. 2000).

In Vissac (2013) is undertook a deep analysis about these interactions, concluding that each kind of polysaccharide has a different manner of interaction to its shape, size and charge.

For instance, the relatively weakly charged, long (cellulose, amylopectin) and fairly rigid molecules would rather act by bridge flocculation, linking several mineral particles, a similar work that straw does in adobe bricks. On the other hand the more highly charged or short-lived molecules (amylose) would act by charge neutralization and total covering of the surface. This phenomenon would lead to repulsion or attraction between the particles depending on the ionic strength and pH conditions.

3 CONCLUSION

In default of laboratory test assays, we can confirm that *Ceratonia siliqua* is an important specimen available for use in the adaptation of existing recipes for earth stabilization extract.

A future line of research in this field could include the study of the ageing properties of these combinations, and in the case of positive results, undertake an economic and ecological feasibility study of this material.

The extraction and pretreatment of *Ceratonia siliqua* can be differentiated based on soil type and especially the different clay crystallographic facies presented. The study of pH and cation exchange capacity can provide references for the degree of reactivity and the type of links that may be obtained. So surely tannins can react very well on montmorillonite as happens in laterítics soils, on the other hand current polysaccharides can generate bonding bridges and longer chains in kaolinite. It would therefore be interesting to know how natural *Ceratonia siliqua* extract would react with each clay. This leaves settled the laboratory basis of the research which has just begun.

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Advanced study of the mechanical properties of compressed earth block

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ABSTRACT: Compressed Earth Blocks (CEBs) are historically local masonry building materials. Nowadays, they are getting more and more attention by the sustainable building community. However, there is still no consensus on the procedure to be adopted to measure the mechanical properties of this material. Thus, a comprehensive study on the measurement of mechanical properties of CEB was conducted, such as compressive strength, tensile strength, elastic modulus and fracture energy. Regarding the measurement of the compressive strength, block units and cubes with two different edge lengths (40 mm and 70 mm), under various contact states between the specimen and the platen of the testing machine (capped with rubber, plywood and without capping) were tested. The results show that the whole block capped with rubber is the appropriate procedure to obtain the real compressive strength. Furthermore, there is an abnormal size effect on the compressive strength, i.e., less resistance with smaller specimen. It is due to the fact that the cubes cut from the whole block were damaged during the cutting process.

1 INTRODUCTION

A considerable number of countries currently have earth building codes. Most of them deal with one or, in some cases, more of these three techniques: adobe, rammed earth and CEB. The CEB represents the most studied technique, being present in almost three quarters of the standards under consideration (Fouad 2013).

Most of the standards for CEB show that the compressive strength is resilient and the main feature to determine the structural quality. However, the compressive strength encountered in these standards (KS 02-1070 1993, IS 1725 1982, Standards Australia Handbook 194 2002, NT 21.33 1998, NT 21.35 1998, UNE 41410 2008, NTC 5324 2004, ARS 670-ARS 683 1996, ABNT 1986–1996, NTE E 0.80 2000, XP P13-901 2001) has notable differences in their test procedures (Cid et al. 2010). It must be pointed out that several variables could influence the obtained results, such as, unit geometry, conditions of specimen surface, moisture and cement contents.

Regarding the geometry of the CEB, there are two prevailing ways presented in standards. Firstly, blocks are halved and stacked bonded by using an earth mortar bed joint to double the slenderness ratio of the test specimen as in the standards of Colombia (NTC 5324 2004), France (XP P13-901 2001), Brazil (ABNT 1986–1996) and the RILEM recommendation (RILEM Technical Committee 164 1997). Secondly, whole blocks are tested directly between platens and following the direction in which they have been pressed during the fabrication. This is usually the direction in which blocks are placed during construction as in the standard of Spain (UNE 41410 2008). The results show that there was no parity between whole block strength and the one following the RILEM recommendation (Morel et al. 2007).

With respect to the condition of specimen surface, blocks are not perfectly formed and their bearing surfaces may not be parallel and free from surface irregularities. The purpose of capping the bearing surfaces is to assure reasonably them parallel and smooth. However, many standards in compressive test do not even mention this fact. One of the main materials used for solving this problem are plywood sheets, while the thickness of the plywood sheets changes from one to another. Standard (KS 02-1070 1993) and Walker (1995) have proposed to cap the specimens with two 3 mm thick sheets of plywood. According to Bulletin 5 (1987) the thickness of plywood sheets ranges between 4 to 5.5 mm. Walker and Stace (1997) used 4 mm thick plywood sheets for their tests. Cyted et al. (1995) adopted different methods to obtain flat and parallel faces by capping the specimen with 3 mm thick of cement paste with plastic consistency.

Table 1. Specimens for the tests.

Test	Mechanical property	Type of specimen	Nº
Compressive tests	Compressive strength	Cubes 40 mm in edge length	20
		Cubes 70 mm in edge length	20
		Whole block	37
	Elastic modulus	Prisms 70 × 70 × 140	10
Tensile tests	Tensile strength	Cubes 40 mm in edge length	10
		Cubes 70 mm in edge length	10
		Whole block	33
Three-point bending test	Fracture energy	Whole block with a center notch	15

As mentioned above, it is obvious that there is still no consensus on the procedure to be used to measure the compressive strength of this material. Thus, a comprehensive study on the measurement of mechanical properties of CEB was conducted, including compressive strength, tensile strength, elastic modulus and fracture energy. Regarding the compressive tests, three different capping methods (capping with rubber, plywood and without capping) were adopted. Moreover, the size effect on the compressive strength was also investigated.

The paper is structured as follows: the experimental program is presented in Section 2, the experimental results are described and discussed in Section 3; and finally some conclusions are drawn in Section 4.

2 EXPERIMENTAL PROGRAM

2.1 *Material characterization and specimens*

The CEB used was manufactured in Madrid, Spain, and stabilized with 6% cement of total weight. Block dimensions were of 290 mm × 140 mm × 70 mm. The average weight in dry state is around 5800 g, corresponding the dry density 2020 kg/m^3.

All specimens used in any test were randomly selected from the consignment of units produced from CEB. Just before testing, the length, width, height and weight of the specimens were measured. During preparation for each test, dry densities were routinely determined using the average external dimensions and net oven dried mass of each specimen. The dried specimens were placed in an oven set at 105ºC for 24 hours, and left in the air for approximately 2 hours prior to testing (Bulletin 5 1987).

2.2 *Tests for measuring the mechanical properties of CEB*

In this investigation, a full mechanical characterization of the material was performed. Specifically, we measured the compressive strength, the tensile strength, the elastic modulus and the fracture energy of the CEB.

The compressive strength tests were carried out on whole blocks and cubic specimens of different sizes: 40 and 70 mm. For the blocks, the tests were performed in a Servosis servo-hydraulic machine of 3000 kN. The tests were run under load control, at a rate of 2.1 kN/s ≈ 0.05 M MPa/s. For cubic specimens, the tests were performed in a Servosis Servo hydraulic machine of 250 kN. The tests were run under displacement control, at a rate of 6.5 and 5.0 μm/s ≈ 0.05M MPa/s for cubes with side of 40 and 70 mm respectively. As it can be deduced, the loading rate was fixed and remain constant throughout the entire series of test irrespective of the shape and size of the specimen. The displacement between the two steel platens was measured through two LVDT (Linear Variable Differential Transducer) as it can be seen in Figure 1. All blocks and cubes were tested in compression capped between two 3 mm thick sheets of plywood, two 3 mm thick sheet of rubber and plane contact surface between the CEB specimens and the steel platens.

Compressive tests were also performed on prisms cut from the whole block to measure the elastic modulus. The machine used was a Servosis of 250 kN. The prisms were capped with rubber to ensure the distribution of load across the surface of the specimens and avoid the constriction caused by the friction between the steel platens and the specimen surface. To obtain the elastic modulus, two clip gauges, with a span of 50 mm, were installed contrary around the prismatic specimens as shown in Figure 2.

In order to determine the tensile strength in whole blocks and cubic specimens of 40 and 70 mm, indirect tensile tests or *Brazilian tests* were performed following the recommendations of ASTM C496 1991, and the suggestions from Rocco et al. (2001). The specimens were loaded through

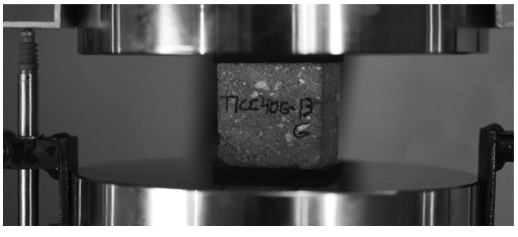


Figure 1. Compressive test on cubes.

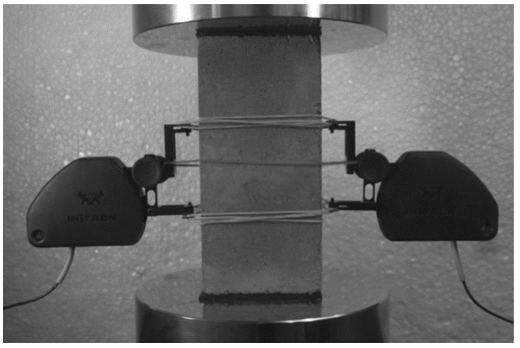


Figure 2. Compressive test to determine the elastic modulus.

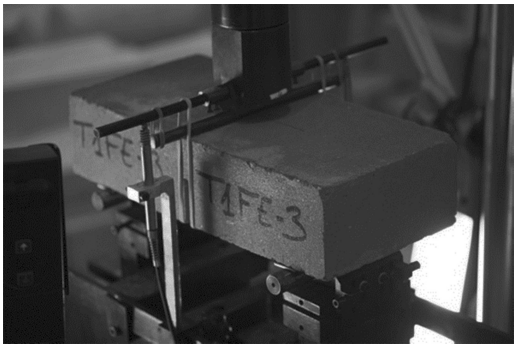


Figure 3. Experimental set-up for three-point bending tests.

plywood strips with width of 1/10 of the specimen height. Tests were performed in control of position at speeds of 0.5 and 0.6 µm/s (0.005 MPa/s) for cubes of 40 and 70 mm respectively.

The fracture energy, G_F, was measured through three-point bending tests following the procedures devised by Elices et al. (1992), Guinea et al. (1992) and Planas et al. (1992). Figure 3 shows an overview of the test to measure the fracture energy. The testing machine adopted to carry out the tests was a hydraulic servo-controlled testing machine. The initial notch depth ratio was approximately 0.5, and the span was fixed at 3 times the height of the block during the tests. Two linear ramps were used at different displacement rates: 0.55 µm/s for the first 30 min., and 2.7 µm/s until the end of the test, until reaching 2 mm of total displacement. In order to obtain the complete failure information from the specimen, the weight compensation technique was adopted during the test, i.e., springs were used to hold the specimen all the time, as shown in Figure 2. The block rests on two rigid steel cylinders laid on two supports permitting rotation out of the plane of the beam and

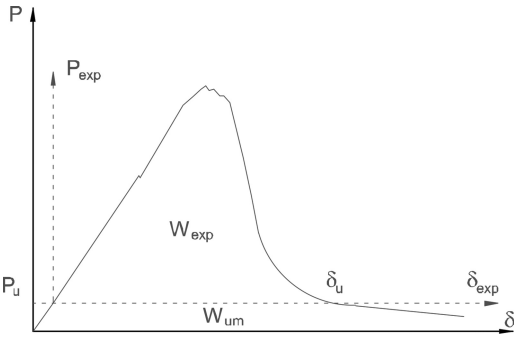


Figure 4. Determination of the fracture energy.

rolling along the block longitudinal axis with negligible friction. These supports roll on the upper surface of a very stiff beam fastened to the machine actuator. The load-point displacement is measured in relation to points over the supports on the upper surface of the block. Two LVDT (linear variable differential transducers) fixed to the steel beam are used to measure the displacement between the loading rod and the steel beam. G_F is obtained as:

$$G_F = \frac{W_{exp} + W_{um}}{B(D-a)} \tag{1}$$

Where W_{exp} is the area under the experimental load-displacement curve $P_{exp} - \delta_{exp}$, and W_{um} is the unmeasured energy that corresponds to the portion of the ligament that is still unbroken when we stop the test. We calculate this by assuming that the crack propagation obeys a cohesive model, which leads to a hyperbolic tail in the $P - \delta$ curve when the displacement is very large and the ligament is very short. Figure 4 illustrates the process followed to obtain the complete fracture energy. δ_u and P_u correspond to the termination of the bending test. It should be noted that the unmeasured energy is less than 10% of the measured one.

3 RESULTS AND DISCUSSION

3.1 *Study of the mechanical properties of CEB*

In Table 2, the mechanical properties of the CEB tested are presented, where SD is the standard deviation and σ_c, E_c, f_t, and G_F are, respectively, the mean compressive strength, elastic modulus, indirect tensile strength and fracture energy.

From the values of E_c, f_t, and G_F measured in blocks the characteristic length, l_{ch}, can be obtained according to Equation (2):

$$l_{ch} = \frac{EG_F}{f_t^2} \tag{2}$$

Table 2. Mechanical properties of CEB.

Property	Specimen	Capping	Value (SD)
σ_c (MPa)	(290 × 140 × 70)	Rubber	9.7 (1.2)
		No	27.3 (3.7)
		Plywood	27.0 (3.7)
	Cubes 40 mm	Rubber	2.9 (0.9)
		No	8.8 (3.2)
	Cubes 70 mm	Rubber	4.4 (0.9)
		No	13.0 (2.6)
E_c (GPa)	(70 × 70 × 140)	Rubber	5.64 (1.8)
f_t (MPa)	(290 × 140 × 70)	Strips	1.37 (0.2)
	Cubes 40 mm	Strips	0.83 (0.2)
	Cubes 70 mm	Strips	0.78 (0.1)
G_F (N/m)	(290 × 140 × 70)	No	74.4 (14)

This parameter was first proposed by Hillerborg *et al.* (Hillerborg *et al*. 1976) for fracture behavior. It is an indicator of brittleness of the material (del Viso 2008); the shorter it is, the more brittle the material is. For the CEB tested it is 608 mm, which is greater than the one of normal strength concrete ranging from 250 mm to 300 mm.

From the results of Table 2, the shape, size and capping effects on the compressive strength of CEB can also be studied as they are discussed in next sections.

3.2 *Shape and size effects in the compressive strength of CEB*

In this section, we study the relationship between the compressive strength of a CEB obtained from whole blocks and that obtained from cubic specimens of different sizes. Figure 5 shows the most representative results of $\sigma - \delta$ curves obtained from different types of specimens tested.

In the case of cubic specimens, it was observed that the initial slope variation depends on the specimen size. Bigger specimens have a greater slope. In both cases, the first branch begins to lose linearity at maximum load approach, indicating the beginning of cracking processes before reaching the peak load. The post-peak behavior depends on the specimen shape and capping. In the case of whole blocks, the location of the damage and the softening zone occur more smoothly than in the case of cubic specimens, where the damage and softening occur after a sharp drop load, specially in cubes capped with rubber.

As for the size effect, we can observe it is very clear in the size range tested in the case of cubic specimens. Small specimens resist less stress than larger specimens which goes against the typical size effect of cohesive materials. This suggests that the results are being influenced by factors other than size but related to it, like the damages that the material could

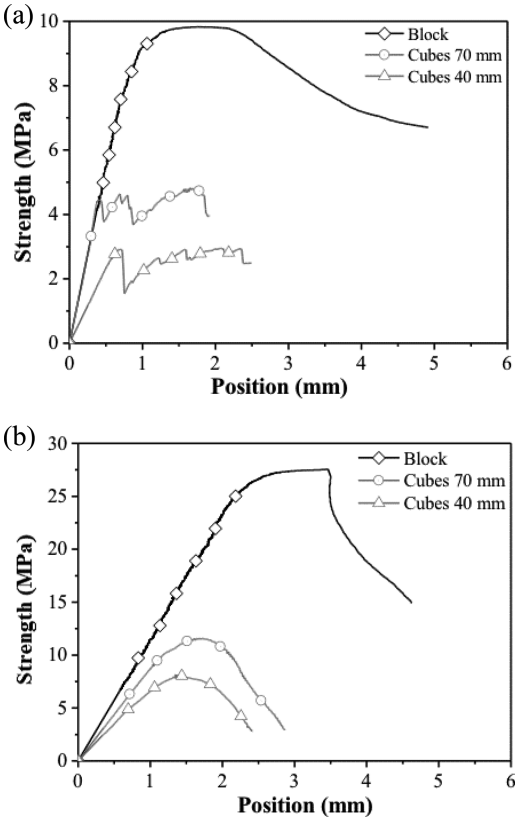


Figure 5. Shape and size effect on the compressive strength of CEB: (a) Capped with rubber; (b) Without capping.

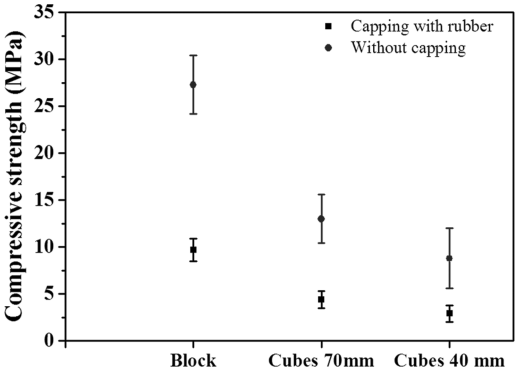


Figure 6. Size effect on the compressive strength of CEB.

suffer in the cutting process (Aubert *et al*. 2016). Figure 6 shows the stress in peak load obtained against a dimension in $\sigma - \delta$ curves that characterizes the size of the specimen. In cubic specimens, scale effect decreases in accordance to the size decrease.

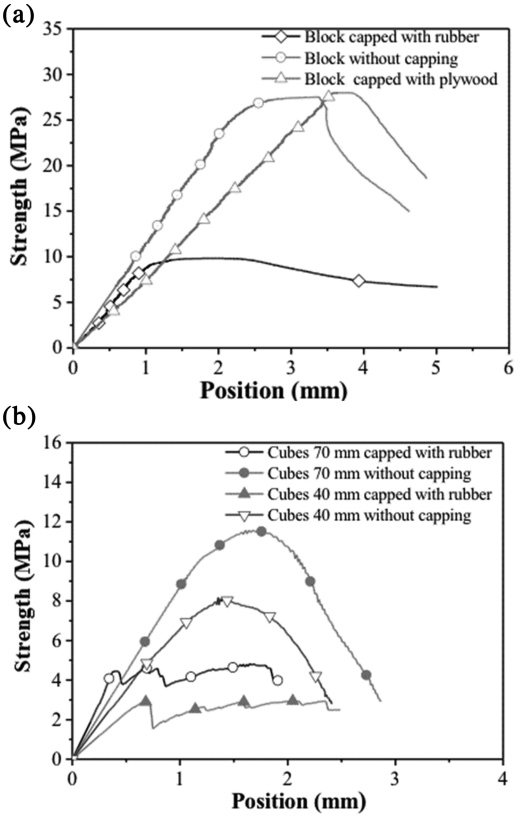


Figure 7. Capping effect on the compressive behavior of CEB: (a) Block; (b) Cubes.

3.3 *Effect of specimen capping in the compressive strength of CEB*

The conditioning of the surface of the specimens in compressive strength tests has a crucial impact on the resistance values obtained for all specimen sizes tested. This constrain has been investigated for other materials like concrete. Indelicato and Paggi (Indelicato & Paggi 2008) conducted a study on the effect of the shape of the specimen in concrete compressive strength, focusing the main cause of the problem on the influence of friction between the platens of the testing machine and the specimen surface. They concluded that the slenderness of the cylinder prevents the friction coefficient from affecting the resistance, while in the case of cubic specimens is a determinant factor.

Depending on the coefficient of friction, in a compressive strength test there may be the following cases of lateral expansion of the sides of the specimen in contact with the platens of the machine: (a) zero lateral expansion, achieved in case of a particularly high friction coefficient, preventing deformation of the specimen in contact with the platens of the testing machine; (b) partially admitted lateral expansion, as usually occurs for steel platens-CEB contact; (c) enhanced lateral expansion, obtained by the interposition along the contact surface of either a high deformable material, or a material with a low friction coefficient (e.g. Teflon, rubber, cardboard) (Indelicato & Paggi 2008).

In this investigation, partially admitted lateral expansion and enhanced lateral expansion by using deformable material, plywood and rubber, are compared (Fig. 7). In the first situation, surface is in *stick* condition, i.e. with vanishing relative tangential displacements between platen and CEB along the interface; whereas, in the second cases the lateral deformation is enhanced due to low friction coefficient. This explanation makes sense since tests with rubber maybe those which provide a more reliable measure of the CEB resistance, and it is probably the answer to the surprisingly high resistance obtained by tests without capping (Fig. 7 and Table 2).

4 CONCLUSIONS

In this paper, we investigated the mechanical behavior of CEB. Specifically, we measured the compressive strength, the elastic modulus, the indirect tensile strength and the fracture energy. We were particularly interested in the problem of contact between the platens of testing machine and the different specimens and in the shape and size effect of CEB. Blocks and cubes were tested at a rate that was kept constant throughout the experimental program. The following conclusions can be drawn from the study:

1. The compressive strength of blocks and cubes are significantly dependent on the friction coefficient. In this case, the higher the friction coefficient the higher the compressive strength is. Compressive strength of CEB capped with rubber is around 65% lower than the specimens capped with plywood or without capping. This is due to the high friction coefficient of the interface of contact surfaces of the last cases. It has been proved that tests with rubber may be those which provide a more reliable measure of the CEB resistance.
2. Experimental results show that the size effect is abnormal. Lowest resistance occurs with the smallest specimen. This is related to the damages that the material suffer in the cutting process. For this reason, it can be concluded that cutting small cubes from the whole block to obtain the compressive strength is not appropriate for measuring the compressive strength.

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Seismic analysis of Portuguese adobe buildings

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ABSTRACT: Considering the likely unfavorable behavior under seismic action of adobe construction, the present work aims at providing a seismic fragility characterization of two adobe Portuguese traditional buildings, using numerical models calibrated over experimental results. Two case-study buildings in the region of Aveiro, were numerically modeled to estimate their structural behavior under seismic loading. Adobe material properties were calibrated based on the experimental results of a cyclic in-plane test of a full-scale I-shaped adobe wall. The method chosen to characterize adobe masonry and model its nonlinear behavior followed a total strain crack-based macro-modelling (TSCM) approach, whereas pushover analysis was carried out to reproduce the pseudo-static experimental test in order to allow a refined calibration of adobe masonry mechanical properties. Fragility functions were then derived, based on the above-mentioned numerical models, using nonlinear static analysis, bringing further insight on the seismic fragility of traditional Portuguese adobe dwellings.

1 INTRODUCTION

Adobe masonry is one of the oldest building techniques; the earthen bricks are produced manually throwing wet earth into formwork and then let air-dry. The combination of good thermal, hygrometric and acoustic properties of earth together with its low cost and easy availability makes it one of the most diffuse building technique, such that around 30% of world population is estimated to live in earthen houses (Houben & Guillaud 1994). On the other hand, when it comes to adobe masonry's seismic behavior, its characteristics may result in a possible unfavorable behavior due to the low-tension strength and the mechanical properties of dry earth (Blondet et al. 2006). As such, and given that the distribution of earthen construction around the world matches fairly the medium-to-high seismic prone areas (De Sensi, 2003), the structural behavior of this construction type may represent a serious threat in terms of social and economic losses in case of an earthquake. Therefore, the principal scope of this research is to calibrate material properties of adobe masonry in order to assess the seismic vulnerability of two adobe dwellings through fragility functions, with the main advantage of precisely using experimental data, in order to achieve a better characterization of adobe masonry, focusing on the particular case of Portuguese construction of this sort.

2 CALIBRATION OF ADOBE MASONRY PROPERTIES

2.1 *Experimental testing*

The experimental data used in the present study is taken from a series of experimental tests conducted in the Laboratory of the Civil Engineering Department of the University of Aveiro, Portugal.

Specifically Varum et al. (Varum et al. 2011) carried out an in-plane cyclic loading test on a full-scale I-shaped adobe wall to analyze the cyclic response of the wall, the damage pattern evolution and to assess an effective retrofitting measure.

Furthermore, more recently ten full-scale adobe wallets were constructed in the laboratory to assess the adobe masonry material properties. Stress-strain relationship, strength, deformation, stiffness and damage pattern of the adobe masonry were derived from the specimens testing. Compressive strength, shear strength, modulus of elasticity and Poisson's ratio were evaluated through simple compression and diagonal compression tests on the adobe wallets (Silveira et al. 2015).

2.2 *Numerical modelling*

In line with the results and characteristics of the studies encountered in the dedicated literature review, a macro-modelling approach was chosen to represent

adobe masonry and a total strain crack model (TSCM) was selected to characterize its behavior.

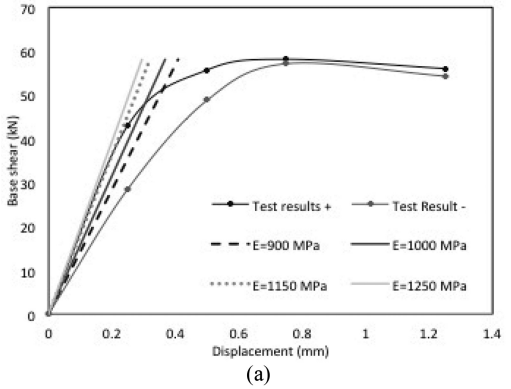
The tests were reproduced using the software MidasFEA (CPS-FEA, 2015) and the wall was modelled using three 4-node rectangular shell elements. To fully reproduce the test set-up (Varum et al. 2011), a horizontal displacement of 1.25 mm was applied at 2.5 m height on one of the transverse walls, to simulate the displacement corresponding to the maximum drift of 0.05% reached during the cyclic test. The calibration is then performed comparing the numerical pushover curve with the experimental envelope of the cyclic force-displacement curve. For the linear range, displacement and frequency were chosen as benchmark parameters to calibrate the elastic modulus (E), while a more refined calibration of the nonlinear material properties, such as tensile strength, tensile fracture energy and compressive strength, was performed by varying each parameter at a time and choosing the value that best fits the test pushover curve results, see Figure 1.

Globally, the total-strain crack model seems to fit the analysis of adobe masonry based on a general agreement between experimental and numerical results: stress and cracks develop diagonally from the point where the load is applied and the maximum value of the principal stress starts at the corner and then develops along the wall. Finally, the numerical pushover curves match the experimental envelope of the force-displacement curves, so that the assumption of adobe masonry as homogeneous material appears appropriate.

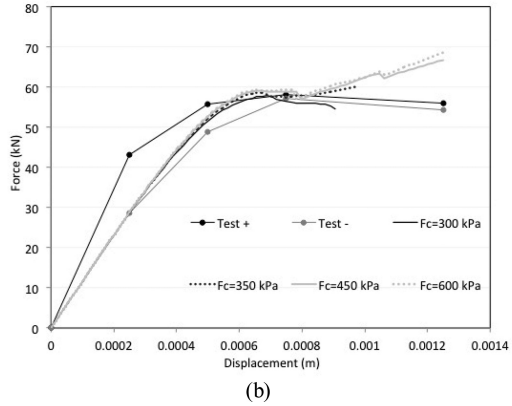
3 CASE STUDY

In Portugal in the 19th and early 20th centuries, adobe masonry was widely used, indeed, in the city of Aveiro it is estimated that approximately 40% of the buildings are made of adobe (Silveira et al. 2013). This building typology is usually regular in plan and height, predominantly with one or two stories.

As such, the buildings selected as case study are located in the municipality of Murtosa, in the Aveiro district. The two buildings, designated as House 25 and House 16 (depicted in Figure 2), are



(a)

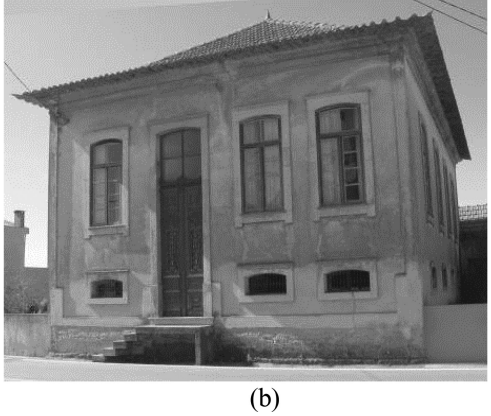


(b)

Figure 1. Calibration of adobe material properties for (a) Elastic range and (b) Nonlinear range.



(a)



(b)

Figure 2. Case study buildings: (a) House 25 and (b) House 16.

both two-story residential buildings, from early 1900 s, featuring external walls made in adobe and internal walls made of a different and lighter material, *tabique*, a typical Portuguese timber structure filled and plastered with earth based materials. The houses show pitched tiles roof.

All the structural elements of the FEM models of the buildings, with exception of the floors, are modeled with shell elements, using a 4-node tetrahedral 0.3 × 0.3 m mesh. Floors are modeled with two cross beams and rigid links tie external walls with floors and internal walls.

The numerical analysis of the two buildings aims at understanding the resisting mechanisms under seismic loading, performing a nonlinear static (pushover) analysis. Seismic load is simulated as a static horizontal force applied proportionally to the mass, ranging from 0.08 g to 0.8 g, in both principal directions (±X and ±Y). Loads were applied in two phases, first the gravity loads and following the horizontal forces.

Although less accurate than nonlinear dynamic analysis, nonlinear static analysis still allows assessing the structural behavior of the building under horizontal loading taking into account the material nonlinearity. The control points for displacement monitoring were identified at the top of the building.

3.1 *Structural analysis*

In order to assess the influence and importance of the different structural elements on the global seismic behavior of the buildings, different configurations were run and compared in terms of capacity curves. Such short parametric study analyzed the buildings' original configuration (0), and few variants eliminating the internal walls (NW), the floors (NF) and both internal walls and floors (NWF). The corresponding layouts are illustrated in Figure 3.

The capacity curves resulting from the analyses of the configurations are illustrated in

Figure 4 for both axes and directions (positive and negative). It is evident that geometrical and construction characteristics have a significant effect in the seismic response of the building. As such, although apparently regular in plan, the stiffness of the buildings changes according to the direction of application of the load. A potential reduction of the building capacity is in fact linked to uneven

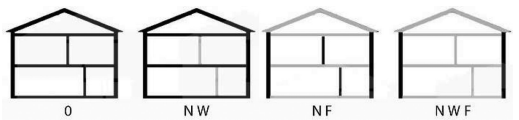


Figure 3. Structural analysis configuration.

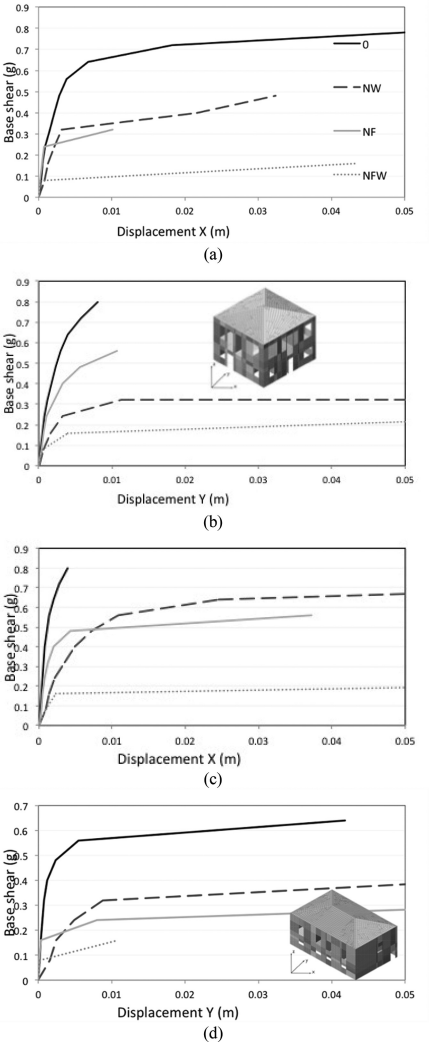


Figure 4. Capacity curves: House 25 along (a) X and (b) Y direction; House 16 along (c) X and (d) Y direction.

distribution of resisting elements and lack of symmetry in one or both orthogonal directions.

As expected, the contribution of internal structural elements, significantly affects the response of the building, being essential to distribute the loads and contributing strongly to its global horizontal stiffness, with contribution of the internal walls (NW) being predominant for house 25, and floors (NF) for house 16.

In both buildings, the scenario with just external adobe walls (NFW) is not able to sustain a horizontal load beyond 0.1g, since the external partitions would act as free standing walls, deforming significantly for low intensity loading and then collapsing.

3.2 *Damage and retrofitting analysis*

In order to represent the typical damaged conditions of the connections between external walls and the other structural elements, given the poor state of maintenance resulted from the survey on the state of conservation of the buildings of the city of Aveiro (Silveira et al., 2013), a brief analysis of damage scenarios and corresponding retrofitting measures is carried out. Four configurations were chosen: undamaged scenario (0), disconnection of external walls with internal elements and roof (DFWR), disconnection with just floor and walls (DFW) and retrofitted scenario (R), as illustrated in Figure 5.

In the FEM model, this is achieved by disconnecting the links of floors and internal walls with external walls, subsequently, retrofitting measures are modeled through the introduction of tie rods at every floor level (R).

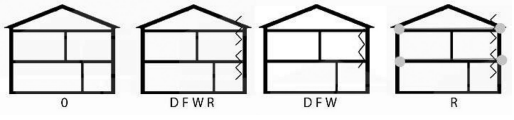
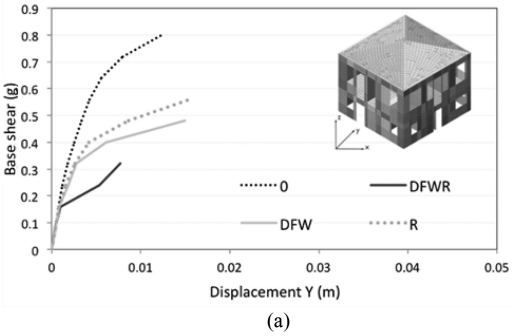
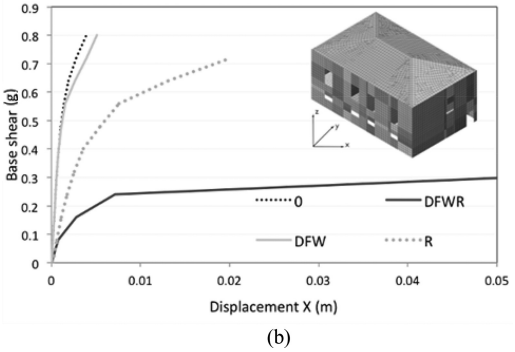


Figure 5. Damage-Retrofit analysis configurations.



(a)



(b)

Figure 6. Damage-retrofit capacity curves: (a) House 25 along Y and (b) House 16 along X direction.

As expected, the building capacity is strongly reduced due to the disconnection of an external wall with the internal structural elements (floors and walls); collapse takes place for values of acceleration in the range 0.1–0.2 g. The introduction of tie rods for retrofitting purposes (R) compensates the damage simulated on the building, increasing its capacity up to more than twice the value for the corresponding damaged scenario, as evidenced in Figure 6.

4 FRAGILITY ANALYSIS

The second step of the present study aims at having an insight on the level of seismic risk these buildings may be subjected to; the physical vulnerability of each of the two case-study buildings is hence characterized through fragility curves.

4.1 *Overview*

Buildings physical vulnerability is typically defined through fragility curves, which represent the relationship between the measure of intensity of a seismic event and the vulnerability of the structure. They indicate the probability of exceedance of a defined limit state (LS), correlated with damage or loss, as function of a given intensity measure of the earthquake (IM).

Literature review on the fragility analysis of earthen construction does not show a real common approach about LS for this category of buildings. Therefore on each capacity curve, points representing clear changes in the material behavior are chosen as engineering demand parameter (EDP) for the quantification of the building damage. Yielding point, threshold of the linear elastic range, and ultimate point, correspondent to assumed collapse, are identified on both curves.

For what concerns the ground motion input, ground motion records, representing the local hazard and necessary for the nonlinear fragility analyses, were collected in terms of peak ground acceleration (PGA), soil type, epicentral distance and magnitude.

REXEL software (Iervolino et al. 2010), a code-based real record selector for seismic analysis of structures, is used in selecting real records waveforms. From the Selected Input Motions for Displacement-Based Assessment and Design (SIMBAD) database, the software searches for a set of seven accelerograms compatible on average to a reference design spectrum, previously created according to Eurocode 8. a_g is defined according to the national annex values; site class selected is D, 'deposit of loose-to-medium cohesionless soil—with or without some soft cohesive layers—or of predominantly soft-to-firm cohesive soil', as Aveiro region has been recorded to have soft soil (Silveira et al. 2015).

4.2 *Development of fragility curves*

Procedures to obtain fragility functions involve a certain degree of uncertainty related to the number of records, modeling approximations and availability of data. For this study, analytical approach has been chosen among the others; fragility functions are hence derived using vulnerability assessment algorithm with direct physical meaning. Curves are built from data obtained from simulation of earthquakes intensities on structural models of the asset analyzed. Although it may be limited by modeling capabilities and computational effort of the analyses, it provides insight and data on buildings that have not yet experienced strong motions, which is not possible with empirical models.

Nonlinear dynamic analysis is typically considered more accurate in predicting the structural response of buildings, however pushover-based nonlinear static procedure, N2 method, is employed to evaluate the seismic behavior of the two buildings, given that it has been shown to provide accurate outputs, close to dynamic results (Pinho et al. 2013) and due to the complexity of the model and the time constraints.

Seven performance points are consequently identified for each of the ten intensity measure levels analyzed and then compared to the damage limit state thresholds, to derive the probability of exceedance, once damage states, in terms of target displacements, have been defined for different PGAs. Lognormal cumulative distribution function is then used to characterize fragility functions, according to Equation 1.

$$P(C \mid PGA = x) = \Phi\left(\frac{\ln x - \mu}{\beta}\right) \quad (1)$$

P is the probability of collapse given a ground motion of PGA = x, and Φ is the normal cumulative distribution function with μ and β as mean and standard deviation of ln (PGA) respectively.

To properly calibrate Equation 1, the estimation of μ and β lognormal parameters is performed using the maximum likelihood method as fitting technique to the different points representing the probability of exceedance per IM and LS, according to Baker (Baker 2015).

Finally, for each limit state, lognormal distribution as function of PGA is then employed to define the fragility curves. Fragility curves obtained for the case-study buildings are shown in Figure 7, following the described procedure.

For a PGA of approximately 0.1g, corresponding to a return period of 475 years, the building H25 has nearly 40% of reaching the ultimate limit state, whereas global yielding is expected for a PGA around 0.2 g or 0.3 g. For values of PGA greater than 0.6 g, the building is expected to collapse. On the other hand, the building H16 seems less vulnerable, according to the fragility results. In fact, less than 20% probability of collapse, half of the value of House 25, corresponds to the reference PGA of 0.1 g, and the ultimate limit state is expected to occur for values of PGA greater than 0.75 g.

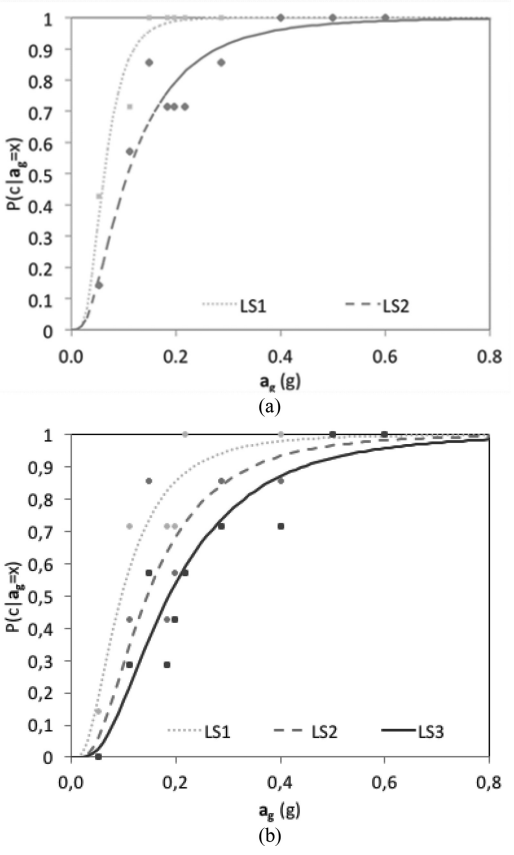


Figure 7. Fragility curves: (a) House 25 and (b) House 16.

The geometrical configuration may be the reason of the difference in the results of these somewhat similar buildings, given that House 16 is more irregular in plan than House 25.

Uncertainty related to ground motion and modeling affects the fragility curves, resulting in higher values of response capacity for the buildings, when subjected to seismic loading.

A reduced number of ground motion records has been chosen for reasons of computational onus of the models, while a higher number of records employed would have led to a less discrete distribution of the probability points to which the lognormal distributions are fitted. Modelling approximations play a significant role too, since by assuming the connections between orthogonal walls as perfect,

the typical weaknesses and damaged condition of such (Ortega et al. 2015) are not represented. Strong connections are in fact not realistic for this type of buildings, which often experience out-of-plane failure mechanisms when subjected to seismic action.

5 CONCLUSIONS

The presented study aims at providing a seismic fragility characterization of two adobe Portuguese traditional buildings, using numerical models calibrated over experimental results.

Since the modeling of adobe masonry parameters features relevant uncertainty given the nature of such composite material, incorporating laboratory results of an I-shaped adobe wall, is meant to increase the accurateness of the numerical model for the adobe buildings.

Given that the experimental and numerical data showed a global agreement, the constitutive model used, TSCM, coupled with macro-modelling approach, results effective in characterizing adobe masonry's nonlinear behavior.

Probability of attainment of the ultimate limit state is hence estimated around 0.5 g, denoting also a generally highly stiff behavior leading to brittle collapse. It has to be considered that uncertainty in the soil composition and numerical modeling approximations affect this result; the assumption of perfectly connected elements, disregarding possible out-of-plane failure, leads to a relatively high 'capacity'.

As such, further developments that may improve the quality of the fragility curves herein produced should focus on:

- Complete reproduction of the experimental test carried out on the I-shaped wall, by performing cyclic analysis on the numerical model;
- Realistic representation of wall-to-wall and damaged connections, assumed as ideal in this study, in order to effectively analyse possible retrofitting measure;
- Nonlinear dynamic analysis to validate the fragility analysis results, given the inherent simplified nature of nonlinear static procedures.

Nevertheless, the presented results can be employed and compared in future risk assessment studies of regions with similar typology of building portfolios. Such information is important to evaluate the seismic vulnerability of such buildings, in order to develop mitigation and retrofitting measures aiming at reducing the loss of life and properties associated to the collapse of this type of construction during earthquakes.

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Improved 2nd order holder. Method for heat transfer calculation for walls

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ABSTRACT: The most frequently used energy simulation programs in the building field are based on the method of response factors (REF) (Mitalas & Stephenson 1967) to assess the thermal energy demand of buildings. They assume a linear evolution of the temperature; however, this evolution is not linear empirically. The American tradition, pioneer in this modeling software, diverted attention from this inaccuracy as the American building tradition does not take into account issues such as inertia. Nevertheless, the inertia is of crucial importance for performing a rigorous study of the thermal behavior of the buildings in the field of vernacular architecture renovation. The paper proposes a mathematical model based on a second order shaping function to estimate the heat transfer calculation in walls. For the same sampling rate the parabolic shaping function gives better results than the linear one. The latter applies to the solutions with more mass even more notably.

1 INTRODUCTION

1.1 *Main concepts and methods*

The term thermal inertia is used (Yannas et al. 1997) to describe a building's overall capacity to store and release heat. The higher the thermal inertia of a building the slower the rate at which its indoor temperature rises and drops. Hence, the thermal inertia of a building fabric may be used to reduce heat flow to the interior of the building in overheating seasons.

The use of higher heat capacity structures also helps in the reduction and time delay of the cooling load peak, decreasing the energy consumption in air-conditioned buildings. The available tools for dynamic simulation of the buildings thermal behavior not assure the exact determination of the transfer function coefficients for very massive building structure (Cellura et al. 2003).

The current most common method and a new approach are compared by calculating the wall temperature evolution, used to calculate energy demand.

The results from the analysis developed on traditional building typologies typical of the Mediterranean area, characterized by high values of thermal inertia, show that optimal choice of the initial parameters of calculation is very important.

Our aim is to check the accuracies by its application to constructive elements that are representative in the existing residential building stock of Spain (Serrano Lanzarote et al. 2011) and which it provides a Refurbishment Performance (EPISCOPE Partners 2014).

1.2 *Objective*

The purpose of this article is to analyze the application of a 2nd order holder for 1D heat transfer in multi-layered walls (Mitalas & Stephenson 1971), and compare it with the traditional model which uses a first degree holder by Mitalas (Mitalas 1968). We also determine its influence in real applications to different typical constructive elements in the building renovation field (EPISCOPE Partners 2014). The variables analyzed have been the insulation location and wall thermal inertia.

It should be noted that for obtaining the new response factors, besides the well-known balance of thermal power on both sides of the multilayered wall, the energy balance within two sampling points must be done. Opposite to the traditional Mitalas' scheme, this ensures that the calculation scheme obtained is now conservative.

The superficial temperatures evolution imposed between sampling instants at both sides of the wall are showed in Figure 1. On the left the linear

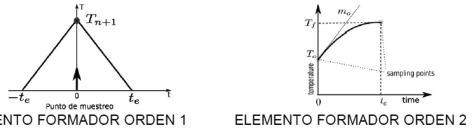


Figure 1. Temperature distribution according to the holder type. On the left 1st order holder. On the right 2nd order holder.

holder used by Mitalas while on the right Figure 1 shows the new 2nd order holder.

The linear (1st order) and parabolic (2nd order) methods are compared for a typical time step of one hour used in energy simulation, versus the linear with a time step of 5 minutes (because a short time step is more accurate). This last short time step for the linear method is taken as the reference (notice although it still contains errors in energy conservation).

2 INPUT DATA WITH DIFFERENT HOLDERS

2.1 *Linear method*

The Mittalas lineal Method (Mitalas 1968) is shown in Figure 2.

Figure 2 shows that the superficial temperature is linear between sampling points, and its continuity condition is expressed as:

$$T_{-j}(t) = T_{-j,n-1} + \frac{T_{-j,n} - T_{-j,n-1}}{t_e} t \tag{1}$$

Note: j means wall, and ± means each side of the wall.

According to Mittalas (Mitalas 1968), the conduction heat power exchanged in a given sampling instant, can be obtained by using the response factors named {X,Y,Z}. For a generic multi-layered wall, at the inside wall surface, it can be expressed as:

$$q_{cond,-j,n} = \sum_{r=0}^{\infty} T_{+j,n-r} Y_{T,j,r} + \sum_{r=0}^{\infty} T_{-j,n-r} Z_{T,j,r} \tag{2}$$

Note: obtaining the response factors {X,Y,Z} is a technique already known since (Mitalas & Stephenson 1971).

Therefore, to determine the thermal power transferred by conduction in wall j is necessary to determine two unknowns, the temperatures in the next sampling point n (time) at both sides of the wall ($T_{-j,n}$ $T_{+j,n}$). In order to obtain these temperatures two thermal power balances (at both sides + and -) are established. In fact these balances are valid at any instant of time, however, the method uses a discrete sampling rate. The balance can be written as follows:

$$q_{cond,\pm j,n} + q_{rad,\lambda\uparrow,\pm j,n} + q_{rad,src,\pm j,n} + q_{rad,solar,\pm j,n} = q_{conv,\pm j,n} \tag{3}$$

The new method needs new response factors named {XX,YY,ZZ}. They allow to get the energy transferred by conduction at a surface within the last time sampling period (Pinazo Ojer et al. 2015). They are used similarly to the {X,Y,Z}:

$$Qcond,(n-1) \rightarrow n = \sum_{r=0}^{\infty} T_{+j,n-r} \cdot YY_{T,j,r} + \sum_{r=0}^{\infty} T_{-j,n-r} \cdot ZZ_{T,j,r} \tag{4}$$

The energy response factors can be obtained with the Laplace transform technique see (Pinazo Ojer et al. 2015). These new response factors can be used with the 1st order holder as well as with the new 2nd order holder. Therefore they will provide us with a tool to meter the energy flows within time steps in both methods. Since the 1st order holder uses a thermal power balance at the sampling points, no energy conservation is forced. In fact it is not conserved and part of the energy disappears at some sampling points and reappears latter, thus leading to a stable numerical scheme.

2.2 *Parabollic holder (2nd order holder)*

Figure 3 shows the reconstruction of the temperature profile obtained using a 2nd order holder.

The continuity of the temperature signal at the sampling points is also forced as with the 1st order holder. The evolution of the superficial temperatures within a time range is given by:

$$T_{-j}(t) = T_{-j,n-1} + \frac{T_{-j,n} - T_{-j,n-1}}{t_e} t - p_{-j,n} t_e \cdot t + p_{-j,n} t^2 \tag{5}$$

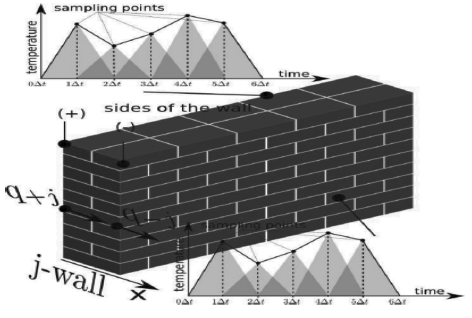


Figure 2. Superficial temperature input signal at both sides, using a 1st order holder.

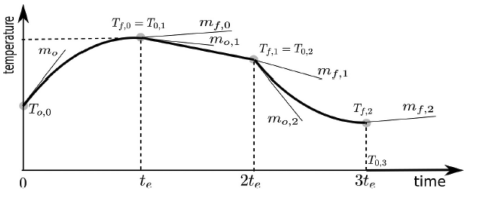


Figure 3. Evolution surface temperatures with forming element 2nd order (Pinazo Ojer et al. 2015).

In this case, two parameters are needed to determine the evolution of the temperature within a range, namely the temperature at end ($T_{-j,\,n}$) and the temperature semi-acceleration ($p_{-j,\,n}$).

Note that if $p_{-j,\,n} = 0$ then we recover the Mitalas method.

The 1D conduction heat power exchanged with this holder is obtained by the expression:

$$q_{-j,n} = \sum_{k=0}^{\infty}\left[T_{+j,n-k}\cdot Y_{T,j,k} + p_{+j,n-k-1}\cdot Y_{p,j,k}\right] + \sum_{k=0}^{\infty}\left[T_{-j,n-k}\cdot Z_{T,j,k} + p_{-j,n-k-1}\cdot Z_{p,j,k}\right] \quad (6)$$

while the energy transferred in this interval by conduction through the surface is expressed as follows:

$$Q_{cond,(n-1)\to n} = \sum_{r=0}^{\infty}\left[T_{+j,n-r}\cdot YY_{T,j,r} + p_{+j,n-r}\cdot YY_{p,j,r}\right] + \sum_{r=0}^{\infty}\left[T_{-j,n-r}\cdot ZZ_{T,j,r} + p_{-j,n-r}\cdot ZZ_{p,j,r}\right] \quad (7)$$

We would like to point out (Pinazo Ojer et al. 2015) two facts:

1. We need to obtain the new response factors for heat power and energy to both temperature and temperature semi-acceleration signals. However it does not involve a much higher computational effort because the greater effort. That is, the "computational cost" for determining these new response coefficients is basically the same.
2. The number of coefficients to be used in determining the power exchanged and transferred energy is twice that in the case of linearity.

Therefore, our new scheme needs to determine four unknowns: the temperature wall ($T_{-j,n}$ $T_{+j,n}$) and the temperature semi—acceleration on both wall sides. In turn two energy balances, at each wall side, are needed to obtain these unknowns.

These balances are written as:

$$q_{cond,\pm j,n} + q_{rad,\lambda\uparrow,\pm j,n} + q_{rad,src,\pm j,n} + q_{rad,solar,\pm j,n} = q_{conv,\pm j,n} \quad (8)$$

$$Q_{cond,\pm j,(n-1)\to n} + Q_{rad,\lambda\uparrow,\pm j,(n-1)\to n} + Q_{rad,src,\pm j,(n-1)\to n} + Q_{rad,solar,\pm j,(n-1)\to n} = Q_{conv,\pm j,(n-1)\to n} \quad (9)$$

3 APPLICATION

3.1 *Constructive elements analyzed*

The Energy Performance of Buildings Directive (EPBD 2002 & EPBD 2010) introduced in 2002 and reinforced by the 2010 recast, requires Member States to ensure that, when existing buildings undergo major renovation their energy performance is upgraded so that they meet minimum energy performance requirements. This is an important step towards boosting building renovation activities. So the professionals need accurate methods.

Therefore, there has been a boom in employment and investment in energy simulation tools.

Many energy simulations of buildings are performed to determine their behavior and estimate changes in energy consumption (Soto Francés 2008).

Consequently, it seems logical that any action to improve the tools for analysis and decision making, this would improve the energy efficiency building project with quality, without assuming an increase in workload.

The solutions tested are taken from the Catalog Constructive Solutions Rehabilitation developed by the Valencian Institute of Building (Serrano Lanzarote et al. 2011) which objective is supporting the technician in the energy renovation field. It focuses on the development of intervention proposals (EPISCOPE Partners 2014), within the scope of passive measures, affecting the constructive elements of the thermal envelope of the building (walls, roofs, windows, etc.).

3.2 *Base case comparison*

As implementation of the new methodology, this section determines the heat transferred by convection to air through a wall. The results are compared with the standard assumption of a linear evolution of surface temperatures. The time steps explored for the linear case and for parabolic have been 1 h. Compared with the reference: the linear case with 5 minutes time step.

To determine the behavior of the enclosure and to perform simple calculations, the following calculation hypotheses are assumed:

- Internal radiation source impinging over the internal surface during two hours; PSRC = 10 [W/m^2] (It is assumed that all incident radiation is absorbed)
- Rest of the internal surfaces of the enclosure are maintained at a constant temperature T_r = 22 [Cº].
- The temperature in the other side wall is also maintained at T_{-j} = 22 [Cº].
- The temperature of the dry air is also maintained T_a = 22 [Cº].
- The radiation coefficient equivalent (linearizing expression radiant exchange long wavelength) constant hr = 5 [W/m^{2}K] remains.
- The convection coefficient is constant; hc = 3 [W/m^{2}K].

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- The convection coefficient is constant; hc = 3 [W/m^{2}K].

3.4 *Results*

As shown in Table 1, errors relative to reference method (linear 5min) listed in the table are decreasing with time. In the case of parabolic method 1 h, the difference is very small as it evolves over time. In order to complete the comparison between the parabolic holder and the linear one, Table 1 compares the energy flow at different sampling points for conduction. The last two columns show the differences with the linear case and 5 (min) time step.

The evolution of the surface temperature of the enclosure according to the different methodologies used and the time step observed in Figure 5.

It can be seen that the closest values are represented by the rhombus symbol line (parabolic 1h) and crosses the cross symbol line (linear 5 min). It shows that the line corresponding to the linear method in red (1h) shows an evolution of the very different and steeper temperature. The tendency of the parabolic fit between 1h method and linear 5 minutes, occurs in all cases sampled.

It can be concluded:

The values of energy transferred to the air for a parabolic shaping function with time step 1h are similar to those of linear shaping function with a time step of 5 min. And clearly with a linear and time step 1h profile results differ greatly from what could be considered acceptable.

It is important to emphasize that the purpose of the shaping function in either case whether linear, parabolic or any other, it is a profile about the evolution of the superficial temperatures between sampling points. The actual evolution of the temperatures is actually unknown.

In short, the choice of one shaping function or another is an arbitrary decision. It should be based on some criteria like; possibility of leading to stable schemes, being computationally cheap, being compatible with certain forcing functions.

The parabolic shaping function gets a better accuracy in thermal massive solutions, typical from the vernacular architecture.

The use of new shaping functions has a great potential to reach improvements in accuracy and speed for the heat transfer applied calculations for new buildings and especially existing and refurbishment strategies.

3.5 *Thermal inertia solution*

In FC01 and FC01EXT, which are compact and heavyweight solutions, the evolution of temperature reflects the phenomenon of slowly heating up.

In FC01 INT, the thermal insulation placed on the inner side allows the inner surface to soon reach a temperature similar to that of the interior of the environment, but at the same time is quickly lost.

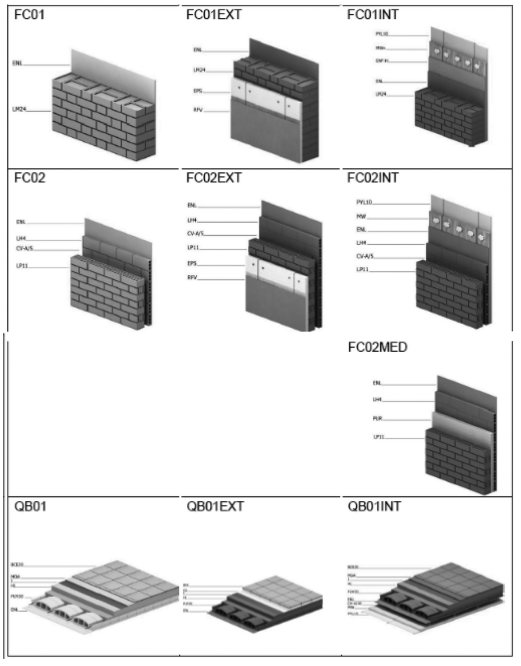


Figure 4. Constructive elements analyzed. Nomenclature elements type: EXT, exterior insulation; INT: insulation inside; MED: isolation in the middle of the enclosure.

Table 1. Heat transferred by conduction (J/m^2) within several intervals. Errors are for the 1 (h) case referred to the linear 5 (min) case. FC01 solution.

Qconduction (J/m^2)					Reference: Linear shaping function (sampling rate 5 min).	
Time step (s)	Parab. (1 h)	Linear (15 min)	Linear 15 min	Linear 5 min	Diff. parab 1 h	Diff. linear 1h
0–3600	–26621	–15949	–23431	–25336	–1285	9387
3600–7200	–22002	–22341	–22455	–22292	290	–49
7200–10800	6430	–4834	3018	5045	1385	–9879
10800–14400	3171	2979	3461	3393	–222	–414
14400–18000	2413	2556	2507	2461	–48	95
18000–21600	1910	2059	1969	1939	–29	120
21600–25200	1579	1698	1619	1597	–18	101
25200–28800	1341	1435	1370	1353	–12	82
28800–32400	1160	1236	1182	1169	–9	67
32400–36000	1016	1078	1033	1023	–7	9387
36000–39600	897	950	911	902	–5	–49
39600–43200	796	842	808	801	–5	–9879
43200–46800	709	749	720	713	–4	36
46800–50400	633	669	643	637	–4	32
54000–57600	567	598	575	570	–3	28
57600–61200	508	535	515	510	–2	25
61200–64800	455	480	461	457	–2	23
64800–68400	408	430	414	410	–2	20
64800–68400	366	386	371	368	–2	18
68400–72000	328	346	333	330	–2	16
7200–75600	294	311	299	296	–2	15
75600–79200	264	279	268	265	–1	14
79200–82800	237	250	240	238	–1	12
82800–86400	213	224	216	214	–1	10

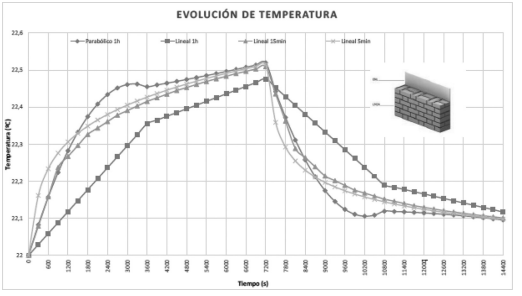


Figure 5. Temperature profile obtained using linear, parabolic shaping function in and different time steps.

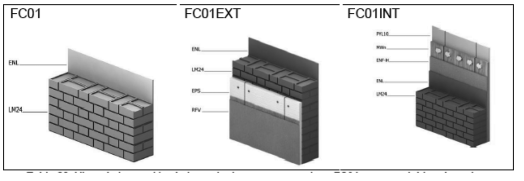


Figure 6. Improvement strategies FC01.

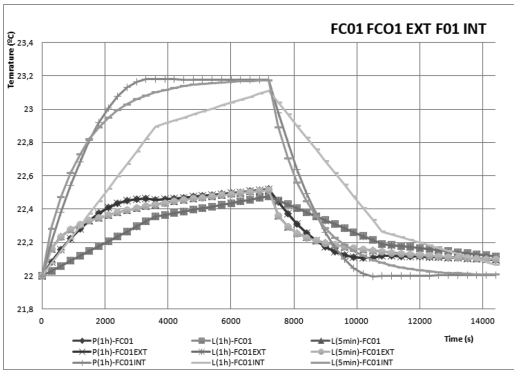


Figure 7. Evolution of the temperature between the different methods of solution FC01 and its variations.

In all the cases the parabolic profile gets more accurate than the lineal one in 1h step time.

It is verified that the presence of insulation and solutions with more mass worsens the results of the traditional method, and they show that the proposal method is more precise.

4 CONCLUSIONS

The policy about energy efficiency of buildings, including minimum energy requirements and energy performance certificate (EPC), have to be also applied to existing buildings in the case of energy retrofit. In this paper, the possible strategies that can be used to reduce the energy needs of traditional massive buildings, that are widespread in the old town of the Mediterranean cities, have been investigated. The energy needs of these building require accurate methodologies evaluated through computer simulation both in the heating and cooling period, on a yearly basis. Unfortunately, over the years a deep change came about in the relationship between architecture and energy. There has been a negative approach in simulation programs focusing only in the active energy systems. An improvement in simulation tools taking into account more accurate the role of passive energy use trough the envelope is necessary in the renovation of existing ones, recovering the importance of Architecture-Climate relation-ship.

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Schematic analysis of traditional Vietnamese houses under the influence of Han culture

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ABSTRACT: This paper is a further pursuit of previous research program, the Genetic Coding System, a methodology research done on comparison of traditional Han houses in Taiwan and southeast China. A six levels of schema program demonstrating the spatial form and the constructional form of house types is developed in this study. This schema program shows the effectiveness of this methodology to determine the inter-relations of different house types. The methodology is demonstrated with the comparison of Vietnamese houses and Han houses and results in three conclusions as below:

1. Han culture appears less influential on the formation of Vietnamese houses. This shows that spatial schemas are not passed on easily between different ethnics.
2. Traditional Vietnamese houses maintain spatial schemas from the culture of the minorities.
3. Han culture is more influential on northern Vietnam house types, in terms of form tactics and structure framework.

1 INTRODUCTION

1.1 *Complexity and differences developed in the evolution of house types*

For a long time it is claimed that housing types must be passed on in accordance with the social customs and political rules even when people migrate. This is true in most of the cases, however, the comparisons and analyses of traditional houses in Taiwan and southeast China show different findings: 1. House types in immigrant areas varied greatly from the house types in the homeland. 2. Some house types have similar outer appearances to their origins with inside features altered. These findings indicate that house types evolve when transferred. The changes in house types also show that materiality and spatiality are separated during the development of new types, resulting in greater diversity and complexity. In our previous studies we have introduced different levels of house type schemas in "Genetic Coding of House Types" as further exploration of research on house typology (2008, Wang).

1.2 *Structural depiction of house types—genetic coding*

Base on the data collection and study, some promising results are outlined as below:

1. House types cannot be identified or defined through a single concept of spatial layout or substantial form.
2. A typology shall be established to connect the separated levels, namely the deep levels of spatial schema, of which determines the spatial layout and relatively surface levels of material schema.

Thus the theory of house typology has to be able to accommodate connotations at different levels in order to look into ideas that have been passed on from generation to generation.

Studies of Han houses usually emphasize the characteristics of Han culture with description of how the central axes define the symmetric spaces while distinguishing the orders of inside and outside, primary and secondary, and the lower front toward the higher rear. This common arrangement in Han houses is hereby named *default schema*, a fundamental practice as well as a cultural principle in Han houses. All the Han house types are designed according to the *default schema*, and yet it is not enough to describe the variations of different house types.

The *default schema* is not able to fully describe Han houses. Types thought to be the same category usually have identical spatial layout, we mark it as genes at deep levels and call it *base schema*, determined by the beliefs of the dwellers. Based on previous research of the houses in southeast China we have identified six *base schemas*, the basic spatial concepts that determines the spatial layout of traditional Han house type, as follows: "Extension", "Extrusion", "Progression", "Escorting", "Infolding" and

"Surrounding" (Wang 2008). *Operational schema* is the secondary level schema, an add-on to *base schema,* unfolds the evolving of house type. Twelve *operational schemas* are identified as follows: "Widening bays", "Deepening frames", "Mirroring", "Overlaying", "Juxtaposing", "Seriating", "Arraying", "Weaving", "Stretching wings", "Adding side chambers", "Adding back chambers" and "Adding ring chambers". *Default schema*, *base schema* and *operational schema* are spatial levels.

In contrary to spatial schemas are the material schemas. Material schema is comprises of three levels, the *building tactics*, *form tactics*, and *surface program*, all reflect constructional building techniques. For example, "bay" is the minimum building unit of all Han house types in southeast China, bay is the *building tactics*; *Form tactics* shows the constructional structure, wooden or brick structures; and lastly *surface program* depicts the ornamental vocabularies.

These six levels are interrelated in most of the cases and in our earlier research we also found in some cases they are independent to each other and can be separated (Fig. 1).

1.3 *Vietnamese house types under the influence of Han culture*

As significant populations of Han people migrated out of China throughout the history, the influence of Han culture can be found in areas surrounding China. House types in those area show considerable characteristics of Han housing.

Theoretically a house type is formed after a long time of adaptation to local conditions, and once a new type is settled it no longer changes unless there are forces driving it to change. When house types are brought to other areas with different natural conditions, different constructional resources and different interrelated cultures, evolution is activated.

Through the typological study, the objectives of this study are to find out, in those house types influenced by Han Culture, which characteristics in immigrant house are identified as the spatial schema or the material schema.

Traits of Han architecture are found in Buddhist temples in Vietnam, often reflected in the spatial layout.

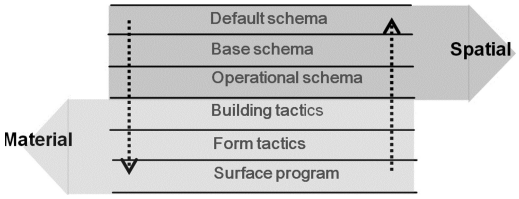


Figure 1. Genetic coding system.

The construction of these temples can be dated back to the beginning of the tenth century (Fig. 2).

On the other hand ordinary houses were mostly built in the seventeenth century, during the end of the Ming Dynasty and the beginning of the Ching Dynasty. They are the evidences that Han culture's spread southward to Vietnam.

Located between the two grand cultures: India and China, Vietnam is exposed to diversified cultures. There are 54 ethnic groups and a number of them belong to Austronesia. Under the influences of native cultures, Han culture and Cham culture among others, architecture in Vietnam presents variations and mixture, a fabulous database for the research of house types.

2 SCHEMATIC ANALYSIS

2.1 *Schematic analysis on Vietnamese ordinary houses*

Base schema: Houses for living in Vietnam usually are very small, a single structure, expansion

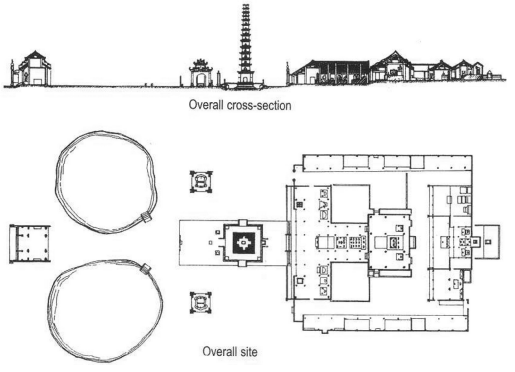


Figure 2. Thien Mu pagoda at Hanoi, Vietnam (Nguyễn Bá Dang 2010).



Figure 3. Vernacular Houses at North of Vietnam (Nguyễn Van Huy 2011).

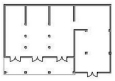
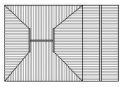
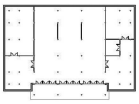
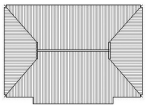
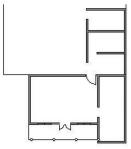
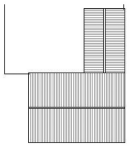
Name / Location	Plan	Roof
House-Yang Hue(middle) (by author)		
An Hien Garden House Hue (middle) (by author)		
House-Dong Thanh Hoa (north) (by author)		

Figure 4. Ordinary house cases (By author and M.J. Hsieh).

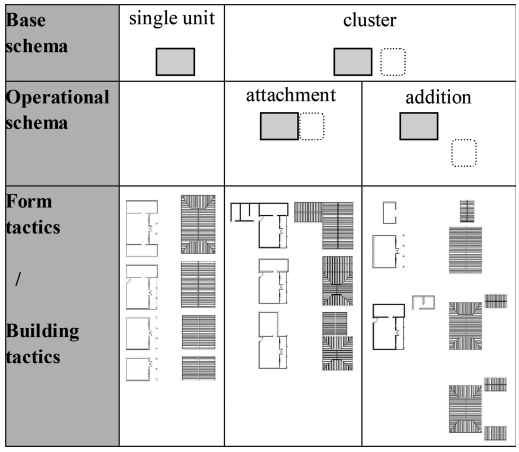


Figure 5. Schematic analysis of Vietnamese ordinary houses.

wouldn't be more than two buildings. From the spatial relationship between the main building and secondary building, our data shows the way of attachment is of all possible geometric arrangements. This indicates that there is no particular rule for such spatial arrangement. The above finding resulted in two *base schemas* for all cases, "single unit" and building "cluster". Building "cluster" is the constitution of a main building and secondary buildings. (Fig. 5)

Operational Schema: The buildings in "Single unit" types are called main building. Hitherto our data shows that most of the main building has the three bay units. There is a "secondary building" attached on the side or rear of the main house, thus the *base schema* is "cluster". And the "cluster" accomplished by two *operational schemas*: "attachment" tight and "addition" separate. In all cases, placement of the secondary building can be parallel or perpendicularly attached or added to the front, the rear or both side of the main building. The only exception is central axis, no secondary building has been found on the central axis.

Form Tactics: Form tactics decides the spaces of the single unit through the bay-column system rooted in the Han culture. The numbers of bay are usually odd and symmetrical following the central axis. Our data shows that most of the main building has three or five bays, while few small houses only have two bays. The entrance of the main buildings is on the central axis, also known as the middle bay, function as area for worship of the ancestor. Bays on side are living and sleeping area. Kitchens and other serving spaces will be in the secondary building.

Building Tactics: Most of the traditional Vietnamese houses are wooden structures with roofs that are similar to the "gable and hip" roof in Han culture. The wooden structures are supported by cantilevered corner beams. The secondary building never overlaps with the main building.

2.2 *Schematic analysis on Vietnamese communal houses*

Base Schema: The functions of the traditional Vietnamese communal houses are worship and congregation. The various gods they worship are aligned along the central axis, thus the space is presented as the *base schema* "Progression" follow the central axis.

Operational Schema: The *base schema* "Progression" toward the back on the central axis is accomplished by the same *operational schema* "attachment" as in ordinary houses. The secondary building shall be placed along the central axis, parallel or perpendicular to the main building. But different to ordinary houses, the attachment of communal houses will array symmetrically on and along the central axis.

Form Tactics: Both the main and secondary buildings of the communal house are constituted by the bay-column system as in Han culture, the odd number of bays and symmetric distribution along the central axis resemblance to the Han architecture. Our investigation found that nine bays is the maximum width of the main buildings, the main entrance is on the central axis. Pathway along the central axis is designed for worship. The side bays perpendicular to the central axis for worship are elevated by 60~75 cm up, and the seconary

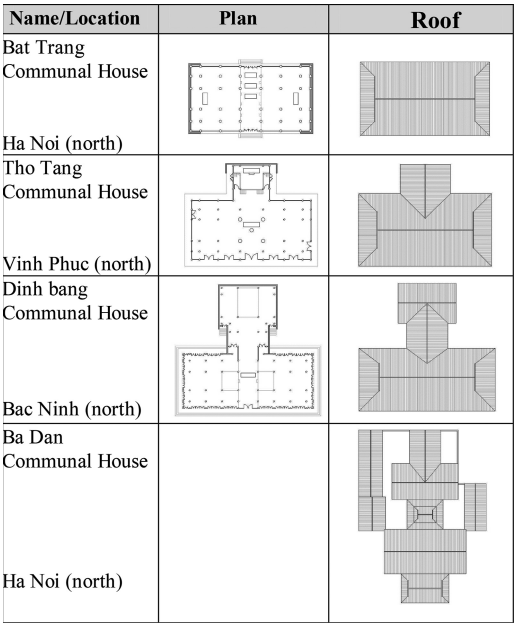


Figure 6. Vietnamese traditional communal houses-plan and roof (By author and M.J. Hsieh).

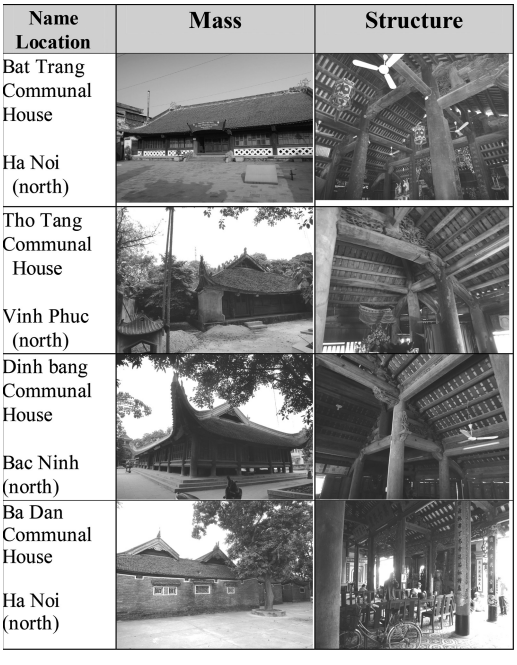


Figure 7. Vietnamese traditional communal houses—mass and structure (By author and M.J. Hsieh).

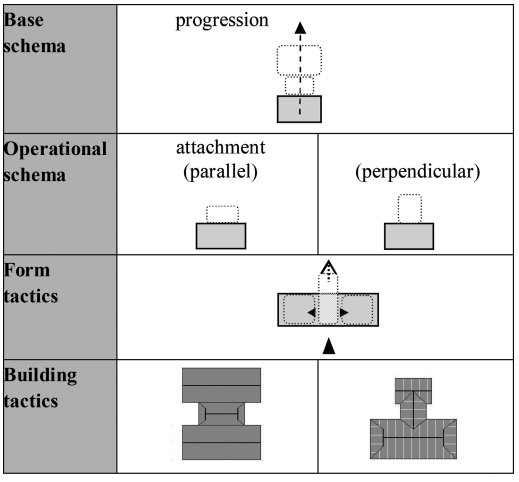


Figure 8. Schematic analysis of Vietnamese traditional communal houses.

building is in line with the pathway of the main building. In larger temples there are two rows of houses as in the Han architecture on both side boundary, those are bedrooms for monks.

Building Tactics: Traditional Vietnamese communal houses are wooden structures with "gable and hip" roof resembling those of the Han architecture. Compared to ordinary houses, communal houses is larger in scale, thus the technique of shuttle-shaped column is a common character. If the roof ridge of the secondary building is perpendicular to the main building, the roofs overlap. Because cantilevered corner beam were widely used for "gable and hip" roof, if the roof ridge of the secondary building is paralleled to the main building, the structures will be separated.

2.3 *Schematic analysis on houses of two minority ethnic groups (Gie-Trieng, Bahnar)*

Based on the analysis on houses of two minority ethnic groups: Gie-Trieng and Bahnar, two *base schemas* were identified: "Single Unit" and "Progression". Minorities' houses have entrance porches along the short side (Gie-Trieng) or long sides (Bahnar) of the buildings.

On the *operational schema*, the "Progression" houses have several buildings seriating from the front to the back, dwellers can walk through all the buildings. Kitchen is located at the rear end corner of the building, the rest of the building is an open space with no partitions, designated for sitting and sleeping.

Bahnar houses and Gie-Trieng houses are similar in terms of the *form tactic*, and most of them don't define spaces with bays.

In terms of *building tactic*, they are all wooden framed without much depth. Structured with lifted

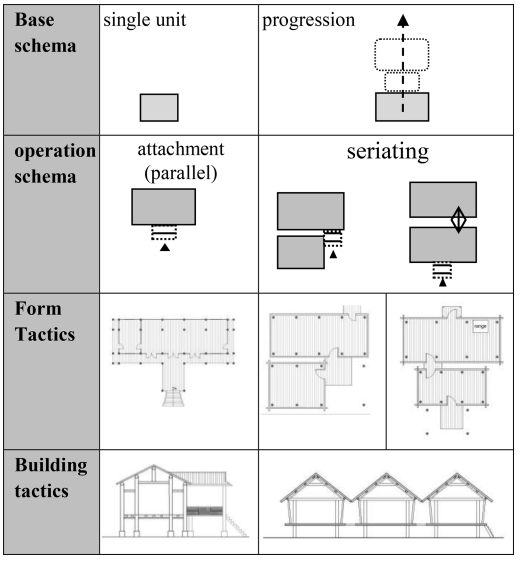


Figure 9. Schematic analysis of Vietnamese minority peoples' houses.

beams, columns are not compulsory. Buildings are all adjoining with roof ridge in parallel, with exemption of the entrance porch.

3 COMPARATIVE ANALYSIS

3.1 *Base schema*

Base on the study above, this section compares the Han house types with the Vietnamese ordinary houses, the communal houses and houses of the minorities. This comparison emphasize on the issue of inter-relation among the above house types.

The *base schema* of the traditional Vietnamese houses is different from the *base schema* we had assumed that is developed from the more elaborate Han houses. Possibly, the reason is that houses in Vietnam are not as large as in China. Thus the relationships between buildings are less organizational or less developed. Furthermore, those houses in Vietnam are very similar to the houses of minorities in terms of scales and arrangements. The scales and arrangements of houses reflect the social relationship of settlements and families, they are more rooted genes, thus are more unlikely to be changed. Larger scales can be found in religious architecture or public buildings, but their larger scales come from growing upward only along the axis.

3.2 *Operational schema*

Most common *base schema* in religious architecture is "Progression on one direction" which is

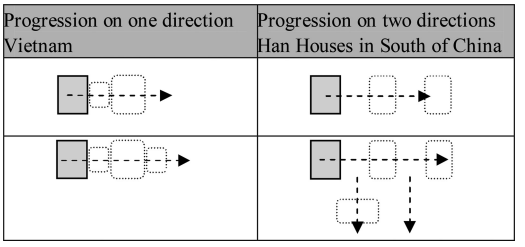


Figure 10. Comparative analysis on *Operation Schema.*

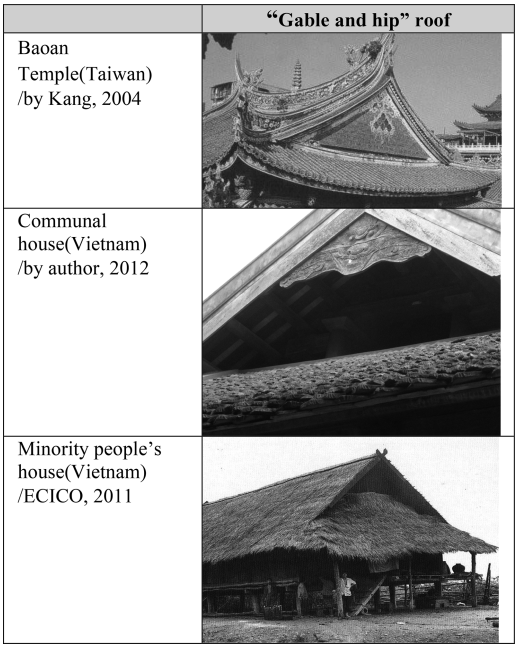


Figure 11. Comparation on *Building Tactic.*

different to the "Progression on two directions" in Han architecture. We have found that it resulted from the difference on *operational schema*. In Vietnamese houses, the buildings seriated closely along the central axis show similar attempt of "Progression" of the Han houses. The difference can be discovered in the spaces between the two successional buildings. The geometric spaces in Han houses constitute another dimension, more sophisticated than the Vietnamese houses. (Fig. 10)

3.3 *Form tactics*

Three bays units are very common in Vietnamese ordinary houses. Their entrances are along the middle bay of the long side, which are different

to houses of minorities as well as the houses in Malayan Peninsula, indicating that these houses might have been influenced by Han culture. Nevertheless, in the three bays units, few have walled bedrooms on the sides, which suggest that these houses tend to maintain the custom of the houses of minorities.

3.4 *Building tactics*

In terms of *building tactics*, these houses are built with "gable and hip" roofs, similar to the roof of Han houses, but different in structural details. The gable walls of Han houses are of solid walls, but in most of the communal houses in Vietnam there are no gable walls. In fact, this is closer to the style of the houses of minorities with thatched roofs.

4 CONCLUSION

4.1 *Spatial schemas are more difficult to pass on, and material schemas are easier to be altered*

There is a close resemblance between the traditional Vietnamese houses and the houses in Malayan Peninsular, opposed to less influenced of Han culture in terms of the base schema and operational schema. In terms of the form tactics, the three bays from Han culture that are never found in houses of minorities provide evidences of Han culture's influence. This indicates that genes belong to *base schema* and *operational schema* are deeper and more unlikely to spread because they project the deeper contents of a society.

The wooden structure, tiled roofs and the "gable and hip" roofs are easily to be identified as genes of building tactics in Han architecture, and the cantilever corner beams are recognized by many studies as borrowed from Japanese architecture. Nevertheless, the houses of minorities have the roof forms that are very similar to the "gable and hip" roof, with application of different materials. The techniques and forms of wooden structures are similar to the crescent-shaped beams from Japan or China.

4.2 *Traditional Vietnamese houses have not been influenced by Han culture as much as they appear*

Having been ruled by Han people for more than one millennium, Vietnamese houses have the appearances of Han architecture and led researchers to believe that Vietnamese living must be influenced greatly by Han culture. Naturally this assumption comes from the dominant Han culture. This can let us comprehend house types more deeply and detail, the spatial schema rooted deeply in a society is not easily altered even by an authoritative culture.

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