Beniamino Murgante, Giuseppe Borruso, and Alessandra Lapucci (Eds.)

Geocomputation and Urban Planning

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1 Introduction

Sixteen years ago, Franklin (1992) estimated that about 80% of data contain geo-referenced information.

To date, the availability of geographic data and information is growing, together with the capacity of users to operate with IT tools and instruments. Spatial data infrastructures are growing and allow a wide number of users to rely on them. This growth has not been fully coupled to an increase of knowledge to support spatial decisions.

Spatial analytical techniques, geographical analysis and modelling methods are therefore required to analyse data and to facilitate the decision process at all levels. Old geographical issues can find an answer thanks to new methods and instruments, while new issues are developing, challenging researchers towards new solutions. The introduction to this volume aims at contributing to the development of new techniques and methods to improve the process of knowledge acquisition.

In this scenario, Openshaw (1998; 2000), at the end of 1990s, coined the term Geocomputation, considering two main issues: intensity of the process and increase of knowledge and intelligence. This expression has been interpreted according to several meanings. Ehlen et al (2002) analyze four aspects of Geocomputation: from a high performance computing point of view, as a set of spatial analysis methods, as the essential aspects of Geocomputation and as their relationship with GIS. The first aspect is related with research on parallel and grid computing; this domain is represented by a small community among researchers on Geocomputation. While the first topic is completely distinct from the others, the remaining three issues are strongly related among them. During the first time of using computers in geography field, it was widely widespread opinion that computers would become slaves of quantitative geographers, but when GIS came, roles changed. Geographers became computer slaves (Gahegan 1999), driven by the availability of data, software and processing power and the need to implement suited-for-purpose solutions. However, geographers as users of GIS are (and should be) to-date not limited to "the mechanism of which buttons to press, but on how to work sensibly with geography in mind" (Unwin 2005). For this reason, great part of geocomputational applications do not adopt commercial GIS softwares. In order to find solutions which could better fit their models and methods, geographers prefer to develop their own softwares or extensions of GIS (Longley 1998). In such sense, Geocomputational tools and solutions are good candidates, together with GIS software, to represent to date's parts of the "geographer's toolbox"

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(Haggett 2001) to address complex geographical issues. The Geocomputational expression is related to the development and the application of new theories, methods and tools in order to provide better solutions to complex geographical problems (Fotheringham et al 1997; Couclelis 1998).

2 Geocomputational Applications in Urban Planning

The geocomputational analysis discussed in this volume, could be classified according to three main domains of applications; the first one related to spatial decision support system and to spatial uncertainty, the second connected to artificial intelligence, the third based on all spatial statistics techniques.

In the field of spatial planning, the complexity of decision making processes has been one of the major issues for over thirty years. In fact, spatial planning is characterized by a multiplicity and a complexity of different actors, objectives, feedbacks and by the active role of "time" considered as both constructor and destroyer of interests, opportunities, resources in the planning process (Lombardo and Petri 2008).

The complexity of interactions between different actors involved in decision processes, regarding actions of territorial transformation, often makes these processes neither predictable, nor concordant in scope (Faludi 1987).

Then, in this new vision of urban planning and modelling, a new concept of decision making emerges and it is based on the search of the so called "optimal compromise" (Roy 1979 1985; Vinke 1981 1992), instead of on the search of the "best" solution.

The search of such compromise is located in an evolutionary context comprising both the study of preference systems by different actors involved in urban and territorial dynamics and the analysis of the effects of sustainable alternatives.

In this context decision support tools are developed and these tools, together with the development of data bases, generate the systems known as Spatial Decision Support System, in which a data base is combined with query procedures and at least with one method of comparison and ordering of alternatives (Bana and Costa 1990; Vincke 1992). In fact, Spatial Decision Support Systems (SDSSs) can be considered as interactive, computer-based systems devised to support decision makers in achieving a higher effectiveness while solving a semi-structured decision problem involving territorial aspects (Malczewski 1999 2006b; Arentze and Borger 1996; Lapucci et al. 2005).

In the field of SDSSs the concept of interaction between the user(s) (who can have different degrees of experience and/or competence in the decision problem under study) and a computer-based system containing tools able to both analyze spatial data and to model spatial decision problems is central.

Densham (1991) suggests that SDSSs should have specific characteristics and some of them are reported below:

- a dedicated design to solve unstructured problems;
- a powerful and user friendly interface;
- a specific tool for interactive and recursive problem solving;
- the capability to combine analytical models flexibility with available data;
- the possibility to explore solution space by building alternatives.

According to Malczewsky (Malczewski 1999; 2006a), the general framework of a SDSS comprises three main components (reported below) and the decision maker is considered as a part of the system itself:

1. a database management system (DBMS) and a geographic data base able to coordinate all the function relative to information management (i.e. data storage, record, extraction from various sources, etc.);
2. a model based management system (MBMS) containing the library of different models necessary for decision making processes and the routines to maintain and manage them;
3. a dialogue generation and management system (DGMS), containing all the procedures for information input/output from and to the system.

The devise of an efficient SDSS enables to integrate two separate tool sets (models and data) into a unified system where the contribute of geographic information sciences is in the knowledge of spatial and attribute data processing in a GIS environment, and the contribute of spatial analysis resides in the knowledge of territorial modelling.

Each discipline involved in environmental planning uses a different approach to represent its own vision of reality. Geological sciences or hydraulics evaluate risks by consistent mathematical models, which are relevantly different to non linear models employed in ecology, and, at the same time, information about significance and value of cultural heritage in a given environment does not easily correspond to value attribution. Different ways of managing values correspond to each method of giving information. The growing importance of the relationship between disciplines and technological innovation in environmental analyses leads to a dangerous consciousness about the possibility of managing great amounts of data, by the use of Geographic Information Systems (Murgante and Las Casas 2004).

A new difficulty rises to the fore, regarding the need of traducing G.I.S. supported complex analyses and evaluative routines into planning instruments which have only crisp definition of zoning, due to their normative issues in land-use regulation. Often objects do not have crisp boundaries or do not have boundaries at all (Couclelis 1992; Burrough and Andrew 1996). In fact, Couclelis (1996) highlights the uncertain nature of entities and the uncertain mode of observing real world, even if the user's purpose is certain (land-use zoning).

Figure 1 reports a classification of uncertainty in spatial information. Geographical information can be certain or not. In the case of well defined data, a degree of uncertainty can be eliminated using probability theory or, in case of several alternatives, it can be solved by adopting multicriteria methods. Poorly defined data have been classified in three groups.

Some data are said to be ambiguous if they can have at least two particular interpretations. Ambiguity leads to a discordance in data classification due to a different perception of the phenomenon. Inaccuracy produces uncertainty in the case of low quality of data, due to a certain degree of error.

Great part of GIS functionality is based on Boolean operators which are founded on a two-valued logic. Vagueness (Erwig and Schneider, 1997) takes into account multi-valued logic and it is based on the concept of "boundary region", which includes all elements that cannot be classified as belonging to a set or to its complement (Pawlak, 1998).

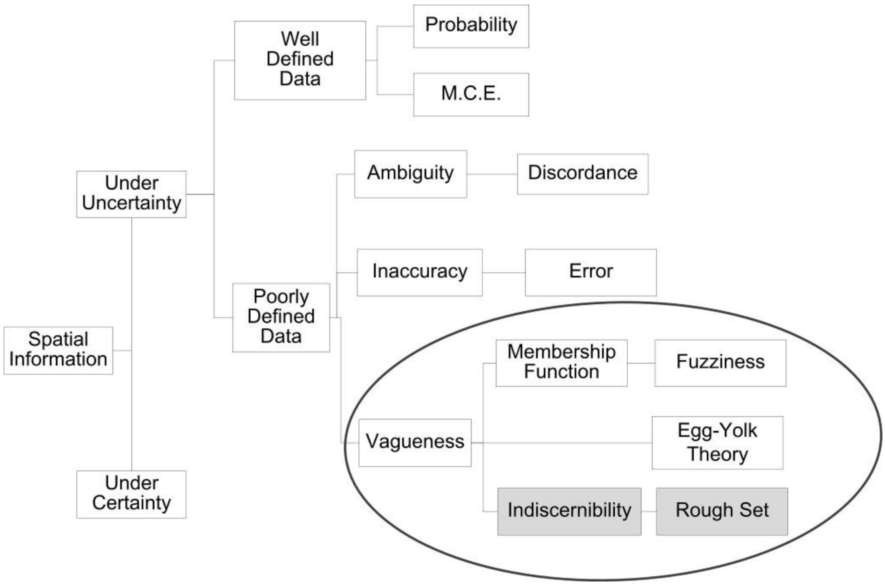

Fig. 1. A Classification of uncertainty in spatial information (adapted from Murgante et al 2008)

Three theoretical approaches to vagueness exist: the first one is based on fuzzy set theory (Zadeh, 1965), which accounts for partial membership of elements to a set; the second is Egg-Yolk Theory (Cohn and Gotts 1996, Hazarika and Cohn 2001) based on the concepts of "egg", i.e. the maximum extension of a region, and "yolk", i.e. the inner region boundary; the third approach is rough set theory (Pawlak, 1997).

In urban and territorial planning, the abandon of deterministic approaches to decision analysis has been quickly developed thanks also to the great opportunities provided by powerful computer tools able to manage very large data bases, to execute more complex comparisons and to support the new simulation tools.

Instruments derived from *Artificial Intelligence* coupled with *GIS systems* consent detailed elaboration on various data types (i.e. thematic maps, population density, transport infrastructures, productive settlements, environmental surveys etc.) and enable to extract and build knowledge directly from experimental data and also to represent the extracted knowledge in form of rules involving the spatial dimension (Lombardo and Petri 2008).

Large amounts of data are available to analyze and simulate the evolution of urban and territorial systems, but the value of those data mainly depends on the capability to exploit knowledge from them. On this purpose, innovative and efficient tools and methods can be found in the field of *Data Mining* and *Knowledge Discovery from Databases* (KDD), the former being the core of the latter (Bonchi et al 2004).

In fact, KDD is a multi-disciplinary field which merges concepts and techniques from different research areas, such as statistics, artificial intelligence, export systems, machine learning, pattern recognition, information retrieval, high performing computing and data visualization (Bonchi and Pecori, 2004).

Data Mining (DM), the nucleus of KDD, is an essential process where intelligent methods are implemented in order to extract data patterns; it comprises a class of database applications which searches hidden patterns in a group of data that can be used to predict future behaviors.

Machine Learning (ML) is a subfield of artificial intelligence concerning the development of techniques which allow computers to "learn"; more specifically it is a method for creating computer softwares by the analysis of data sets. Machine learning overlaps heavily with statistics, since both fields study the analysis of data, but unlike statistics, it is concerned with the algorithmic complexity of computational implementations (Kanewski and Maignan 2006).

Artificial neural networks, *decision trees*, *genetic programming* and *Bayesian networks* are some of the most powerful and well-known machine learning topics.

In urban planning, environment machine learning can be a powerful instrument to increase the capabilities and the potentialities of spatial decision support systems. On the hypothesis that human expert knowledge is based on applying decision criteria to a given domain, ML systems can be built with the peculiarity to learn how to identify these criteria, with sufficient access to domain specific information sources (Oh et al. 2006, Peng and Gero 2006).

In urban and territorial planning, the final aim of spatial modeling and simulation systems is to open new knowledge windows by working on the relations acting in time and space between spatial phenomena. Those models can support decision makers in better understanding the consequences of their choices and to help them in the decision making process itself.

The first generation of models and systems was often based on simple input-output relations, weak in terms of behavioural principles and spatial scale. Most of them were based on the assumption of perfect and full information, so that uncertainty was rarely addressed, but in a territorial context characterized by an increasing *uncertainty,* forecasts are inevitably subjected to several limitations.

Geocomputational methods for urban planning may therefore include innovative approaches to reasoning based on human tolerance uncertainty, incompleteness, imprecision and fuzziness in decision-making processes (Diappi 2004).

With the development of chaos theory and powerful tools offered by GIS and soft computing, traditional complex models were replaced by new ones as Cellular Automata and Multi Agent Systems (Batty 2001; Benenson and Portugali 1997).

While the former ones are often based on the belief that simple rules and principles are sufficient to generate complex emerging patterns, the latter are mainly focused on the analysis of the strategic choice of actors involved in a urban environment. Even though some multi agent systems are still based on simple, primary data driven principles, others are trying to deeply investigate the behavioral foundation of models (van Leeuwen and Timmersmans 2006, Petri et al 2008).

An important element on which the analysis urban modelling has to be focused is the identification of *rules*: we refer to spatial simulation tools which, based on the definition of the territorial system elements (agents, sub areas, etc.) and of the environment enveloping them, allow the simulation of the relations between elements and between elements and their environment (e.g. Cellular Automata, Multi Agent Systems) (Lombardo and Petri 2008).

In the context of simulation applied to territorial sciences, the building of evolution rules applied to the "actors" (be they individuals, groups, or spatial unities) follows three main approaches:

1. the adoption of well established theories: rules are derived from analytical models as in Harrys and Wilson's model (Wilson 1981, 2000; Lombardo and Rabino 1983) or economical models such as Discrete Choice Models (Heppenstall et al. 2005);
2. the "building" of rules based on "expert knowledge": those rules derive from the modeler's know-how of from common sense. Such rules can follow the BDI (Beliefs, Desires and Intentions) framework (Nonas and Poulovassilis 1998) or the "Activity Based Approach" (Ettema and Timmermans 1995);
3. the "discovery" of rules: this is the more complex approach as rules are derived directly from data, by techniques belonging to the field of Artificial Intelligence, such as Decision Tree Induction, Neural network, Genetic Algorithms, Bayesian Networks etc. This way often produces limited sets of rules, because it needs still more studies and developments, but presents some advantages, as specified below:
   - It enables to extract (possible new) knowledge from very large spatial data bases;
   - It consents to derive rules specific for the study area;
   - It enables to verify the rules adopted in approaches 1) and 2);
   - It verifies if and what rules are unchanging in time;
   - It represents a way to build new theories.

The geocomputational approach adopts the third type of rules, as it assumes that information processing should itself be able to find out rules through a learning procedure.

The main aim of spatial analysis is a better understanding of spatial phenomena aggregations and their spatial relationship. Spatial statistical analyses are techniques which use statistical methods in order to determine if data show the same behaviour of the statistical model. Data are treated as random variables. Events are spatial occurrences of the considered phenomenon, while points are each other arbitrary locations. Each event has a set of attributes describing the nature of the event. Intensity and weight are the most important attributes; the first one is a measure identifying the event strength, the second is defined by the analyst who assigns a parameter in order to define if an event is more or less important according to some criteria.

According to Bailey and Gatrell (1995) spatial statistics techniques can be grouped in three main categories: Point Pattern Analysis, Spatially Continuous Data Analysis and Area Data Analysis.

The first group considers the distribution of point data in the space. They can follow three different criteria:

- random distribution: the position of each point is independent of the others points;
- regular distribution: points have an uniform spatial distribution;
- clustered distribution: points are concentrated in some building clusters.

The second group takes into account the spatial location and the attributes associated to points, which represent discrete measures of a continuous phenomenon. The third group analyzes aggregated data which can vary continuously through space and can be represented as point locations. This analysis aims to identify relationships among variables and *spatial autocorrelation.* If some clusters are found in some regions and a positive spatial autocorrelation is verified during the analysis, it can describe an attraction among points. The case of negative spatial autocorrelation occurs when deep differences exist in their properties, despite the closeness among events. It is impossible to define clusters of the same property in some areas; a sort of repulsion occurs. Null autocorrelation arises when no effects are surveyed in locations and properties. Null autocorrelation can be defined as the case in which events have a random distribution over the study area (O'Sullivan and Unwin, 2002). Essentially, the autocorrelation concept is complementary to independence: events of a distribution can be independent if any kind of spatial relationship exists among them.

Spatial distribution can be affected by two factors:

- first order effect, when it depends on the number of events located in one region;
- second order effect, when it depends on the interaction among events.

If these two definitions seem more clear, it is not as much clear as the recognition of these effects over the space.

Among widely used spatial analytical techniques, point pattern analysis represents one of the more interesting and adopted ones. This is also due to the fact that point structures are among the easier ones to use, process and represent by means of spatial analytical programmes and GIS softwares, consisting of a minimum set of coordinate pairs with – or without – attribute data for those locations. If the simple scatterplot of point features helps in giving some information about the pattern under exam, however more refined techniques can be applied to better understand it. Techniques and methods to analyse first and second order properties have been implemented, measures based on density, i.e. Kernel Density Estimation, and those relying on distance, i.e. Nearest Neighbor Analysis and K – functions, respectively.

Space representation in such sense is a simplified one, as geomorphologic features and human actions, in terms of built environment and infrastructures, do not arise automatically when we simply consider a (flat) study region of space (an area) and a set of events (points) in a two-dimensional space.

Only recently some efforts have been made, thanks to improved processing power and algorithms, to include some of the physical and human constraints onto spatial analytical techniques, and in point pattern analysis in particular. This is an effort to go further the 'classical' geographical assumption of isotropy and homogeneity of space, therefore modeling it in a more realistic way. Networks, in particular, have been considered, in order to adapt analytical methods to a space influenced by the presence and the actions of humans, especially urban areas.

In fact, many human-related events in space are related to network-led spatial features as road transport network, therefore over non-homogeneous, non-Euclidean spaces. Recently, Batty (2005) recalled a need to implement more refined network analytical techniques into GIS software. Miller (1999) as well, noted that assuming space as continuous and planar is too strong for analyzing events occurring in a subset of such space.

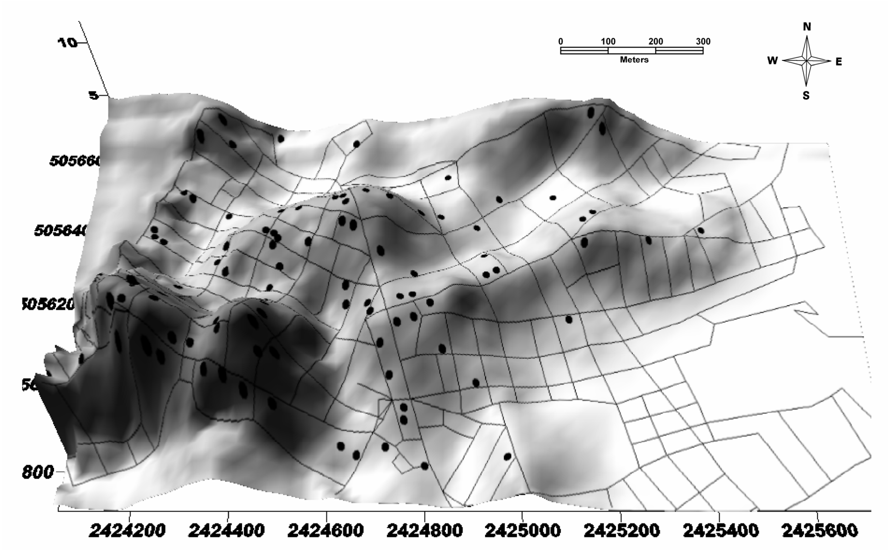

Fig. 2. Density estimation on networks: Example of linear Network Density Estimation (NDE) over banks and insurance company in the central urban area of Trieste – Italy (adapted from Borruso 2008)

In recent years, authors involved in spatial analysis focused mainly on second order properties, as Nearest Neighbor Analysis (Okabe et al 1995) and *K* - functions on networks (Okabe and Yamada 2001) and their application to real cases (Yamada and Thill 2004, 2007). Recently other authors (Borruso 2005, 2008 and Downs and Horner 2007a,b) studied network-related analytical techniques for first order point pattern analysis, actually adapting Kernel Density Estimation to a network structure. In their applications they focused respectively on density of human activities in a network urban space (Figure 2) implementing a method called Network Density Estimation (NDE) and on networks of movement trajectories of animals for home ranges estimation, Network-based Kernel Density Estimation.

Spatial Statistics has not been used enough in the field of urban planning. Planners generally prefer to carry out the traditional statistical analysis, pasting results to the geographical entity. Compared to classical statistical analyses, autocorrelation techniques allow to discover where the concentration of several indicators is located. An application of autocorrelation methods in order to produce more detailed analyses for urban regeneration policies and programs has been applied in Bari municipality (Murgante et al 2008). Generally, a municipality proposes an area as suitable for a urban regeneration program, considering the edge of neighbourhoods established by bureaucrats. Socio-economic analysis can account for a huge amount of data related to the whole neighbourhood. Nevertheless sometimes it is possible that only a part of a neighbourhood is interested by social degradation.

In these cases the indicator is diluted and it does not capture the phenomenon throughout its importance. Furthermore, it is possible that the more deteriorated area belongs to a part of two different adjacent neighbourhoods.

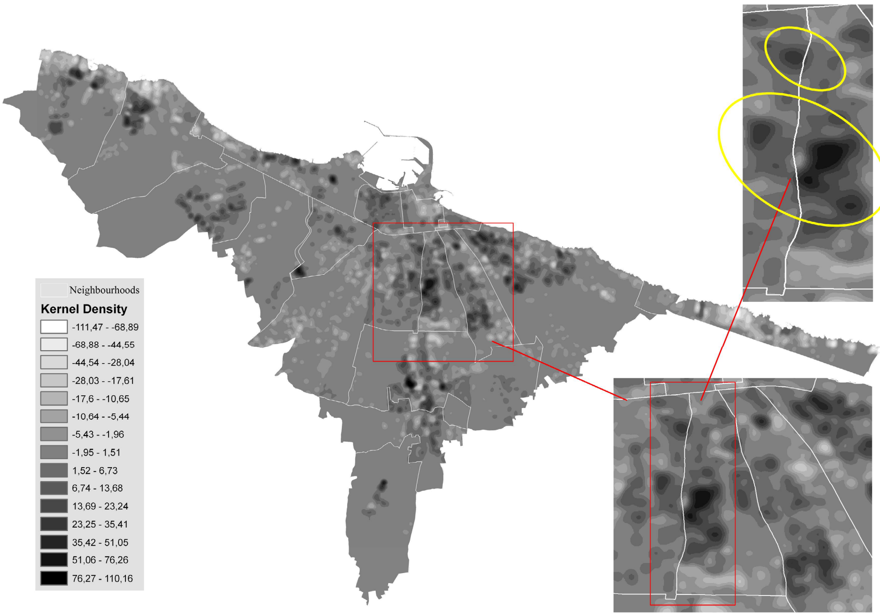

Fig. 3. Synthetic index of Kernel Density Estimation of social indicator (adapted from Murgante et al 2008)

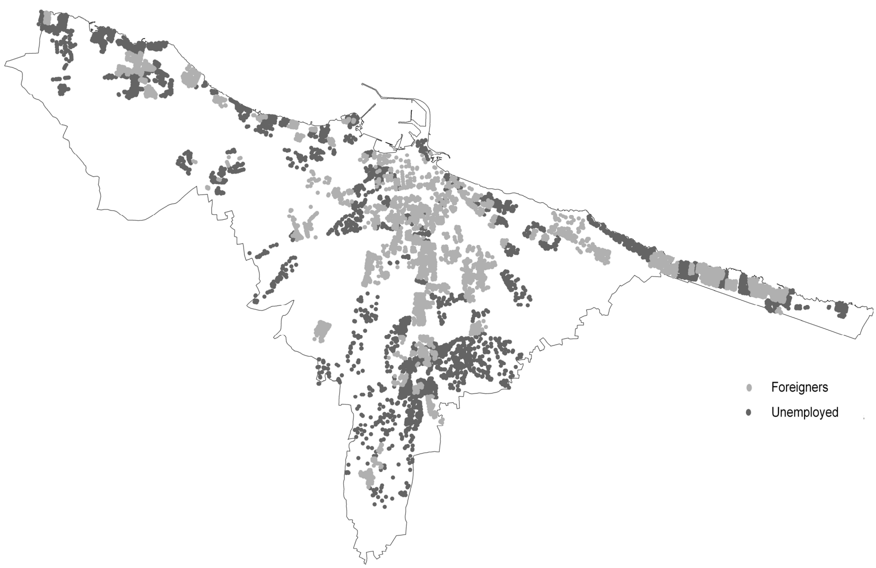

Fig. 4. Comparison of medium and high values of spatial autocorrelation of unemployment rate and foreign population per 100 residents (adapted from Murgante et al 2008)

Considering distributed data for each building, it is possible to apply spatial statistics techniques. Figure 3 highlights two important issues. Highest values (black areas) represent the concentration of several negative social indicators. The two details on the right panel of figure 3 show how areas with high values are located on both parts of neighbourhood boundary and zones which need more urgent interventions are situated across the white line inside the oval. This kind of measure shows all limits of traditional analyses.

In order to determine the exact location of these problems, further analyses are needed. It is important to adopt local autocorrelation measures. Getis and Ord's function is a suitable index to determine where several phenomena are concentrated and consequently where policies should be applied.

Considering Getis and Ord's function for two or more variables at the same time (figure 4), it is possible to achieve interesting interpretations. Areas with the strongest autocorrelation of immigration are far from zones with high concentration of unemployed. This means that no spatial correlation exists between immigration and unemployment.

3 The Chapters of This Volume

Socio-economics in space and time is always one of the cornerstone of urban planning. City development needs Knowledge about service locations and residential tendencies. In order to improve choices of decision makers about urban strategies, statistical and learning algorithms could produce a socio-economical distribution of town trends. *Tuia et al* present a new approach adopting an unsupervised classification method, based on Ward's classification and self-organized maps, in order to analyze the socio-economic structure of Vaud and Geneva cantons in Western Switzerland.

Borruso and *Porceddu* focus on the observation of urban form and functions in order to identify a method for the cartographic definition and representation of CBD (Central Business District). The paper is based on analyses related to spatial statistics in a GIS environment, especially point pattern analysis to model the spatial distribution of central activities within an urban area, in order to highlight hotspots as a measure of centrality. In particular, kernel density is used to test concentration of activities and, therefore, delineating CBD, presenting evidence from two urban areas in Northeastern Italy (Trieste and Udine).

Montrone et al present a paper where statistical data are used to identify territorial zones characterized by the presence of urban poverty, related to real estate ownership and the availability of residential services. In particular, a Total Fuzzy and Relative (TFR) approach is applied in order to detect, within clusters of poverty at urban level, differences in individual accessibility to the real estate market, capturing the multidimensional characteristics of the phenomenon and to allow comparisons over space and time. The approaches were implemented and improved using SaTScan methodology, a circle-based spatial-scan statistical method for poverty hot spot detection, with an application to the urban area of Bari (Italy).

The paper by *Cutini* starts from the concept of segregation of social housing in urban peripheries to implement a methodological approach based on configurational techniques to analyse urban settlements. In particular, edges of towns are examined, in order to account for the effects of the configuration of the urban grid on their condition of segregation and marginality. The purpose is to test the configurational techniques on several case studies, so as to prove them as a reliable and useful tool to analyse and understand such areas and to support town planning. Local Italian cases, such as the cities of Leghorn, Pisa and Grosseto, are analysed, observing the edges of these urban settlements, trying to find a way for understanding, describing, and even measuring their actual level of segregation and marginality.

Spatiotemporal aspects are fundamental in risk management. The increase of economical and social costs, following disaster, has led to a prevention strategy for damage reduction. Furthermore, this strategy can guarantee a briefer time to recover system efficiency. A preventive measure ensuring a better accessibility and evacuation may be the right approach to urban planning. Risk analysis has not been used enough in the field of transportation systems; just several experiences exist in analyzing material and immaterial infrastructures' vulnerability. In the great part of cases there is the need to design evacuation measures during the event or immediately after it. For this reason models and algorithms calibrated before the events are not suitable in emergency conditions. *Di Gangi* presents a new approach based on a mesoscopic dynamic traffic assignment (DTA) model, which acquires information during the evacuation simulation of an urban area considering the connected flow phenomena.

The contribute of *Moons et al* is still related to traffic safety. Since 1990s Levine (1995a 1995b 1998) developed several experiences about spatial concentration of vehicle crashes. *Moons et al* face the problem of accident hot spots location applying local autocorrelation indexes. But a simple use of local indicators of spatial association is impossible on a road network, because of a great spatial discontinuity. For this reason, the use of Moran Index has been tailored using Monte Carlo simulation, in order to solve this problem.

Visual impact assessment has always been totally neglected in urban planning, particularly in the location of new neighbourhoods. In order to increase the level of objectivity of visual analysis, GIS can be an useful tool. Since 1990s a lot of applications have been developed using the viewshed for visual impact assessment. Viewshed computation identifies every cell visible from one or more observation points. In order to improve viewshed analysis two extension have been realized: multiple and cumulative viewshed. The former combines all single viewsheds with union operators, the latter sums all single viewsheds using map algebra. While multiple viewshed produces a binary grid which distinguish visible from not visible objects, cumulative viewshed provides information on how many objects can be seen in a certain zone. *Danese et al* have developed a new viewshed operator, *Identifying Viewshed*, which shows how many and which targets are visible from a certain cell.

The contribute of *Ioannilli* and *Rocchi* addresses the problem of Urban Canopy Parametrization (UCP) which allows to describe geometric and morphological characteristics of urban agglomerations by a range of parameters derived from the analysis of high resolution databases.

This issue has a great relevance in the study of meso-scale meteorological models used to study air quality and pollutant dispersion processes in urban areas. The analytical approaches, present in literature, do not consider the process spatial resolution to simulate fluid dynamics and thermodynamics in and around buildings and other urban structures which can modify atmospheric characteristics.

Authors implement an innovative method which aims to analytically determine some of the UCP parameters in an automatic procedure implemented by Arcgis 9. Input data are in the vectorial numerical geodatabase of IX district of Rome city.

Very few studies are now available, concerning the application in existing urban contexts of theoretical models of urban roughness parameters estimation. A comparison among the devised procedure and the most relevant model, available from literature, is performed: it highlights that the analytical approach, adopted by the authors, can be suitable for every urban context and for any wind direction.

Geographical information is characterized by an extremely complex nature. Geographic data can be represented in multiple scale and grids may come from different sources and can be generated at different times, and especially, may have different semantics. Moreover, usually, the quality of data lacks in terms of accuracy and completeness. On the other hand, the management of geographic data in the long term is necessary for a lot of activities based on the management of spatio-temporal data. *Plumejeaud et al* define a theoretical framework for storing, managing, querying, evaluating and analysing different thematic indicators associated with geographic data, ensuring at the same time the observance of quality parameters. A data model based on the objects paradigm is presented. It takes into account thematic, spatial, hierarchical and temporal component of geographical information allowing a long-term modelling of geographic data and related indicators. Relying on this model, a system architecture for the assessment of missing values, based on geographic and thematic ontologies, is proposed.

The paper by *Carneiro et al* deals with an application of GIS and Airborne Light Detection and Ranging (LIDAR) data analysis for computation of buildings visibility, solar exposition and extraction of morphological indicators in the context of urban group analysis and morphogenesis geosimulation. A simulation model is implemented using GIS and LIDAR data aimed at urban simulation and at understanding dynamics of cities and metropolis, as auto-organized urban systems, as well as at simulating and analyzing form and shape of a city. Their application deals with the urban area of Lausanne (Switzerland).

The issue of urban expansion characterization is carried out by *Telesca et al* introducing a new approach in which spatial fractal analysis is applied to multidate satellite imagery. The understanding and the monitoring of urban expansion processes are a challenging issue concerning the availability of both time-series data set and updated information on current urban spatial structure and city edges in order to define and locate the evolution trends. In such a context, an effective contribution can be offered by satellite remote sensing technologies, which are able to provide both historical data archive and up-to-date imagery. The paper is focused on fractal analysis of the border of four small towns in southern Italy, using multidata NASA Landsat images acquired in 1976, 1991 and 1999. The border was analyzed using the box counting method, a well-known technique to estimate the spatial fractal dimension that quantifies the shape irregularity of an object. Such method computes the degree of irregularity of city borders, therefore the higher the fractal dimension, the more irregular the border. Analyzing and comparing three different years, the process of urban morphology variation is observed and the value of the fractal dimension of the urbanized area enables to determine whether their structure can be described as more or less regular. The relevance of the technique used here is that it provides a reliable way of quantifying the urban structure and its transformation through time.

Voiron-Canicio presents a new modelling approach dealing with the spatial spreading of built-up areas in order to both predict the broad outlines of urbanized areas extension on a regional scale and to provide decision makers with a system which allows them to explore spatial consequences of different urbanization policies. The devised spatial model, even though similar to cellular automata approach, presents the peculiarity to use image processing methods and mathematical morphology (MM) algorithms. MM is an efficient image processing method which offers several advantages over other techniques, in particular it preserves edge information, uses shape-based processing and is computationally efficient. MM is relevant for analysing phenomena where both the structural description and the determination of laws co-exist.

In this model, spatial spread process depends on both proximity and morphology of built-up areas located in a space whose configuration also determines the shape of spatial spread: such features explain the "spatio-morphological" qualifier given to this model. The spreading process of built-up areas is based on dilations and closing transformations. The model is deterministic and assumes that spreading process is essentially complied with an elementary rule of distance to the built-up areas, which explains the major part of the spreading process and goes beyond the prescriptions registered in the documents of town planning. Experimentations are conducted on the coastal part of Languedoc study area in Southern France. The model is carried out with multitemporal data and enables to simulate urbanized areas spread and predict future built-up surfaces up to 2010.

The spatio-morphological model presented provides interesting results which demonstrate that spatial rules simply based on notions of distance, shape and neighbourhood suffice to describe the major part of built-up areas spread, independently of town planning constraints.

Blecic et al introduce a Multi Agent Geosimulation Infrastructure (MAGI) which aims to be a “good” tool for urban and territotial planning: it therefore must have specific characteristics, in terms of modularity, flexibility, user-friendliness, generality, adaptability, computational efficiency and cost-effectiveness.

The Multi Agent Geosimulation Infrastructure presented is designed and developed for the purpose of supporting the process of Multi Agent System (MAG) model building, while at the same time offering a rich environment for carrying simulations and conducting controlled experiments. MAGI is an integrated environment allowing users to build *ad hoc* agent-based geosimulation models, then the main strength of the tool lies in the generality of underlying meta-model, embodying the possibility to model a large variety of real systems. Modelling environment has many features for developing and carrying simulation models; in fact, besides modelling “mobile” agents, the generality of meta-models covers also the family of cellular automata-like models with “static” agents, without making compromises to the simplicity and elegance of the modelling practice.

The MAGI modelling and simulation infrastructure presents characteristics, features and computational strategies particularly relevant for strongly geo-spatially oriented agent-based simulations. The infrastructure is composed of a development environment for building and executing simulation models, and a class library based on open source components. Differently from most of the existing tools for geosimulation, both raster and vector representation of simulated entities are allowed and managed with efficiency. Several characteristics of MAGI model are discussed in the paper: generality, user-friendliness and modelling flexibility, interoperability with GIS datasets and computational efficiency. A specific attention is given to one of the distinctive aspects of multi-agent geosimulation models: the process of agents' spatial perception.

In the complex and multifaceted field of Multi Agent Sistem (MAS), *Lapucci et al* deal with the development of a system able to analyse the dynamics of sustainable mobility of an historic city centre in Tuscany (central Italy). The focus of the entire analysis is the extraction and the study of agent behavioural rules adopting a bottom-up participative method. The Activity-Based micro-simulation approach is adopted: it consists in the possibility of obtaining the behavior of a complex urban system at meso or macro scale, as derived from millions of choices performed by individuals belonging to the system itself. On this purpose, both a detailed "temporal" Geodatabase and a dedicated population sample are devised: the former contains spatio-temporal information on private activities and public services (delivered over time) offered by the city, the latter introduces participative methods in order to reconstruct citizens' preferences on mobility demand. In this second step, both a paper questionnaire and an on-line one are designed for the survey; the last one is implemented by a WEB-GIS application for the spatial location of agent journeys and city services. The model final step comprises the extraction of agents (residents and commuters) behavioral rules from both territorial and survey data by Artificial Intelligence tools. Two different Data Mining techniques are adopted: at first Decision Trees are used in the exploratory phase and rules (extracted in an IF-THEN form) allow to identify the important variables connected to each target choice; in a second phase, the most relevant variables are employed as input data for the *Bayesian Networks* able to extract conditional probability distribution tables necessary for the model implementation. The model elaboration, currently in progress, its testing on Pisa case study and the tools implemented till now already represent a new decision support system useful both to plan sustainable mobility policies and to locate new activities inside the city centre, in order to improve the quality of present services.

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Detection of Urban Socio-economic Patterns Using Clustering Techniques

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Abstract. Modern urban planning needs efficient descriptors of the distribution of socio-economic features in space and time. Knowledge about residential patterns and distribution of services can help the decision makers for future strategies of cities' development. In order to facilitate this process, clustering of urban features is a very efficient tool, because it allows the reduction of the information from a very high-dimensional and complex input space to a low dimensional and visualizable output space. In this chapter, an unsupervised clustering method and a cluster detection method are discussed and applied to analyze the socio-economic structure of the Swiss regions of Vaud and Geneva. The unsupervised method, based on self-organized maps and hierarchical ascending classification, groups the spatial units by their similarity measured between socio-economic variables. The self-organizing map allows to account for nonlinear similarity. The cluster detection method, the spatial scan statistics, is used to find hot spots in the distribution of the residential patterns of professions. The method is applied to the distribution of business manager and workers in the region of Vaud. Moreover, the distribution of hotels and restaurant services has been studied at the intra-urban scale, to detect over- and under-densities of services and compare them to the residential patterns observed previously. Results show the effect of peri- and sub-urbanization in the region and are discussed in both transportation and social terms.

Keywords: clustering, self-organizing maps, spatial scan statistics, urban features.

1 Introduction

The distribution of socio-economic features defines the needs for transportation and services in urban space. For instance, planning has been longtime led by principles of local self-sufficiency, aiming at the production of nuclei of urbanity containing a sufficient number of activities, in order to avoid transportation and privileging development of local markets. Nonetheless, urban transition started in the 1950's induced an important change in the conception and the planning of cities: urban areas were growing fast, mobility was increasing exponentially, following the metropolization processes (Schuler and Bassand 1985; DaCunha 1992; Bassand 1997). Phenomena like peri-urbanization or sub-urbanization changed the urban landscape, modifying the distribution of socio-economic features within the city and between the city and its countryside. Polycentric structures and functional poles were emerging, creating evasive cities, which could not be analyzed with classical urban theories: the urban

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dynamics became more and more complex (Batty 2005). Planning in this period was principally led by hierarchical development, favoring networks and mobility, considering the city as an entity.

Cities also organized themselves in regional systems, with specialized poles and growing suburbs, where the complex dynamic of the intra- and inter-urban structures increased the need for mobility and the impact on environment and society (Both 2005).

Modern challenge of sustainable development obliges the concepts of urbanism to be reviewed and forces the planners to integrate the multi-scale nature of urban space in the decision process. Therefore, the understanding of the new city remains crucial for the urban planner, for instance to plan the best transportation system and avoid social unfairness or environmental pollution: the need for new tools to describe the urban systems is real.

The first step to understand such a system in terms of socio-economic features is the analysis of their distribution in space: socio-economic features are unequally distributed between the spatial units (for instance municipalities) and have the tendency to group in coherent ensembles. Therefore, it is possible to group similar units depending on their socio-economic profile in variable space. The features being complex and associated to high numbers of dimensions, the classification of urban spatial units into a small number of classes can be very effective to understand and visualize the structure of the urban space and to discover functional relationships, for instance between the centers and their periphery. Classification of such data is a typical unsupervised problem (also called clustering), because the number of classes is not known in advance nor examples to train the model are available. Several clustering models exist, going from hard partitionment methods (k-means (Jain and Dubes 1988) or Self-organizing maps SOM (Kohonen 2001)) cutting the features spaces into distinct regions, to hierarchical methods aggregating the observations depending on their similarity (hierarchical ascendant classification HAC (Ward 1963)).

Once the structure of the urban space has been modeled, a natural second step is to detect whether the distribution of a certain feature is constant in space or if there are outbreaks of areas where the density of such a feature is higher than normal. This way, emerging residential patterns or poles of a certain type o of service can be detected. Cluster detection methods have been developed to answer this kind of questions. Several cluster detection methods exist, including the Local index of spatial autocorrelation LISA (Anselin 1995)), the Turnbull's Cluster Evaluation Permutation Procedure CEPP (Turnbull et al. 1988)), the Geographical analysis machine GAM (Openshaw et al. 1987; Fotheringham and Zhan 1996)) and the Spatial scan statistics SSS, (Kulldorff 1997). Comparison of the methods can be found in Lawson et al. (1999), Kulldorff et al (2003) and Song and Kulldorff (2003).

In this chapter, we propose two methods for the analysis of clustering of urban spatial units depending on socio-economic features: first, we propose a fusion of SOM and HAC for the clustering of urban municipalities depending on their socio-economic profile. Such a fusion can be found in Leloup et al. (2007) for the classification of oceanic currents behavior. Second, we apply the SSS for the detection of clusters of high density of specific socio-professional features, in order to detect spatial structures related to phenomena such as peri- or sub-urbanization.

The chapter is organized as follows: Sect. 2 discusses the hybrid HSOM model and the SSS. Sect. 3 presents the datasets studied in the applications shown in Sect. 4. Concluding remarks are given in Sect. 5.

2 Models

2.1 Hybrid Self-organizing Map (HSOM)

The self-organizing maps (SOM) are a type of artificial neural networks (ANN) using an unsupervised learning technique in order to represent a high-dimensional space (where the term “dimensions" stands for the number of observed variables) in a two-dimensional space, called a map. A SOM is useful for the visualization of multivariate data, but can also be used for classification.

In a self-organizing map, each data sample is mapped to a neuron. Neurons are organized in a square or hexagonal grid (figure 1). The SOM creation can be divided into several steps.

In the first step, the neurons of the SOM are initialized, associating to each of them a randomly generated data vector of the same dimension as the inputs.

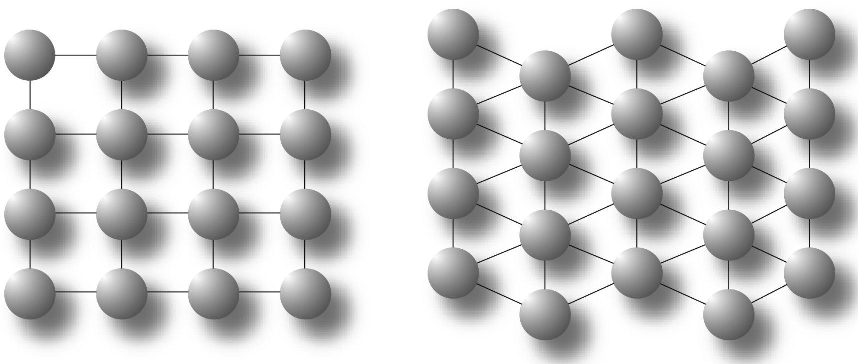

Fig. 1. A squared SOM grid (left) and a hexagonal one (right) in 2D. The circles are the neurons.

In the second step, the ordering phase, each data sample is compared to the neurons and attributed (mapped) to the most similar one. The data vectors of the selected neuron (the winner or best matching unit) and its neighbors are updated in order to match better the input data sample following Eq. 1:

$$w_i(t+1) = w_i(t) + \alpha\theta(i,t)\big(x(t) - w_i(t)\big) \tag{1}$$

where $w_i(t)$ and x are respectively the weight of the neuron i and its closest initial pattern at iteration t, α is the learning rate (decreasing in time) and $\theta(i,t)$ is the neighborhood function decreasing with the distance to the winner. The simplest neighborhood functions are binary (where the winner and its n nearest neighbors have a value of θ of 1 and the others 0), but more complex functions, as a Gaussian neighborhood centered in the winner, can be used instead.

The second step is repeated iteratively, in order to adjust and match the neurons of the SOM to the input data. The importance of the update (the learning rate α decreases during the iterations). This process is a competitive learning process, which corresponds to unsupervised learning and can be considered as self-organization of the neuronal map.

The third and final step, the convergence phase, is basically the same as the second step, except that it considers a smaller neighborhood size, a smaller learning rate and a higher number of iterations. It is supposed that after the second step, the neurons are quite well ordered. The third step is just a refinement of the neuron's vectors to better represent the input data set.

One of the problems of the SOM algorithm is the unknown optimal number of neurons. If used for clustering, a too small SOM will decrease the quality of the cluster boundaries. Large SOM are able to represent better the input data structure, but there may be too many clusters. A small SOM will generalize more the input data. Generally, big SOM are preferable to very small ones. However, the number of neurons should not be bigger than the number of input samples. The SOM size defines the amount of generalization of the input data.

Once the training has been completed, the neurons of the SOM are clustered using another algorithm. By doing that, the SOM acts as a non-linear transform of the original features space. In this chapter, the hierarchical ascendant classification (HAC) is used for this purpose. This is a well known, traditional classification algorithm.

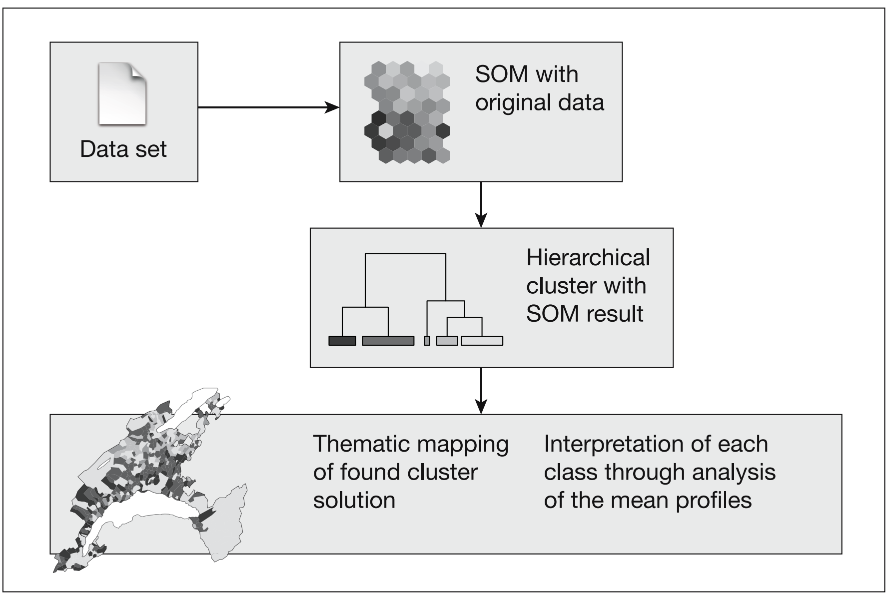

Fig. 2. The classification and mapping process using HSOM

The combination of the two procedures is the Hybrid SOM (HSOM). The algorithm can be illustrated as follows (see also figure 2):

1. Pre-processing of the data with the SOM. This step corresponds to a non-linear transformation and a generalization of the data. The degree of generalization is determined by the grid size; a small grid will generalize more than a bigger one.
2. HAC of the self-organized map divides the neurons into groups. The number of groups can be determined with standard methods like the analysis of the dendrogram.
3. The original data are assigned to a group through the neurons of the SOM. Each data sample is assigned to one neuron which in turn has been assigned to one of the classes. Finally a thematic map of the spatial distribution of the groups is drawn. The analysis of the profiles of the classes enables to label each group.

2.2 Spatial Scan Statistics (SSS)

Contrarily to the SOM, cluster detection methods consider the distribution of a unique process. In this sense, SSS analyzes spatial point processes and searches for over- (or under-) densities in the distribution of the real events by comparison to a process defined for random locations. Several SSS models have been developed so far, the most popular being the Poisson model that applies when the number of events is very small compared to the population considered.

The Poisson Model

In the Poisson model, a circular moving window scans the area under study defining sub-areas called zones z_i. Each zone is characterized by a number of events c_i and a population p_i, given by the sum of events and of population belonging to the spatial entities in the scanning window. The hypothesis of spatial randomness H_0 is $x \sim Poi(\lambda_0)$, where λ_0 are parameters bounded with respect to the hypothesis of spatial randomness. When events and population have been attributed to a zone, the likelihood functions L_0 (with parameters bounded λ_0) and L_1 (the same function, but with parameters unrestricted) are computed (see Kulldorff (1997)). Each zone being associated to a different population, the parameters are calculated separately for each zone. The Likelihood Ratio $LR(Z)$ for the zone is computed as the ratio between these two likelihood functions:

$$LR(Z) = \left(\frac{L_1}{L_0} \right)_Z \tag{2}$$

The most probable high rate cluster between all the regions analyzed is the one maximizing $LR(Z)$.

$$T = \max_x (LR(Z)) \quad 1 < T < \infty \tag{3}$$

The same model can be used to detect low rate clusters: in this case, the cluster selected is the one minimizing $LR(Z)$.

For a Poisson distributed random point process it has been proved (see Kulldorff (1997)) that *LR(Z)* takes the following expression, comparing the events within (subscripts *i*) and outside the zone (subscripts *i'*):

$$LR_i = \left(\frac{\left(\frac{c_i}{\eta_i}\right)^{c_i} \left(\frac{c_{i'}}{\eta_{i'}}\right)^{c_{i'}}}{\left(\frac{c_{tot}}{\eta_{tot}}\right)} \right) I \tag{4}$$

Where η is the expected number of cases under the H_0 hypothesis and *I* is an indicator function discarding results when the ratio observed/expected is higher (lower for low rate clusters) outside of the zone than inside.

The analysis is performed for every zone within the region, the scanning window taking every spatial entity as a center and considering different radii (figure 3). To avoid untreatable computational cost, overlapping windows are not taken into account and a stop criterion can be applied (for instance, maximum radius length).

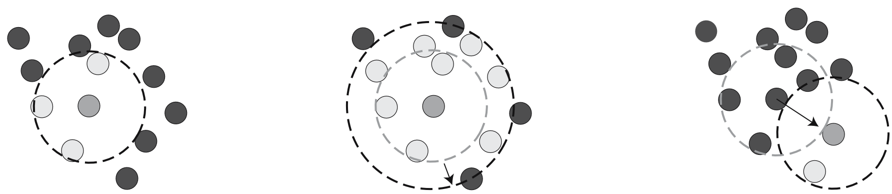

Fig. 3. Scanning window principle in the SSS. During the analysis, the scanning windows (left) are increased in size (center) and centered in different spatial entities (right).

Cluster Significance Test

Once the most likely clusters have been highlighted, their significance has to be tested. The significance test is done in order to avoid situations where the most likely cluster is in fact included in the interval of confidence of a distribution respecting H_0. Such testing is done using Monte Carlo simulation: a certain number of data simulations $j = 1, \ldots, m$ respecting the null hypothesis H_0 of spatial randomness (absence of spatial clusters) is generated and the maximum $LR(Z)_j$ of each replication is compared to the most likely clusters of the real data. If the clustering observed on real data is strong, we will observe $LR(Z) > LR(Z)_j, \ \forall j \in m$. Nonetheless, this assumption is too restrictive, the secondary clusters naturally showing smaller values of likelihood ratio and the simulations being affected by little clustering: for these reasons, the data replications are used as a statistical significance test. If the real clusters LR is included in the top 5% quintile of the distribution of the likelihood ratio of the simulations, the HO hypothesis is rejected and the cluster found are considered as significant.

Spatio-temporal Scan Statistics

The spatio-temporal model follows the same procedure, but, instead of considering spatial circles, spatio-temporal cylinders (figure 4), analyzing different spatial and temporal neighborhoods, are used. The temporal scale is given by the coarseness of the data and can go from daily to yearly. The cylinders are defined by temporal neighborhood, i.e. being continuous in time and non overlapping. They can be bounded in length (in temporal extent or in number of cases) to decrease the computational time that can become prohibitive for a complete search.

Temporal analysis can be performed in two ways: retrospective (looking for clusters present at a certain time in the time-series) and prospective (looking for clusters still existing at the last time of analysis, the "emergent clusters"). In this work, the prospective method has been used, in order to detect active clusters that will influence future planning.

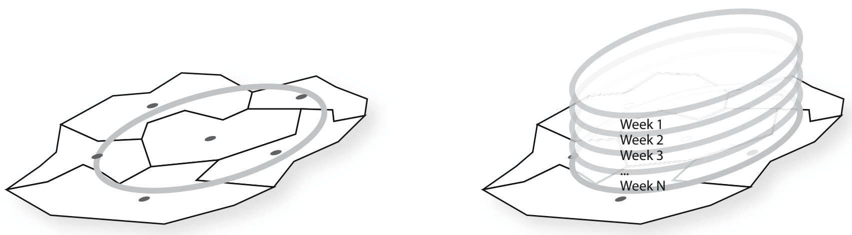

Fig. 4. From the purely spatial scanning window principle (left) to the the cylinders of the spatio-temporal scan statistics (right)

Highlights of the SSS

As stated in the introduction, several statistical methods exist to identify clusters. For urban cluster detection, SSS seems to have a series of advantages:

- Size of clusters is not specified in advance and is discovered by the algorithms maximizing the *LR(Z)*.
- The weighting of events by population avoids the size effects.
- The test statistics is based on a Likelihood ratio and the null hypothesis is clearly stated.
- Since the LR is computed for every zone by taking into account specific events and population within and outside the zone, the method is not sensitive to spatial non stationarity/trends (Coulston and Riiters, 2003).

3 Data and Models

3.1 HSOM

The HSOM clustering has been applied to the municipalities of the cantons of Vaud and Geneva, in Western Switzerland. The data contain 75 socio-economic variables for 427 municipalities. The objective is to get a map of the socio-economic structures in this region, and to group all municipalities in a suitable number of coherent classes.

The data set is composed by 54 economic variables about the number of employments per economic domain in 2000, 20 demographic variables about the age structure in 2000, and 1 variable about the percentage of foreigners in 2000. For all variables, the percentage for each municipality has been computed and the values have been converted to standard scores.

The determination of the SOM grid size is important. For this case, a grid of 16 x 16 cells has been chosen. This means 256 neurons for 427 municipalities, or a ratio of 1.65. Experience shows that a ratio between 1 and 2 generally produces a satisfying result. The neurons have been initialized using random values. The ordering phase has been done with 1000 iterations and an initial learning rate of 0.1. The convergence phase has taken 10'000 iterations with an initial learning rate of 0.01. The Gaussian function has been chosen for the neighborhood function, with a radius of 8 cells for the first phase, and 2 for the second.

The SOM obtained is a series of connected neurons representing the input space embedded into a 2-dimensional grid. Therefore, is would be possible to visualize the SOM for every variable of the input space (figure 5 illustrates 4 of the 75 input variables).

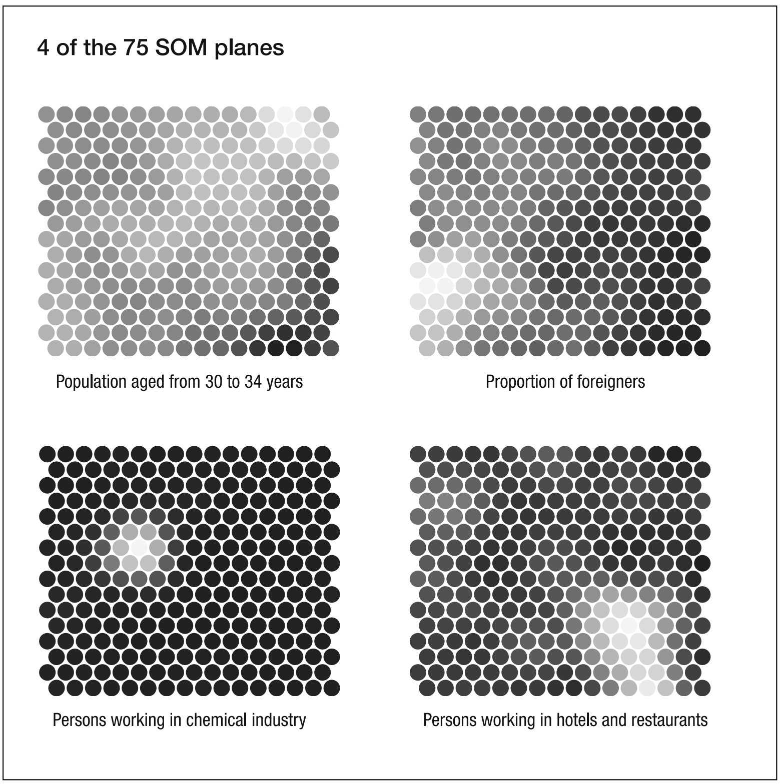

Fig. 5. SOM representation of 4 of the 75 input variables

Finally, the neurons of the SOM are classified using HAC (figure 6). The dendrogram on the left side of the figure suggests the creation of 5 classes that, applied to the SOM, give a partition of the embedded space as the one shown on the right side of the figure. The result on the SOM being difficultly interpretable, the classification is visualized on the geographical space (see figure 8 in section 4.1)

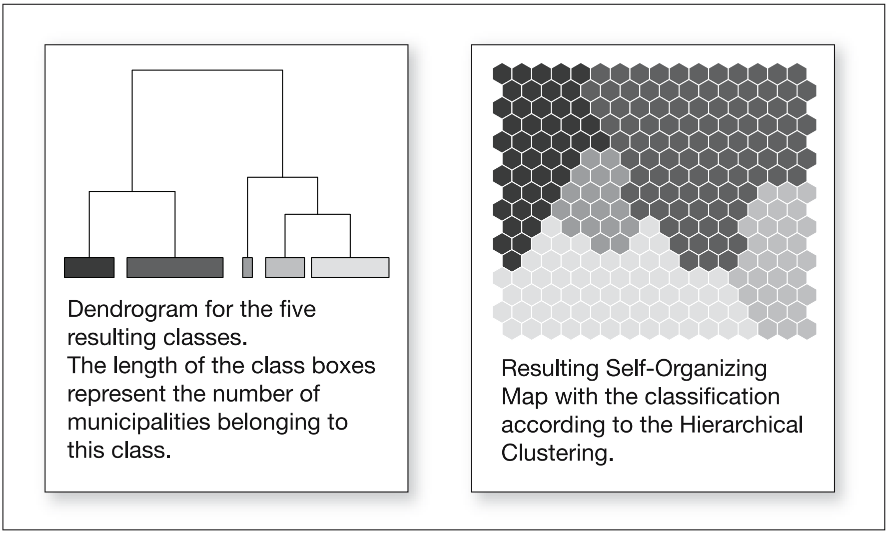

Fig. 6. The resulting dendrogram from the HSOM process and the classified SOM

3.2 SSS

SSS have been applied for two different purposes: the first, to detect overdensities in residential patterns for given professions and the latter shows a novel use of SSS in order to detect clustering in the distribution of services at the intra-urban scale.

Case study #1: Spatial Analysis of Residential Patterns of Employment

Contrarily of the HSOM example, only the region of Vaud has been used in order to analyze the distribution of employment. The region counts 385 municipalities, for a total population of 600'000 inhabitants. The region is organized by four cities attracting the most services and tourism: Lausanne, Nyon, Montreux-Vevey and Yverdon.

The data used come from the population census 2000 at a resolution of a hectometer. Such a high resolution allows to detect clusters at the intra urban scale and to be independent to the political apportionment of the municipalities. As discussed later, such a liberty will be very useful for a big municipality like Lausanne, where the distribution of socio-economic features is very different for diverse neighborhoods. In order to speed up the analysis, original data have been aggregated to a 200 meters grid.

The model used is the spatial Poisson Scan Statistic, the analysis have been performed using the free software SatScan (http://www.satscan.org). The neighborhood is defined by circular windows bounded at a radius of 3km. The extension of the stopping criterion to larger radius results in the inclusion of low rates areas in large hot spots detected, giving a false image of shape and size of the clusters. Therefore, the maximum radius has been kept short, resulting in small circular clusters composing, at a larger scale, the larger irregular clusters.

Case study #2: Spatiotemporal Analysis of the Distribution of Services at the Intra-Urban Scale

The second case study[1] analyzes the distribution of services in the agglomeration of Lausanne (Western Switzerland): this agglomeration, counts 300'000 inhabitants for 68 municipalities. The attraction power of Lausanne, as well as the performing transport network, guarantees fast and reliable accessibility to the center of the agglomeration, i.e. the center of Lausanne.

The data used come from the Population and Firms Census: the former counts several features related to population at a resolution of one hectometer. The latter counts the number of firms and employees for different kinds of activities with the same resolution. As for the previous case study, the hectometer data have been selected and aggregated to a 200 m grid: this grid represents the spatial entities (figure 7). Unfortunately, the Census are not available for years previous to 1990: therefore, the Population Census 1990/2000 and the Firms Census 1991/2001 have been used. The analysis has been limited to the emergence of clusters during this period.

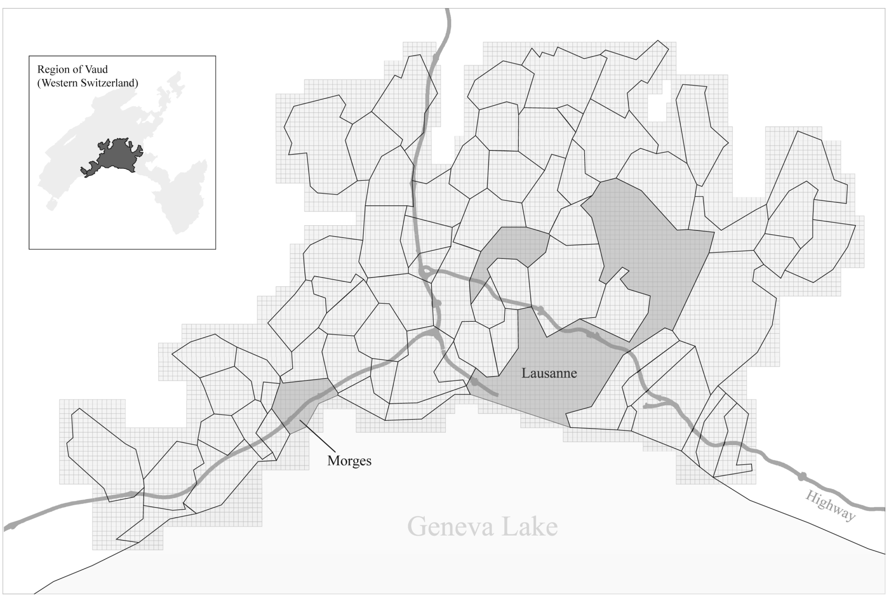

Fig. 7. The urban agglomeration of Lausanne. Gray area corresponds to the grid used in the study. (Source of GIS data: Swisstopo).

[1] Preliminary results have been presented in Tuia et al. (2007).

The model used for the analysis is the prospective space-time Poisson Scan Statistic. The analyses have been performed using the free software SatScan. The neighborhood is defined by circular windows bounded at a radius of 1km.

Studying the spatio-temporal distribution of restaurant and hotels, the use of residential population (Kuhnert et al., 2007) as population variable in the SSS could be questioned: if the residents use restaurants, the same holds for workers and tourists. This observation is even more flashing if we think about hotel business, that touches very lightly the residential population.

To increase interpretability of the results, an adjustment of the population in the SSS has been done: in a second run, the population variable used has been replaced by the sum between residential population and number of workers. This way, the weighting variable takes into account the persons that work in the area without living there and the detection of clusters is not affected by the size effect related to them. By comparing the results obtained using the residential population only (thus depending on tourism and number of workers, but not on resident population), we can define the origin of the clusters highlighted by the two models: if a cluster detected with the residential population is still there when using the hybrid population (thus not depending on population AND workers) it will be a cluster probably related to tourism. If the cluster disappears, it is probably a cluster related to commuters. This approach is similar to the covariates approach in the SSS (Klassen et al., 2005): by adding information suspected to influence the distribution of the cases, it is possible to influence the LR statistic. If a cluster disappears after this adjustment, it means that the cluster is highly dependent on the covariate.

Not having information about the cases themselves (the law on data protection prevents to have information about the single firms) we propose here an adjustment of population that leads to similar results for zones characterized by a high number of workers.

4 Discussion

4.1 HSOM

The HSOM classification map is shown in figure 8 for the Vaud and Geneva regions. As stated in the previous section, the neurons of the SOM have been classified into five classes, partitioning the socio-economic landscape of the region considered. Typical spatial structures of the region can be seen on the map.

The first class (in black in figures 6-8) represents municipalities characterized by working class and commuters. Such municipalities are in the attraction radius of the cities of the region and represent workers that can afford living out of the cities in peri-urban areas and at the same time make profit of the urban amenities.

The second class (dark gray - the wider in the result of the HSOM) represents municipalities classified as residential. These places are far from the cities and not on the principal transport networks and also associated to small villages.

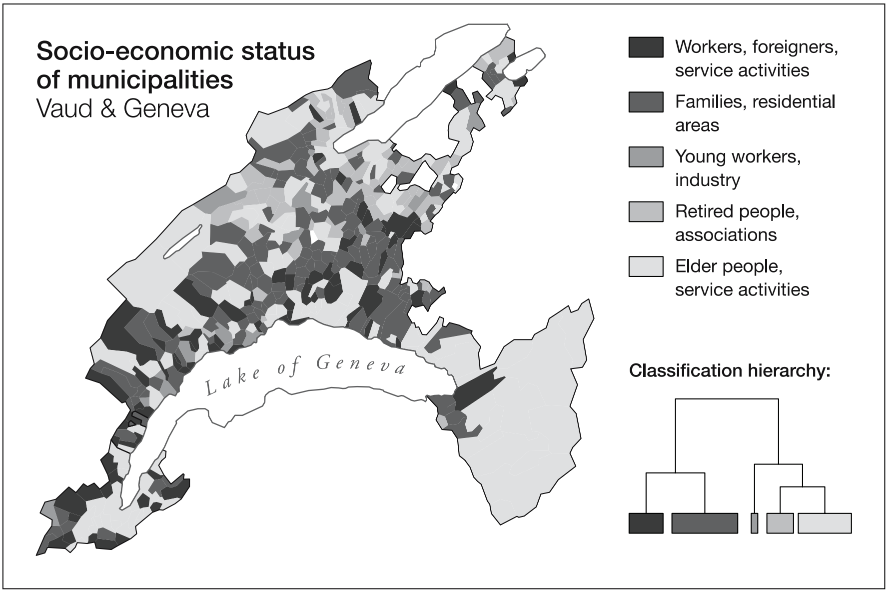

Fig. 8. Thematic map for the resulting classification

The third class is a very small class associated to industrial particularities of the region: the regions of Vallorbe, la Vallée de Joux, Moudon or Payerne are characterized by strong employment related to such particular industries (for instance, la Vallée de Joux is a well known for its clock industry). The profiles of these municipalities are that atypical in the socio-economic landscape, that they are clustered in a separate class.

The fourth class is more difficult to interpret and seems to group rural municipal lities associated to retired people.

The last class (light gray in figures 6-8) groups service-related municipalities, like the cities of Lausanne, Geneva, Yverdon and Montreux. The number of employments in the sectors of services is the common denominator of these cities. Another common characteristic of the municipalities composing the fifth class is the overdensity of old-aged population: it is well known that elder people have the tendency to move into the city. This phenomenon has two major consequences on the results of the classification: first, the rural areas in the east of the region are also classed in this class; and second, the classes four and five become similar in the dendrogram aggregation.

The results presented allow to have a look on the socio-economic landscape of the region. Such a cartography allows to simplify interpretation about local specificities (the dimensionality of the space has been reduced from 75 original variables to an unique map consisting of 5 groups). In this process, the SOM allows to take into account the nonlinear relationships to be learned by the algorithm. The coupling of the SOM with the HAC allows to decide easily and rapidly the number of classes and to build mean profiles of the classified neurons for the labeling of the classes.

4.2 SSS

Case Study #1: Spatial Analysis of Residential Patterns of Employment

In this first example, SSS has been used to discover areas in the region where the density of a) business leaders and b) working class is beyond expectations. Such results could be used to plan new transport connections (for instance to connect areas showing overdensities of workers to the major factories) or to project land prices in following years. Figure 9 shows the results of SSS for the business leaders: width of the circles corresponds to the importance of the cluster, while the number is the ordering, going from the most probable (1) to the less (12). Only the 12 most probable clusters have been retained.

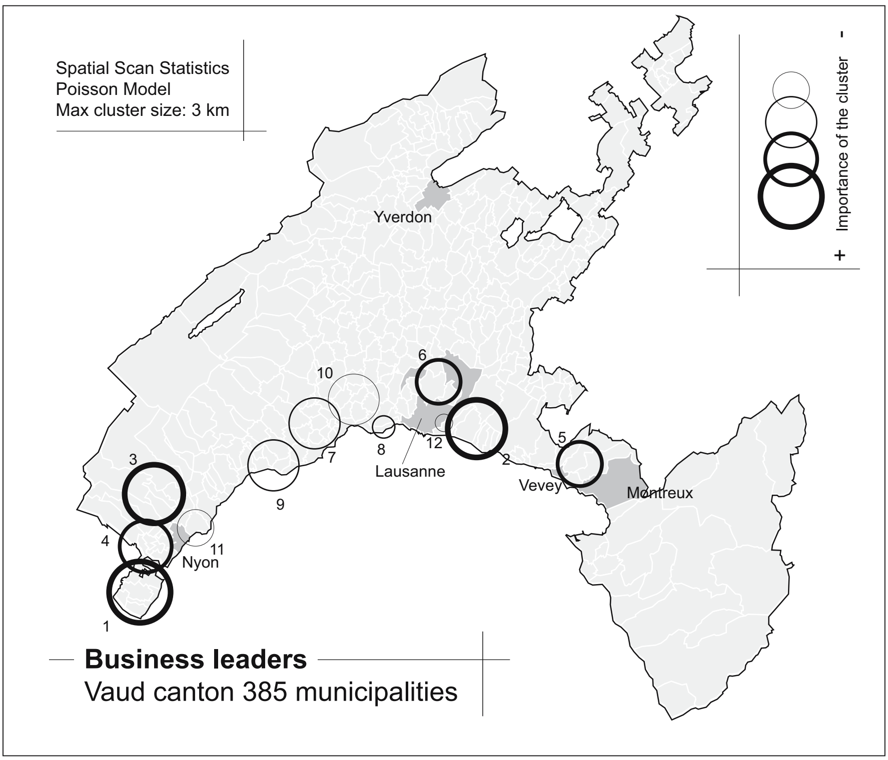

Fig. 9. Business leaders clusters detected

At a first glance, it is obvious that the business leaders are typically peri-urban, settling in areas close to the cities. The areas of the clusters had been classified in the two first classes by the HSOM. These areas are well connected to the urban centers. A particularly interesting region is located in the surroundings of Nyon (West of the map, clusters (1), (3) and (4)): by its position of proximity to Lausanne and Geneva and by its excellent connectivity to both the rail and highway systems, this region hosts the most important business managers clusters. Lausanne's East (2) and North (6) are also very pleasant areas known for their abundance of managerial professions. Cluster (5) shows the region between the cities of Vevey and Montreux, which are perfectly accessible by car from that distance.

Figure 10 shows the distribution of working class professions in the region. The SSS detects all the industrial municipalities highlighted by the HSOM except the first one, i.e. the most important! This is due to the different scales of the analysis: the HSOM algorithm has been applied on a municipality level, while the SSS has been applied on a 200m grid covering the region. The Lausanne's industrial area (1) is on the territory of Lausanne and this particular municipality is characterized by a mixed and numerous population. Thus, the importance of working class becomes lower in such a big municipality. When considering a finer spatial scale, the West of Lausanne is no more weighted by the total population of the city and the high rates of working class can be detected.

Other minor industrial areas as the Payerne's (2), the Nyon's (7), the Yverdon's (3) are detected and show similar situations of urban worker neighborhoods. Small specialized industrial areas can be seen in more unusual locations like Moudon (9,12), Vallorbe (10) or La Vallée de Joux (8). As explained above, these areas are industrial regional particularities.

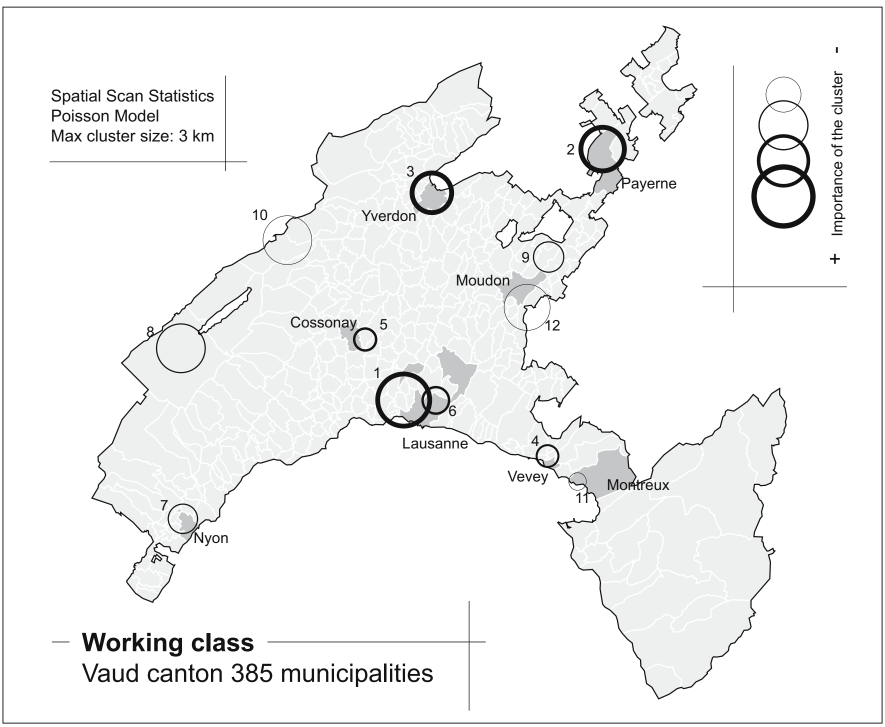

Fig. 10. Working class clusters detected

Case Study #2: Spatiotemporal Analysis of Distribution of Services at the Intra-urban Scale

SSS have been applied to the grid discussed above, taking the number of firms in the sector (weighted by the size of the firms) as events and the total population as population. Figure 11 shows the spatial repartition of the emerging clusters: filled circles show the areas of high-rate clusters, while dashed circles show the areas of low-rate clusters. Numbering is no more related to the strength of the clusters, but is used to identify clusters instead. The irregularity of shape of the areas highlighted is due to the simultaneous presence of several small clusters in the same area.

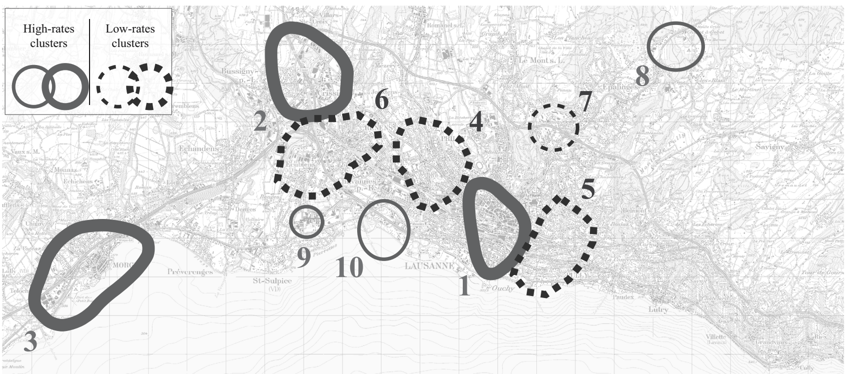

Fig. 11. Results of the SSS on the intra-urban dataset using the resident population. Only clusters with significance level of 0.001 are represented. Filled circles show high-rates clusters, dashed circles show low-rates clusters.

Clusters (1) and (3) highlight the Lausanne and Morges city centers, hosting several hotels and restaurants. Cluster (2) shows the industrial region of Crissier, where the presence of commercial malls increase the number of restaurants in an area characterized by low population. Residential areas in interaction with clusters of high rates, characterize low-rates clusters (4), (5) and (6). Clusters (4) and (5) interact with the center of Lausanne, while cluster (6) interacts with the peripheral area of Crissier highlighted above. These areas, even if characterized by low-rates of hotels and restaurants, are within walking distance to the center or are connected by high-frequency public transports. Cluster (7) shows the suburban area of Vennes: this suburb is characterized by high-rise buildings and council housing and the ratio-population/number of services is low. High rate cluster (8) is located in the forest of Chalet à Gobet, where several amenities have been created for people practicing outdoor sports. High rates cluster (9) is a particularity of the region: it corresponds to the Institute of Technology of Lausanne, which do not have any residential population, but is characterized by several services related to students. Finally, high rate cluster (10) shows the tourist area of Vidy, characterized by several restaurants on the lakefront.

Some of the clusters observed, (principally clusters (2) and (9)) are highly related to the presence of employment in the area: the use of hybrid population should

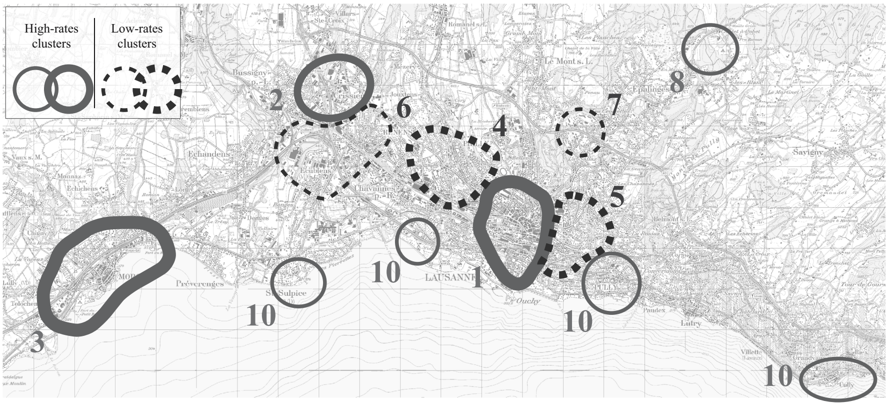

Fig. 12. Results of the SSS using the sum of population and employment as population parameter. Only clusters with significance level of 0.001 are represented. Filled circles show high-rates clusters, dashed circles show low-rates clusters.

remove the influence of working population and show the areas related to tourism. Results obtained using the hybrid population are shown in figure 12.

Clusters (1), (2) and (3) are confirmed, but they have decreased in importance (the employment has weighted the LR). This is observed mostly for cluster (2) that suffers of the adjustment of population: this cluster is manly related to employment and therefore its strength decreases radically. Cluster (6) simply disappears, showing its relationship with the employment (students are considered as regular workers in Swiss statistics). Cluster (8) is confirmed and grows in importance. Several tourist areas (10) in the lakefront emerge. Looking at the low-rates, a certain stability is observed. Nonetheless, cluster (5) loses its importance, because the population of the area has grown less than expected by adding the employment data.

5 Conclusion

In this paper, two methods have been presented for the analysis of clustering of the urban space. First, HSOM, a hybrid method based on hierarchical classification of the nodes of a self-organizing map, has been presented for the embedding and clustering of high-dimensional features spaces. Such a method has shown its potential in an application of unsupervised classification of socio-economic profiles of the municipalities of the regions of Vaud and Geneva (Western Switzerland). HSOM has allowed to group the municipalities of the region in five classes defined using the similarities (linear and nonlinear) between the spatial units.

Second, the spatial scan statistics has been proposed for the detection of high rates clusters in space. Applications to business leaders and working class distribution in the region of Vaud allowed to appreciate the power of the method to detect hot spots (even at a very fine scale). High rates regions for both categories corresponded to the corresponding regions highlighted by HSOM, confirming coherence of the results.

The only disagreement between the methods was the most probable working class cluster, but the difference can be easily explained by the differences in terms of spatial scales between the applications.

Finally, spatiotemporal scan statistics have been used to detect high and low rates clusters in the distribution of urban services : distribution of hotels and restaurants has been studied in the agglomeration of Lausanne and emergence of leisure areas in the agglomeration have been detected. These regions correspond to the new urban nuclei of the agglomeration and are surrounded by connected areas where the density of restaurants is lower. The effect of taking into consideration the working population has also been studied and led to interesting observations about the purpose of the cluster found.

New challenges for such methodologies would be, for the unsupervised methods, to use new methods for the classification of the socio economic profiles rather than HAC: methods such as spectral methods (Von Luxburg, 2006) have shown better performances on clustering problems than classical HAC or k-means classification algorithms and their integration in such a scheme could be effective. For the cluster detection problem, the implementation of searches for irregular cluster shapes could be of great interest, because (for instance for a region such the one studied) physical constraints prevent the emergence of naturally circular clusters. In this study the size of the clusters has been limited to overcome this problem, but some studies on irregular cluster detection have been published so far (Conley et al., 2005; Duczmal et al., 2006).

Acknowledgments. This work has been supported by the Swiss National Science Foundation (projects "Urbanization Regime and Environmental Impact: Analysis and Modelling of Urban Patterns, Clustering and Metamorphoses", n.100012-113506 and "Geokernels: Kernel-Based methods for Geo- and Environmental Sciences", n.200021-113944).

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A Tale of Two Cities: Density Analysis of CBD on Two Midsize Urban Areas in Northeastern Italy*

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Abstract. The paper is focused on the observation of urban form and functions and is aimed at identifying a method for the cartographic definition and representation of CBD (Central Business District). The analysis is developed to explore the formation of centers of different order in the urban environment, starting from the locations of a selected set of human activities located in urban areas. An index of concentration of central activities is presented to allow the visualization of the functional urban environment by means of a density surface, therefore highlighting areas where central activities and functions concentrate. The paper is based on analyses related to spatial statistics in a GIS environment. We provide a short review of the literature on CBD research, briefly describe the kernel density estimation method, and propose how this can be used in order to test the index of concentration of activities and therefore delineating CBD, presenting evidence from two urban areas in Northeastern Italy (Trieste and Udine).

Keywords: Central Business District, Kernel Density Estimation, GIS, Nearest Neighbor Analysis, Trieste, Udine.

1 Urban Analysis and the Definition of Centers

The Central Business District as a geographical concept is to-date quite settled and has been examined through the years by the researchers in many different urban contexts around the world. The activities carried on in the CBD have changed during the years, as well as the same location of many Business Districts that, in time, have often abandoned a central location in favor of more decentrated ones where central constraints - high rents, competition for land use, lack of floor space suitable for large businesses, traffic congestion - limit to-date financial and directional activities locating in the 'true' geographical centre of an urban area.

However, centers maintain their importance in shaping cities and orientating their functions and roles. Despite some activities move out from the centers, many ones remain there, therefore characterizing central urban landscape and functions.

Studies intended to highlight functional areas within urban areas have drawn the attention of geographers and scholars from other disciplines, as urban ecologists,

* The paper derives from joint reflections of the authors. Chapter 1, 2.1, 2.2, 3.1, 3.3, 3.3.1, 4.1, 4.3 and 5.1 are realized by Giuseppe Borruso and chapter 2.3, 3.2, 3.3.2, 4.2 and 5.2 by Andrea Porceddu. In general, elaborations and comments on Trieste were performed by Giuseppe Borruso, those on Udine by Andrea Porceddu.

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sociologists and economists. Burgess, Hoyt (1939) and Harris and Ullman (1945) are among the first ones to be interested by the urban phenomenon, particularly in terms of the definition of the urban shape and highlighting functional areas within cities, as the central business district (CBD) or other areas characterized by different kinds of human activities.

Central places' theory has been applied to the 'internal' urban environment, highlighting those human activities relevant for defining urban hierarchies and for organizing the urban space (Scaramellini 1993). Several authors have hypothesized the existence of density functions decreasing from the central areas of the city in terms of urban land use and its value (Knos 1962; Haggett 2001), the supply of transport infrastructures (Alonso 1960) and the population distribution (Clarke, as reported in Yeates and Gardner 1976).

Different patterns of development have been considered. First urban models were simpler and based on a circular and concentric structure of urban areas, followed by sector models and radials ones from a central location in the central city. In recent years the debate concerned the monocentric versus polycentric nature of cities (Hoch and Waddel 1993; Waddel, Berry and Hoch 1993), where the existence of a central urban nucleus is discussed and compared to patterns of development not so homogeneous and uniform but where several centers coexist and whose origin can be derived from the presence of activities different from those that are typically 'central' ones and from the individuals' behavior in terms of residential choices. Several researches in the first years of this century are focused on these behaviors on residential choices, following the studies on urban polycentrism. The time factor is dominant in these studies and considered to explain the patterns of mobility and accessibility, not only towards the central areas of a city but also, and particularly, to the places of individual interests that are not necessarily located in central areas (Weber and Khan 2002). Physical distance is therefore put in second order, mainly considering more complex and 'non-Euclidean' elements as the time component of accessibility and the geographical or time distance is considered mainly over a network, and therefore characterized by non homogeneity and anisotropy, and therefore creating directional spaces for the individuals (Miller 1994, Batty 2005, Borruso 2008).

In order to analyze an urban environment not so homogeneous and uniform but characterized by the presence of different centers, new and more refined methods are required to study the urban development and its functions, among these the spatial statistics (Cuthbert and Anderson 2002), GIS (Batty and Longley 1994) and urban modeling.

The combined experiences from these research agendas allow the observation of urban space and the deepening of the urban dynamics. New analytical instruments together with the wide availability of geographical data recall the need of new methods and instruments for extracting new information. Among these we can remind the use of surfaces to analyze and represent urban phenomena, as the density of population or human activities more in general. Although these are not really new methods and concepts (Matheron 1963; Atkinson 2005) and now consolidated in the analysis of urban functions, their application is to-date possible and interesting thanks to the availability of data and analytical tools.

The efficiency of such methods is developed together with the simple structure of the data used, represented by sets of points in space, characterized by the position of human activities in space, these representing the starting elements to obtain continuous density functions for estimating the spatial distribution of a phenomenon (Gatrell 1995), to define urban centres (Thurstain - Goodwin and Unwin 2000), other than being particularly effective from the cartographical point of view.

2 Indexes of Urban Centrality

2.1 The CBD

The Central Business District (CBD), following studies carried out in urban geography and sociology during the first half of the Twentieth Century is located in the central part of a city, together with particular activities, as banks, offices, hotels, cinemas and theatres (Haggett 2000). The CBD areas are generally characterized by tall buildings, high density road traffic and high population density in daytime. In the CBD the land values are higher than in the rest of the urban area, generally following a decreasing function starting from the city centre, where the highest value is reached, towards the peripheral areas. From a cartographical point of view urban geographers visualize such function by means of a three-dimensional surface determined by the different land values over the urban space. Such land value function is generally decreasing as the distance from the city centre increases and can present variations and lower intensity peaks located at minor settlements and at the intersection of major arterial roads. The land value surface will represent the different accessibilities of the different parts of the city and show the locations where a higher competition for space between human activities take place.

2.2 Towards the Delimitation of the CBD

Scholars involved with urban studies have tried to find methods do delimitate the extension of the CBD and to represent it cartographically. In such sense both qualitative and quantitative indexes are implemented, with the former being mainly based on individual choices and observation and the latter mainly used in quantitative analysis.

It is possible to recall some of the most used indexes in Anglo-Saxon literature, as reported by Murphy and Vance (1954b) and re-examined in several urban geography studies (Table 1). Most of such indexes are referred to the concentration of central activities that can be computed starting from other indexes of intensity of CBD, not only referred to the surfaces occupied by central activities, but also from the height of buildings in central areas, as well as the intensity of central activities.

The concentration of the activities defined as ‘central’ is generally quite high in central areas and coupled with high land values, and the land value function generally appears as decreasing when moving out from a city centre with minor peaks at major road intersections or at minor settlements. Such concentration was used to delineate the shape and extensions of a CBD (Murphy and Vance, 1954a).

Other authors stress the importance of the comparison between day and night populations (Carol, 1960), underlining the substantial lack of resident population in CBD areas where people are present only in working times during the day with some

Table 1. A classification of Land Uses in the CBD (Murphy and Vance, 1954b)

A – present and apparently typical	Restaurants; Women's clothing; Men's clothing; Furniture; Hardware and appliances; Department stores; 5 and 10 stores; Drug stores; Jewellery and gifts; Amusement establishments; Banks Insurance and Real estate; Personal service; Clothing service; General offices; Commercial parking; Hotels and other transient lodging
B - Rare enough to be absent or essentially so from one or more of the CBDs	Supermarkets; Automobile sales; Service stations; Accessory, tire, and battery sales; Newspaper publishing; Headquarter offices; Railroad station; Bus station; Residences; Industrial; Wholesale
C - Occupying substantial space in all CBDs but not typically central business land use	Public land and buildings; Organizational and chartable institutions; Vacant building or lot space

Activities collected in Murphy and Vance' field notes research (1954a and 1954b).

exceptions for people in search of leisure and free time activities at night. Such characteristics have changed during the years, making it necessary to calibrate analytical instruments and to focus also on other elements of observation.

With reference to the research carried out in Italy in urban studies, this is not the place to recall the overall path marked by scholars through the years, but just to recall how from the end of Sixties they developed and went in depth with studies on cities and observed the dynamics over the different national contexts, reminding the complete analysis performed by Scaramellini (1993). However it is important to recall, with particular reference to the local cases examined here, the works by Bonetti (1967; 1975) on central places and urban functions; by Battisti (1980) on metropolitan functions and by Corna Pellegrini e Pagnini (1975) on retail activities[1].

The attention on CBD has been focused on different kinds of activities, as tertiary activities (Bonetti, 1967), although this term was not used, but recalling particularly central activities, as already implicit in Berry (1967). The CBD represents the central place having the highest rank, the place where the most important activities of a city are located, not only as the more specialized retail activities, but also considering the administrative and professional ones.

A metropolitan city (Bonetti 1975) represents the specialized nucleus of a metropolitan area and constitutes itself a region. With that in mind different centres and their catchment areas for different functions or combinations of functions can be highlighted within a metropolis. CBD services are available not only for the city but also for its tributary area, definable as *hinterland* or *umland*.

The main subject of studies on CBD however are not only services but, as Scaramellini points out (1993b) there is a difference between the 'tertiary sector' and a central function. The former is referred to a historical-morphological distribution of economical activities, while the latter is referred to activities classified according to their capacity of action over space.

[1] Among the Italian local cases it is important to remind the analysis on CBD carried out by De Matteis (1966) on the urban area of Turin.

Central functions are not only the tertiary ones but also the secondary one dedicated to the local market. Industrial production can be central as urban location but also to serve a surrounding area with the products realized (Scaramellini 1993b). Functions become therefore central from their capacity of organizing spaces according to the needs originating from urban people.

The question to-date is what are the activities and categories to be considered for determining the CBD. For retail activities, Bonetti highlights the importance of those for individuals, as selling of goods and provision of services, not only retail. The more specialized activities or those providing the highest quality or variety of goods will be based in the CBD. These will be high value retail activities, as fashion retail, jewelleries, financial activities as banks and insurance companies, professional bodies – lawyers, architects, accountants, public bodies.

Among the 'classical' characteristics of CBD studied particularly in North-American cities, it must be reminded how the residential density is quite low in central areas, with a crater-like shape in some cities. Such shape is also confirmed for some urban areas in Italy (Borruso 2003), leaving room to interpret this as a higher diurnal population density if compared to the residential one. Other processes are ongoing, as the *gentrification*, or the progressive infill and redevelopment of central urban soils thanks to particular and 'creative' activities and the related population (Morrill 2006), with an increased use of such areas not only for working daily activities but also for those related to free time and leisure, spread over a wider timeframe during the day and covering also evening and night times. Also, in recent years urban tourism has increased, thanks also to the dynamics of urban centre redevelopments and re-definition of central functions of the city.

2.3 CBD and New Locations

The choice of central activities to-date should consider the changes intervened through years in urban structure and settlements. Many activities have abandoned the urban areas or at least their more central parts. This is the case of retail after the development of wholesale retail and the settlement of huge retail areas outside the city centres and along major communication routes (*shopping centres* and *malls*), moving a certain kind of shopping and retail out of the centres, spoiling them of the exclusivity of retail supply[2], although many cities are experimenting a renewed attention by retail activities towards a central location.

Also CBDs in many urban areas tend to move outside the city centres, mainly moving to more peripheral areas that are characterised by lower rents but also a suitable level of accessibility by means of private transport means and public ones, forming functional quarters inhabited during the day but deserted at night, these areas consisting mainly on directional buildings hosting banks, financial and insurance companies.

A similar trend can also be noticed in the case of headquarters of big companies that tend to move outside central areas, thus creating 'peripheral' CBDs, therefore not linked to the urban 'geographical barycentre'. Examples in different contexts can be

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[2] See Bullado and Buzzetti (2001) and Bullado (2002) for a complete analysis of the characters of wholesale retail in Italy.

reminded, as the new business district at Canary Wharf in London (UK), born after the urban redevelopment of the Docklands area, outside the traditional City of London square mile, as well as the Lujiazui CBD quarter in Shangai (Jones Lang LaSalle 2007). Examples closer to the study area being analysed can be reminded, as directional centres of insurance (Lloyd Adriatico - Allianz Group) and shipping companies (Lloyd Triestino, now Evergreen) moved out from the true barycentre of the city to the industrial and port areas. In the case of Udine, a new area of development of offices, financial services and retail has developed north from the city also in this case out of the *core* itself.

3 Density Analysis of CBD

3.1 The Method

The Kernel Density Estimation (KDE) used allows transforming point events in space in a continuous density function over the study region considered, thus allowing a visualization of the phenomenon by means of a three-dimensional surface, not limited to the single point event, but representing the variation of density of point events across the study region. The method allows modelling point data over a grid structure that covers the entire study region. Each grid cell is attributed a density value according to the events' distribution. KDE is generally used for applications regarding generally earth science, biology and epidemiology, but recently a wealth of applications to social science have flourished, as to examine the density and distribution of population or the clustering of human activities over space. The kernel consists of a family of 'moving three dimensional functions that weight events within its sphere of influence according to their distance from the point at which the intensity is being estimated (Gatrell et al 1996; Gatrell 1994). The general form of a kernel estimator is:

$$\hat{\lambda}(s) = \sum_{i=1}^{n} \frac{1}{\tau^2} k\left(\frac{s - s_i}{\tau}\right) \quad (1)$$

where $\hat{\lambda}(s)$ is the estimate of the density of the spatial point pattern measured at location s, s_i the observed i^{th} event, $k(\ )$ represents the kernel weighting function and τ is the bandwidth. τ represents a circumference's radius, centred in location s, within which events s_i are counted and will contribute to the density function (Gatrell, 1994). The bandwidth, or searching radius, τ represents the only arbitrary variable which defines the extent of the searching function. Too low values of τ produce a too 'spiky' representation of local peaks or, on the contrary, excessively wide bandwidths can cause a too high dilution and homogenization of the observed phenomenon.

The procedure considers using a fine grid over the study region and performing a routine that calculates the distance between each of the reference cells and the event's locations, evaluates the kernel function for each measured distance and sums the results for each reference cell (Levine 2004).

The result obtained consists on an estimate - for each cell in the study region - of the density of events observed within an area defined by the bandwidth, or searching radius, weighted according to the distance of the events from the same cell's centroid.

The cells covering the study region therefore present density values that can be expressed and represented by means of a density surface, which approximates a continuum in the space, presenting ‘peaks and valleys’ according to the different patterns draw by the distribution of events[3].

3.2 The Study Area

The research has been carried on considering two mid-size cities, Trieste and Udine, in North-eastern Italy, in the Friuli Venezia Giulia Region, at the Italy-Slovenia state border. The two cities represent the two 'souls' of the region and present different characteristics in terms of their locations, roles and economic features and performances.

According to a simplified representation of 'two regions' within one administrative region we can therefore observe the setting of a model based on Trieste and one on Udine as representative of the Friuli area (Figure 1).

Trieste, the Region capital, presents as a province a limited surface of 211 km^2 counting 6 municipalities, making it the smallest Italian province, where however live 236,000 people – 86.8% in the Municipality of Trieste (84.7 km^2), characterizing it as the third province - after much bigger cities as Milan and Naples - in terms of high population density. The population is decreasing due to the very high average age of people, contrasted by an increasing demographic rate particularly from the beginning of the XXI century.

The city is living a decline following a lose of the logistic role as a port and a market for former Yugoslavian consumers, mainly based on a privileged position on the 'iron curtain', suffering as well from the transformations occurred in the European area during the last decade. Trieste dimensions were in fact related to a wider transnational hinterland, both in terms of its port and services - bank, insurance and shipping companies just to name a few. The city is also competing with the neighboring city of Udine for the setting of regional activities and functions, as well as with the port of Capodistria - Koper (Slovenia) in terms of traffic and port functions.

The economic structure is characterized by a production mainly based on services - services counts for the 70.8% of the regional added value: figures raise to 84.6% of provincial GDP, that makes of Trieste the second Italian province in terms of the weight services has on added value creation, mainly addressed to the local community as retail and buildings, together with big players with a solid structure mainly in the insurance, bank and shipping sectors, as well as some big players in heavy industry, while intermediate firms and manufacturing are mainly lacking.

The retail sector is structurally suffering a bigger dimension that the local demand is not able to absorb. Strong elements in terms of future opportunities of development are based on a relevant presence of scientific and research structures, as well as a strategic position to the enlarging market of Eastern Europe.

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[3] See Thurstain-Goodwin e Unwin (2000) for an application of KDE to the analysis of urban centers and on the definition of ‘urban centrality’ indexes to define statistical units for urban areas. Other applications to city centers for recreational activities in Italian areas are reported by Boffi (2004), while Borruso (2003) examined the population distribution and density, as well as the decreasing density of road transport infrastructure when moving out from the city centre.

Fig. 1. The study area. Trieste and Udine in the Friuli Venezia Giulia Region.

The province of Udine presents a wider surface (4,893.07 km^2) and number of municipalities (137) with 535,992 inhabitants. The Municipality of Udine presents a surface of 56.87 km^2 and counts over 95,000 inhabitants.

If Trieste set on year 1989 - fall of the Iron Curtain - the start of a different declining economic period, Udine can dates back to 1976 - the year of the big earthquake - the start of a process of economic renewal, changing its role from that of a poor area characterized by outbound migrations to a new one of spread, localized and self-generated industrialization, based on small and medium-size enterprises, therefore extending the phenomenon of the industrial districts eastwards from the Veneto area.

Although the industrial sector is quite dynamic and has grown significantly during the last few years, it still presents some weaknesses, mainly concentrated on a general lack in terms of advances services to firms, as well as delays in the realization of connecting transport infrastructures.

Udine also presents important figures in the services - still the one that shows an increase in terms of active firms - and particularly in the retail sector. This latter however experimented a decrease in the number of active firms, although more limited than in the neighboring Trieste.

3.3 The Choice of Data

In order to test the method and to highlight the areas where a higher concentration of urban activities takes place, different categories of activities were chosen, these being among the most suitable of being located in central locations. Categories were selected among those available in the Yellow Pages service and we tried in particular to follow previous researches on central functions (i.e., Murphy & Vance 1954), therefore focusing on activities as retail, mainly in terms of high quality one, professional bodies, public offices, financial and business services, real estate, leisure activities, arts and culture[4].

Table 2. Urban central activities and their categories in the Municipalities of Trieste and Udine

Category		Sub-category		Total N. of activities	
Order	Description	Description	N. of subcategories	Trieste	Udine
1	Clothing	Clothing (classic; sport; women & man)	4	141	133
2	Arts & culture	Art galleries; auction, theaters, cinemas, museums	5	41	37
3	Banks and Insurance companies	Banks, insurance companies	2	259	194
4	Retail	Commercial agencies, fashion, antiques, jewelers,	6	186	27
5	Professionals	Architects, craftsmen, lawyers, solicitors, notaries, surveyors, designers, consultants on road damages, industry, accountants, commercial and financial consultants, certifiers, chartered surveyors.	19	747	778
6	Services to firms	Translators, interpreters, events management, industrial and technical services, Internet services, Internet web design, marketing, import-export	7	196	58
7	Real estate services	Real estate agencies	1	188	110
8	Free time (Leisure)	Hotels, bars & cafe, B&B, pubs, restaurants, agritourism, pizza house	8	568	269
9	Public buildings / activities	Embassies, Consulate, Local bodies, Public Associations	4	68	53
	Total		56	2,394	1,685

Source: elaboration from Yellow Pages (http://www.paginegialle.it), accessed December 2007 (Trieste); elaboration from Yellow Pages data via Google Earth, accessed June 2008 (Udine).

The main categories considered are also organized in disaggregated sub-categories. This will be particularly important in future research as both qualitative and quantitative weights for the different sub-categories could be assigned before the overall analysis of the spatial index in order to explore different shapes of the CBD itself.

[4] See Bertazzon and Lando (2003) for a recent analysis on high rank service activities in urban and tourist systems, based on Yellow Pages (SEAT - Pagine gialle) aggregated data.

After extracting data from Yellow Pages the activities were georeferenced, geocoding addresses to cartographic street numbers supplied by the municipality of Trieste. It was therefore possible to produce a scatterplot of 'central' activities using GIS software and explore their distribution within the territories of the municipalities of Trieste and Udine.

3.3.1 Trieste

Table 2 presents the activities considered in the Trieste area, grouped by categories and sub-categories. The total amount of activities counts for 2,394 for the Municipality of Trieste, grouped in nine (9) main categories and 56 sub-categories. From the analysis of Table 3, it can be noticed that the first 10 sub-categories cover more than 50% of the total, these corresponding to 1,301 entries. Activities related to food supply, as restaurants and bars among the others, are the most numerous ones. However, high values can be observed also in the overall number of real estate agencies, banks and insurance companies, lawyers, among the professionals, and jewelers in the retail sector.

Figure 2 (right) shows the spatial distribution of the 2,394 activities in the Municipality of Trieste, together with the city road network.

The simple observation of the locations of central activities allows already to notice their concentration in a 'central' area of the city of Trieste, together with a certain correspondence of the more peripheral activities and the main road axes. As De Matteis reports (1991), this is a kind of 'elementary geography', only apparently represented by a simple collection of addresses, that present a more general message concerning the configuration of the geographical space where we live. This scatterplot is however not enough for allowing a more in depth observation of the observed phenomenon, also considering that in many cases a same address point, and therefore a single point element on a map, can be related to several activities, located in different floors spaces in a same building. Different professional activities in higher floors can share the same building with retail activities or public offices.

Table 3. First ten sub-categories of central activities in the Municipality of Trieste

	Category	Sub-category	Number of events	%	Cumulative %
1	Leisure	Bar & cafe	189	7.88	7.88
2	Real estate services	Real estate agencies	188	7.83	15.71
3	Professionals	lawyers	169	7.04	22.75
4	Financial activities	Banks	163	6.79	29.54
5	Retail	Jewelers	112	4.67	34.21
6	Leisure	Restaurants	108	4.50	38.71
7	Financial activities	Insurance companies	96	4.00	42.71
8	Professionals	Surveyors	94	3.92	46.63
9	Services to firms	Import – Export	91	3.79	50.42
10	Leisure	Restaurants	91	3.79	54.21

Source: our elaboration from Yellow Pages data (http://www.paginegialle.it), accessed December 2007.

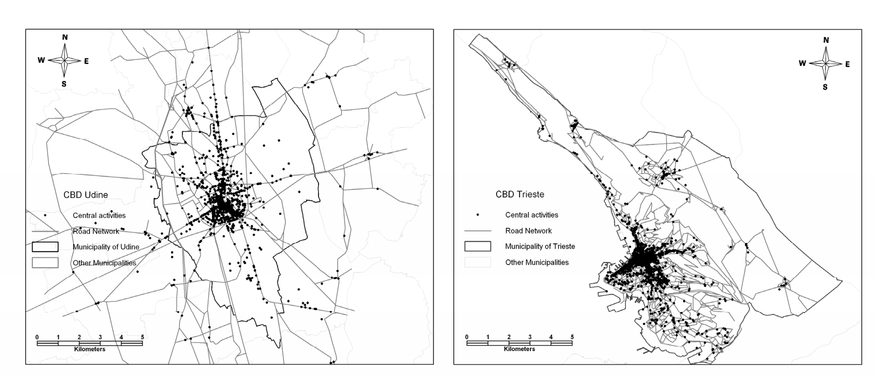

Fig. 2. Central activities and their spatial distribution in the Municipalities of Udine (left) and Trieste (right)

3.3.2 Udine

A similar dataset has been built with reference to the urban area of Udine. Differently from the Trieste case, the activities extracted from Yellow Pages were georeferenced at street number address level by means of Google Earth and converted in GIS formats to be loaded in as a geographical database (Figure 2 left). The 'elementary geography' of activities here refers to an area slightly higher than that enclosed within the borders of the municipality of Udine. The city of Udine in fact developed during the years following the orientation of some major road axis without encountering particular morphological obstacles and therefore spread other the original boundaries. For the activities used in the analysis the area is therefore slightly wider than the municipal boundary. Professionals, with lawyers and architects, as well as clothing, leisure activities as bars and real estate agencies lead the activities located in the municipality of Udine, flanked by banks and insurance companies.

4 Elaborations and Results

4.1 Trieste and Its CBD

Data obtained from the grouping of Yellow Pages activities were processed using Kernel Density Estimations. A fine 20m grid has been overlaid on the study region of the Municipality of Trieste. The 20m cell represents the minimal sampling unit for the density analysis. The kernel function chosen is a quartic one with a 400m bandwidth[5]. Such distance was chosen after several simulations and was considered as one of the most suitable for an urban area of dimensions as Trieste, similarly to what previously developed in other researches on urban areas where a 300m bandwidth is used (Thurstain-Goodwin and Unwin, 2000).

[5] Other kernel functions can be used, as the normal, the triangular or the uniform ones. This depends on the importance, and therefore on the weight, we want to assign to events according to their distance from the cell's centre. When using a quartic function closer events to the cell are weighted more than those located on the external border of the searching function.

Higher values of the searching bandwidth cause an excess of smoothing of the density function and therefore a higher dilution of events across the study region, while narrower ones can produce a function characterized by too many 'peaks and valleys'[6]. The function provides also a measure of accessibility, showing for each cell the events that can be reached within a certain distance, assigning a higher importance to closer events, as expressed by the weight inserted in the quartic function. The 400 meters can be considered as the average walking distance in 5 minutes. In this case the 400 m distance is furthermore obtained by means of a nearest neighbor computation using a K = 50 rank that means computing for each dataset the average of intra-events distances of different orders (Chainey et al, 2002). Therefore the control of the variable is moved from the bandwidth to a k-nearest neighbor choice. In such sense it is possible to adopt a method that, although involves different bandwidth distances for different datasets, does consider the spatial distribution and organization of events within a study area.

The function has been therefore used to estimate the number of events within 400 meters from each reference cell, counting and weighting them according to their distance from a cell's centroid according to a decreasing function and dividing the value by the area underneath the same function. Each cell is therefore attributed a relative density value corresponding to the number of events within 400 metres from the cell weighted by their distance from the same cell and divided by the area underneath the function.

Cells of relative density were mapped as a 3D function and isolines corresponding to homogeneous density values have been obtained. For the thematic classification of the density surface positive standard deviation values were used[7], following Chainey et al. (2002) we adopted a method based on mean or standard deviation for deriving isolines suitable for suggesting possible delimitation of the CBD. Here a standard deviation method is portrayed, although the mean-based one is also providing similar results. In the first case as shown in Figure 3, denser cells, and therefore those having the higher concentration of central activities, can be observed in the central area of the city where the density surface presents a relevant 'peak' if compared to the rest of the municipality of Trieste. This is also confirmed by the number of activities located in the area. Nearly 64% of the activities considered, these corresponding to 1,532 over a total value of 2,394, are located within the more external isoline in Figure 3 (right), that is the one delimiting the area above one unit of standard deviation over the mean value, with a minimum density value of 288.45 activities/km^2 and an average of 926.18 activities/km^2 in the enclosed area. The other standard deviation values (two, three, four units and more) delimitate smaller and more concentrated areas, highlighting a true 'peak' in the density surface.

In order to delineate the area where the CBD is likely to be located we examine the tail values of the density function, starting from two standard deviation units, with

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[6] In an extreme case of a too narrow bandwidth, not much more information than the simple observation of the spatial distribution of events is supplied.

[7] It is frequent that several events in space do not present a normal distribution, moving towards one of the tails of the distribution itself. This is due to the tendency of several phenomena, as population and other human activities, of grouping together (Harris et al., 2005).

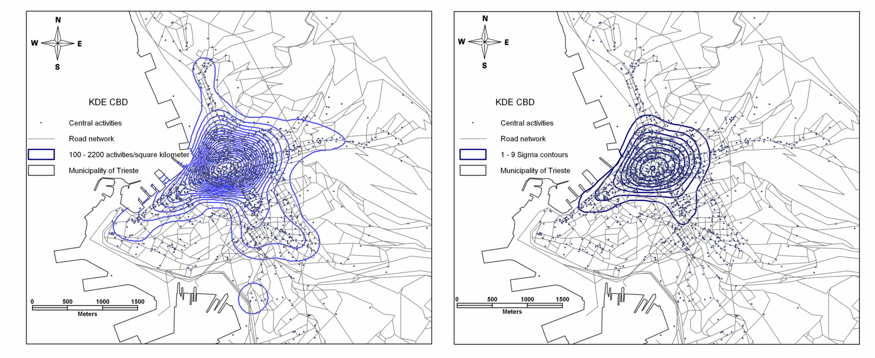

Fig. 3. Isolines of central activities density function in the city of Trieste. Quartic KDE, 400 m bandwidth (K=50). Lines spaced by density values multiple of 100 activities/km^2 (left: 100 – 2,200) and by density value multiple of 1 standard deviation (right: 288 – 2,047 activities/km^2). Mean = 68.58; Standard Deviation = 219.87; Max = 2,250 activities/km^2.

particular reference to those values higher than three[8]. The borderline of the cells belonging to such value delimitates an area of 0.75 km^2, covering 47% of the activities located in the whole territory of the Municipality of Trieste (1.130 events), delimited by the 728 central activities/km^2 isoline and with a mean density of central activities of 926.18/km^2, versus an average municipal density for Trieste of 28.25/km^2. Here 48% of banks and insurance companies branches (124 events over 259), are present, that represents the 11% of all activities in the three standard deviation area, making it a candidate for representing the borderline of the CBD of Trieste.

Central functions tend therefore to be concentrated in a circumscribed area of the city of Trieste that, as seen above, presents an evident peak to demonstrate the high density of the considered activities and a monocentric structure. It must be however noticed the alignment of many activities along some main roads as observed in the ‘simple’ data scatterplot. We can particularly notice a decreasing density and its elongation along the seaside main road and its parallel streets, close to the central part of the city and following a Northeast – Southwest orientation in the southern part of the city, along a North - South axis in the northern area of the central part of the city, starting from the railway station and also a North - South axis in the South – Southeast part of the city. The more smoothed and rounded shape of the function in the eastern part of the city highlights an East – West main axis represented by parallel streets characterized by central activities, while there is a fuzzier distribution along an East – Northeast axis.

Figure 4 confirms visually what is observed by means of isolines obtained through standard deviation – as in Figure 3, providing profiles of the ‘cone’ of economic activities in the centre of Trieste, thanks to the uniform spacing in terms of central functions’ density, portraying a quite sharp decrease of density activities out of the same centre.

[8] Chainey et al. (2002) propose the method based on the standard deviation units for delimiting the border of hot-spot areas, suggesting a value of three units among the most suitable ones for this kind of analysis.

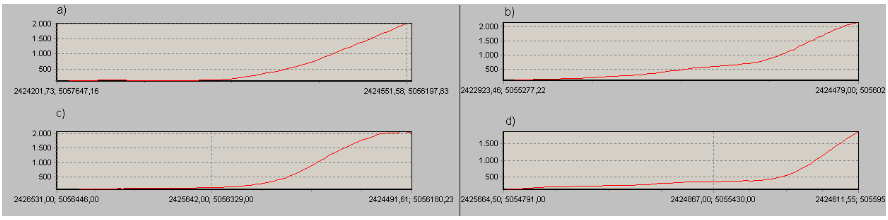

Fig. 4. Profiles of the density function in the city of Trieste following main axes. a) North-Northwest - Centre; b) West-Southwest – Centre; c) East-Northeast - Centre; d) South-Southeast – Centre.

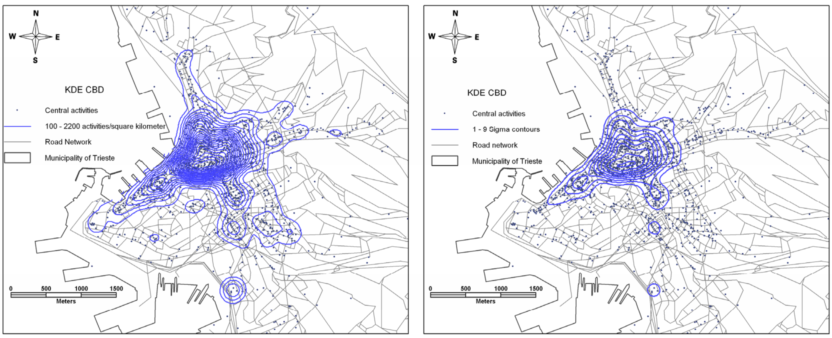

Fig. 5. Isolines of central activities density function in the city of Trieste. Quartic KDE, 255 m bandwidth (K=25). Lines spaced by density values multiple of 100 activities/km^2 (left: 100 – 2,200) and by density value multiple of 1 standard deviation (right: 305 – 2,151 activities/km^2). Mean = 74.39; Standard Deviation = 230.78; Max = 2,175 activities/km^2.

We experimented also the application of a different bandwidth based on nearest neighbour analysis, and particularly relying on a K = 25 order, that producing a 255m bandwidth.

Results are portrayed in Figure 5, where isolines are derived from the 3D function and respectively spaced by 100 units of activities/km^2 (left) and standard deviation values (right). The central peak of CBD activities is maintained reducing the bandwidth, however it is more evident that activities out of the cone are oriented according to the direction of main road axes accessing the city centre. Also, some minor clusters appear in other parts of the city.

4.2 Udine and Its CBD

A similar procedure was followed for the analysis on Udine area, with a 20m mesh overlaid onto the study region centred on the Municipality of Udine. Given the spreading of activities over an area wider than the pure Municipality, neighbouring municipalities were considered, mainly in the northern area, for the kernel density estimation, while analysis and comments are based on the Municipality of Udine. In order to compare the results for the two areas, a quartic function was used for the kernel density estimation, using a 389m bandwidth. This value came out from the nearest neighbour computation over the activities in the wider Udine area and corresponding to a K = 50 nearest neighbour value. The distance is quite close to the one used in Trieste and that helps in the comparison of results, thus also inducing to notice some similarities in the density function' shape in the two areas.

The density function was converted in isolines, both represented in Figure 6 as spaced by 100 activities/km^2 (left) and also by values of standard deviation (right). The activities in the city of Udine are clustered in the area of the historical centre of the city, mainly in that enclosed within one of the old city walls.

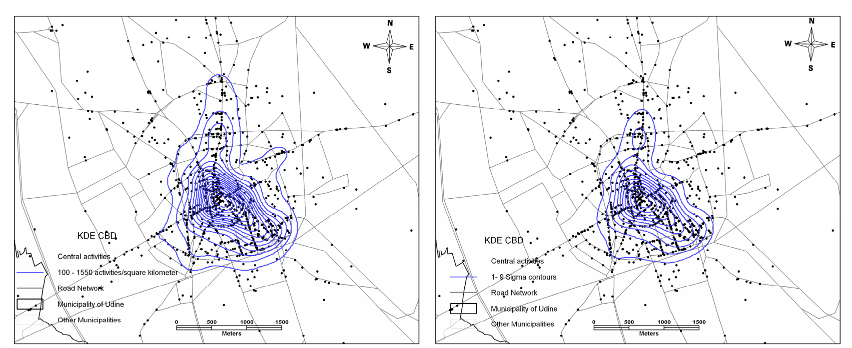

Fig. 6. Isolines of central activities density function in the city of Udine. Quartic KDE, 389 m bandwidth (K=50). Lines spaced by density values multiple of 100 activities/km^2 (left: 100 – 1,500) and by density value multiple of 1 standard deviation (right: 188 – 1,621 activities/km^2). Mean = 45.26; Standard Deviation = 143.29; Max = 1,570 activities/km^2.

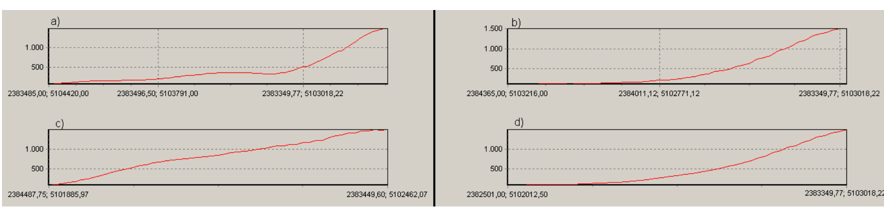

Fig. 7. Profiles of the density function in the city of Udine following main axes. a) North-South - Centre; b) Northeast-Southwest – Centre; c) Southeast-Northwest - Centre; d) Southwest - Northeast Centre.

A monocentric structure is quite evident, as in the case of Trieste, although with lower density values, with a central shape elongated towards Southeast, as well a general alignment of activities along main access roads to the city centre can be noticed. This is evident when we look at the North-South and Southwest – Northeast access roads. Standard deviation values used to delineate isolines offer interesting elements for discussion. The first value of standard deviation (188 activities/km^2) enclose an area where 69% of activities of the Municipality concentrate (1,159 over 1,685), producing a mean value of 559 activities/km^2. Higher standard deviation values correspond to more concentrated areas.

These results are also evident when we look at the density profiles obtained, portraying (Figure 4) a cone of high density of activities elongated towards the Southwest axis (Figura 4 c). We can observe it decreases quite regularly, while the other profiles (Figure 4 a, b and d) present a sharp fall of the density values when moving out from the central area.

In order to test different bandwidth and scales of analysis, a 265m bandwidth was also tested. It corresponds to a K = 25 nearest neighbor value. The same message of a monocentric structure is delivered, with an elongated shape and with some privileged axis along main access roads. Furthermore, a closer scale of analysis allows to highlight minor ‘sub-centers’ located outside the core of the city’s CBD (Figure 8).

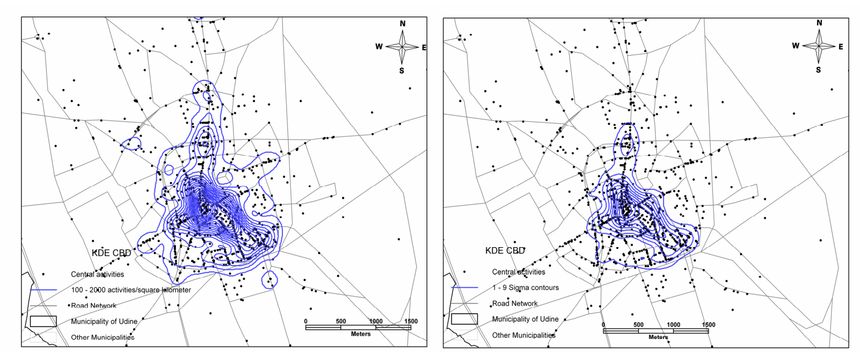

Fig. 8. Isolines of central activities density function in the city of Udine. Quartic KDE, 265 m bandwidth (K=25). Lines spaced by density values multiple of 100 activities/km^2 (left: 100 – 2,000) and by density value multiple of 1 standard deviation (right: 305 – 2,151 activities/km^2). Mean = 62.61; Standard Deviation = 180.01; Max = 2,011 activities/km^2

4.3 Comparisons

Standard deviation values were chosen to produce isolines suitable for delimiting a CBD area, and particularly values of three, four and five standard deviation units seemed to produce interesting results as ‘candidates’ for bordering a CBD, or, in any case, to define an area definable as truly ‘central’. As suggested by Chainey et al (2002), standard deviation values can be used to define ‘hotspots’, however what is this value is what still need to be determined. Values higher than three standard deviation units seem to be suitable in highlighting areas of high and growing concentration of (central) activities, given both their number and the surface of the area enclosed by such isolines. Furthermore, as in the two cases examined, being such isolines quite narrowly spaced, the differences between these units are not so huge. By observing Figure 9, we can notice that the more external three standard deviation isoline seems to be capable of delimiting a ‘central area’.

This is true both for Udine, where such line touch two important nodes in the road network that actually represent the access to the historic centre (limited road traffic zone), and for Trieste, where the standard deviation isoline follow some roads enclosing the city centre, two main squares and access points to the geographical centre. Higher standard deviation values, as five, can help in delineating the ‘true’ CBD, as can also be noticed observing Table 4. A limited area (0.40 km^2 in Trieste and 0.46 km^2 in Udine) still encloses a high percentage of all the activities in the municipality (over 35%) and consequently very high rates in terms of density values.

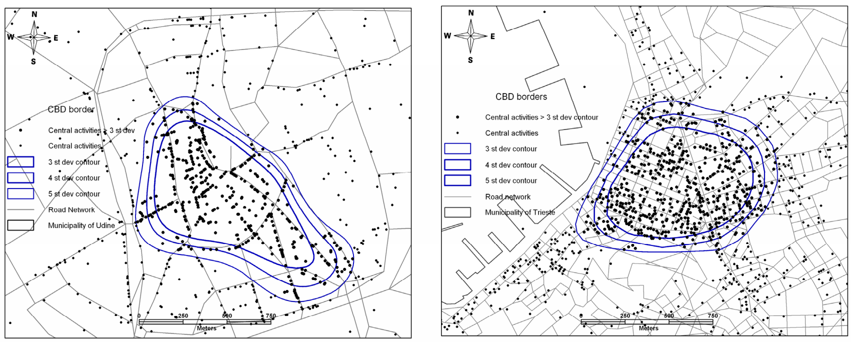

Fig. 9. Selected isolines of central activities density function in the cities of Udine (left) and Trieste (right) with standard deviation values of 3, 4 and 5 as 'candidates' for delimiting CBD area

Table 4. Central activities and their distribution in areas defined by standard deviation values

Region	Activities (*Banks & Insurance*)				Area km^2		Density activities/ km^2	
	Ts	% (*B&I over total*)	Ud	% (*B&I over total*)	Ts	Ud	Ts	Ud
Municipality	2,394 (*259*)	100.00 (*10.65*)	1,685 (*194*)	100.00 (*11.51*)	84.73	56.87	28.25	29.63
3 st. dev isoline	1,130 (*124*)	47.20 (*10.97*)	806 (*74*)	47.83 (*9.18*)	0.74	0.85	1,524.08	950.14
4 st. dev isoline	1,002 (*112*)	41.85 (*11.18*)	719 (*65*)	42.67 (*9.04*)	0.55	0.63	1,811.30	1,143.00
5 st. dev isoline	843 (*105*)	35.21 (*12.46*)	615 (*55*)	36.50 (*8.94*)	0.40	0.46	2,098.74	1,343.33

Ts = Trieste; Ud = Udine; Banks and insurance companies figures in brackets and italics. Percentage values related to activities are referred to the total figures in the municipality. Percentage values related to banks and insurance companies are referred to the total number of activities for each of the sub-areas considered.

The differences between the two urban areas must also be noticed. Although the mean density values for the two cities are quite similar, if the activities are related to the overall surface of the Municipality, things change when we look at more limited areas and the activities located there. In the Trieste area as we move towards the true centre the density rises to more than 2,000 activities/km^2, while the value in Udine just overcomes 1,343. More interestingly, the kind of activities change as well, with a considerable number of banks and insurance companies branches concentrated in Trieste, whose percentage on the overall activities grows, while in Udine such concentration of financial services is less clustered and room is left to professionals.

5 Conclusions

5.1 General Notes

Central Business Districts have been studied in the past as the areas with high value activities take place in an urban area and give it the attribute ‘central’. To-date things have changed, with major companies and head offices moving out from the center of cities and locating in semi-peripheral business districts. However city centers are still lively and host a wealth of activities still considerable as central. These include leisure and other ones related to people work life and also free time. Classical theories on urban functions, forms and shape can however be rethought to date and studied again, adapting some characteristics to the changes intervened. In such sense the data available and GIS and geocomputational tools can help and provide scholars, as well as planners and decision makers, with means of analysis, representations and discussion over a territory in order to understand its characters. The starting point is the geographical location of activities, processed to obtain density surface that can produce isolines whose values are under exam as candidate elements to delineate area of really ‘central’ activities and functions. The analysis was performed over two mid-size neighboring cities in Northeastern Italy, although there is still a need to test the methods on other urban areas, as well to examine more in depth the composition of activities within the dataset in order to better understand the different ‘central activities’ that characterize different cities.

5.2 Local Results

With the limitations afore said, we find two different situations for the city considered, both in terms of density and variety: Trieste is characterised by a prevalence of banking and insurance activities, which are clearly clustered (as the density ratio shows) and which follow the main road axis. Udine, instead, is characterised by a prevalence of professional and consultancy activities which, differently from Trieste, are not clustered, but are located along an ideal North-South axis. The aim of future researches on this topic will be the one of finding out, for each kind of sub-category, the relative density distribution and its contribution to the overall function, furthermore considering infrastructural and geomorphologic features as well as the urban structure as driving elements for the spatial pattern. That could allow obtaining a more refined analysis where simplistic assumptions of homogeneity and isotropy of space are relaxed.

Acknowledgments. GIS analysis was performed using Intergraph GeoMedia Professional and GRID 6.0 under the Registered Research Laboratory (RRL) agreement between Intergraph and the Department of Geographical and Historical Sciences of the University of Trieste.

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Identification of "Hot Spots" of Social and Housing Difficulty in Urban Areas: Scan Statistics for Housing Market and Urban Planning Policies*

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Abstract. The objective of the present work is to use statistical data to identify territorial zones characterized by the presence of urban poverty related to property ownership and the availability of residential services. Poverty clusters have a high concentration of poor people, but that does not mean that everyone living in them is poor. While poverty is widely accepted to be an inherently multi-dimensional concept, it has proved very difficult to develop measures that both capture this multidimensionality and make comparisons over time and space easy. With this in mind, we attempt to apply a Total Fuzzy and Relative (TFR) approach, based on a fuzzy measure of the degree of association of an individual to the totality of the poor and an approach of semantic distance (Munda 1995), based on the definition of a "fuzzy distance" as a discriminating multidimensional reference to rank the availability to property in real estate market, as complement of urban poverty, in the specific case of the City of Bari. These approaches have been improved using the SaTScan methodology, a circle-based spatial-scan statistical method (Kulldorff 1997; Patil and Taille 2004; Aldstat and Getis 2006). It concerns geoinformatic surveillance for poverty hot-spot detection, used as a scientific base to lead urban regeneration policies.

Keywords: hot spot, urban poverty, fuzzy, multicriteria analysis, urban planning.

1 Introduction

The question of housing in Italy is of interest to academics, politicians and social operators. Some estimates of the Bank of Italy show that more than 28% of Italian families (six million households) were already in a state of residential discomfort in 2002. The Italian housing problems come after other countries experienced the same difficulties, due to high housing costs heavily affecting household budgets (Poterba 1984),

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or due to the inadequacy of housing, of urban facilities and of high quality dwellings. New social groups that suffer housing problems are identified in the lower middle class and working class in areas characterized by high urban density. In the light of the actual conditions it becomes necessary and urgent to deal with the policies that should be adopted to manage the housing emergency in metropolitan areas: the lack of available housing or the offer of acceptable rent levels, the lack of social services and household overcrowding, or the inadequacy of economic resources to achieve a better living standard are all conditions which can cause housing problems and that means urban poverty.

Poverty does not only mean scarcity of financial self-funding: it embraces a plurality of social and cultural issues, such as education, health and housing. In other words it represents a measure of the inequality of access to various basic goods and services.

This work aims to determine territorial zones (hot spots) characterized by the presence of urban poverty in the City of Bari, based on the most recent available data released by ISTAT (Italian National Statistics Institute) in the last Population and Housing Census (2001).

Such multi-dimensionality suggests an exploration of a new definition of indicators useful to describe housing discomfort, related to the poverty of small areas and to real estate values (Montrone et al. 2007).

The presence of a varied range of definitions on the theme of poverty shows the necessity of no longer relying on a single indicator but on a group of indicators which are useful in the definition of living conditions of various subjects.

The approach chosen in order to arrive at the synthesis and measurement of the incidence of relative poverty in the population in question is the so-called "*Total Fuzzy and Relative*" method, "which uses the techniques of the *Fuzzy Set* in order to measure the incidence of relative poverty within a population, beginning from statistical information gathered from a plurality of indicators" (Lemmi and Pannuzi 1995).

Furthermore, the use of clustering based on indicators makes it possible to identify continuous urban aggregation by the imposition of spatial constraints (Patil and Taillie 2004; Kulldorff and Nagarwalla 1995). Special attention has been given to the approach suggested by Kulldorff (1997), based on the identification of a circular window focused on a centroidal point with a given radius. By measuring the density of problematic conditions measured by indicators in a given context, this method can be helpful to identify target areas for urban policies aimed at increasing property market regulation and the availability of cheaper housing services.

2 Identifying Indicators of Social and Housing Difficulty

2.1 Introduction

Since the end of the 1970s, numerous studies have been based on a variety of approaches, each of which adopted an attentive definition and conceptualization of the phenomena. Townsend (1979) defines poor families those that “lack the resources for a quality of alimentation, participation in activities and enjoyment of the living conditions which are standard, or at least widely accepted, in the society in which they are living”. The reference is, therefore, towards a concept of poverty as relative privation, which takes into account the particular historical, economic, social, geographical, cultural and institutional context under examination. Within this study, twelve principal dimensions of poverty were identified which are: diet, clothing, housing costs, costs within the household, living conditions, working conditions, health, education, the environment, family activities, recreational activities and social relations. It may be noted that three of the twelve areas considered are connected to housing conditions. The twelve categories described above have been used in many later studies based on the concept of so-called multidimensional poverty, carried out amongst others by Gailly and Hausman (1984), Mack and Lansley (1985) and Desai and Shah (1988).

2.2 Measuring Indicators of Social and Housing Difficulty

The subject of this study derives from the necessity to identify geographical areas characterized by situations of residential deprivation or urban poverty in the City of Bari (hot spots). In order to analyse the phenomena of residential poverty on a geographical basis, this work uses data from the most recent *Population and Housing Census 2001* carried out by ISTAT. This information allows geographical analysis in sections according to the census, albeit hindered by the lack of more recent data. Specifically, the geographical units of the survey are the 1,421 census sections within the City of Bari, 109 of which are uninhabited areas or are designated for other uses (i.e., parks or universities).

The choice of the indexes to consider has been made according to the analysis of some socio-cultural aspects of the resident population in the City of Bari considered useful in defining urban poverty: these are education levels, working conditions and living conditions.

It emerges from the study of "Relative Poverty in Italy" conducted annually by ISTAT that low levels of education, exclusion from the employment market and precarious residential standards are closely linked to conditions of poverty.

The various indices were classified into *two sets*:

- *Social difficulty*, related to the conditions of the resident population within the various census sections (educational qualifications, working conditions, overcrowding);
- *Housing difficulty,* related to the housing conditions of dwellings occupied by residents in the various census sections (housing status, lack of functional services such as landline telephone, heating systems and designated parking space).

The indexes have been calculated both at the scale of the census section and at the scale of the neighbourhood. Table 1 shows average indexes of household poverty for each neighbourhood.

The analysis of urban poverty, referring to the census sections of the City of Bari, shows that the minimum level of school attendance is reached by 55% of citizens aged over 19. This index shows the highest average percentage in a popular neighbourhood (San Paolo) and the old town (San Nicola), and the lowest percentage in the city centre (Murat).

As regards unemployment the average rate is about 20%; the worst result is 28% in the San Paolo area, and the best result is an 11% rate in the Murat area.

Table 1. Average of indexes[1] per single area of the City of Bari - 2001

Neighborhoods	Index 1	Index 2	Index 3	Index 4	Index 5	Index 6	Index 7
Carbonara	0.61	0.22	3.55	0.26	0.19	0.07	0.51
Carrassi	0.43	0.15	2.92	0.21	0.10	0.07	0.64
Ceglie	0.71	0.25	3.61	0.32	0.22	0.08	0.45
Japigia	0.50	0.20	3.23	0.29	0.12	0.07	0.31
Libertà	0.66	0.22	3.93	0.36	0.18	0.21	0.86
Roseto	0.66	0.25	3.49	0.19	0.20	0.03	0.26
Madonnella	0.53	0.21	3.30	0.43	0.18	0.20	0.84
S.Girolamo F.	0.63	0.21	3.88	0.30	0.21	0.07	0.27
Murat	0.28	0.11	2.28	0.24	0.09	0.06	0.84
Palese	0.52	0.19	3.25	0.23	0.17	0.04	0.26
Picone	0.44	0.16	3.13	0.22	0.11	0.06	0.44
S.Nicola	0.74	0.25	5.00	0.47	0.33	0.38	0.92
S.Paolo	0.84	0.28	4.03	0.46	0.15	0.07	0.36
S.Pasquale	0.43	0.16	3.29	0.23	0.13	0.08	0.53
S.Spirito	0.58	0.20	3.44	0.30	0.20	0.07	0.24
Stanic	0.70	0.27	4.00	0.24	0.27	0.11	0.20
Torre a Mare	0.51	0.19	2.85	0.27	0.26	0.08	0.19
Bari	0.55	0.20	3.42	0.29	0.17	0.10	0.53

Source: Our elaboration of the data from the Population and Housing Census, 2001.

The dwelling space index is 3.42 on average (more or less three inhabitants per 100 square meters). Overcrowding is relevant in the San Nicola area, with five inhabitants per 100 meters (20 square meters per capita) and four inhabitants per 100 meters (25 square meters per capita) in the Stanic and San Paolo areas.

[1] **Index 1-** Index of lack of progress to high school diploma: ratio between the total number of residents aged 19 or over who have not obtained a high school diploma and the total number of residents of the same age group.

Index 2 - Rate of unemployment: the ratio between the total number of residents aged 15 or over who are in search of employment and the workforce of the same age group.

Index 3 – Index of overcrowding: the ratio between the total number of residents and size of dwellings occupied by residents.

Index 4 - Incidence of the number of dwellings occupied by rent-payers: ratio between the number of dwellings occupied by rent-paying residents and the total number of residents.

Index 5 - Incidence of the number of dwellings lacking a landline telephone: ratio between the number of dwellings occupied by residents without a landline telephone and the total number of dwellings occupied by residents.

Index 6 - Incidence of the number of dwellings lacking heating: ratio between the number of dwellings occupied by residents without a heating system and the total number of dwellings occupied by residents.

Index 7 - Incidence of the number of dwellings lacking parking space: ratio between the number of dwellings occupied by residents without a parking space and the total number of dwellings occupied by residents.

As regards typology of occupation, the index measures the percentage of the total of dwelling occupied by renters. In the City of Bari the average percentage is more or less 29% (while 6% are free used, and 65% are owned by occupants). More specifically, there are 31,558 rented homes, while there are 72,587 owner-occupied homes. Again, San Nicola (47%), San Paolo (46%) and the Madonnella (43%) show the worst conditions, while the peripheral Loseto area shows the best conditions, even if the property values are not highly rated, and its newest properties are often rented to young couples.

When it comes to facilities, on average 17% of households do not have a contract for a landline telephone and 10% of households do not have heating systems. Car parking is lacking, because on average 53% of households do not have a parking place.

The critical condition of the San Nicola area is confirmed also by the lack of facilities: 33% of households do not have a contract for a telephone line, 38% of households have no heating systems and 92% of households do not have a parking place.

The difficulties caused by the lack of facilities are a common problem of the Madonnella and Libertà areas, the most degraded areas in the centre of the city. The Murat area has a good range of facilities, except for parking places. Despite the scarcity of parking places in the Murat area, the property value is quite high, due to the presence of many of historical residential buildings that have been restored and represent the best quality supply of offices and residence in the city centre area.

3 The Geographical Zoning of Data

3.1 Introduction

The great availability of data deriving from the use of Information Technology (IT) and Digital Mapping (DM), the frequent recurrence to Geographic Information Systems (GIS), increases the interest in geographical analysis and modelling to support the heuristic creation of new scientific knowledge. In the field of statistics, such instruments are already read and numerous; for instance, Ordinary Data Mining (ODM) is used in market investigation in order to assess consumer preferences (with Conjoint Analysis).

However, in the field of spatial analysis, despite awareness of the need to associate spatial entities with information, Geographic Data Mining (GDM) did not achieve the same level of stability of results - due to the complexity of computation - in problems of geographic clustering, bordering and modelling, caused by the intrinsic character of the spatial data.

In fact, on one hand, if in ODM some specific issues are:

- explorative data analysis,
- thematic mapping,
- multivariate methods,
- logistic regression/general linear modeling,
- clustering,
- decision/segment trees,
- neural networks application,

on the other hand, in the case of GDM, it is necessary to consider as preliminary hypotheses:

- dependency and self-correlation of spatial-temporal data,
- dependency of systematic biases often associated with spatial entities (spatial structured biases),
- non-stationary data,
- importance of location and of scale in relationship between data,
- non-linearity of models,
- non-normal distribution of data,

in order to use both approach for data treatment.

Sometimes traditional methods are likely to be more useful for geographic studies ODM, due to the difficulty in the management of spatial-based entities. ODM traditionally finds relationships between entities without explaining the connection with spatial location, represented by topographic reference or belonging to a special geometric group. ODM does not consider in fact topological relationships or applications.

3.2 Spatial Clustering

In order to answer the questions above, spatial databases (SD) and GIS have been developed starting from the 1970s. SD and GIS, thanks to their Dynamic-link library oriented to the integration with external software, help to integrate conceptual and pragmatic dimension of the relationship among spatial entities. An incompletely resolved problem is that GIS, and/or geographic analysis machines (GAM) give only a visualisation of problem solution, by heuristics that require very complex computation.

If it is possible to reduce the analysed problem to a few aspects of the observed phenomenon (such as incidence of diseases and/or crimes in a territory), in this case the cartography becomes a thematic map where areas of interests join each other with spatial contiguity. The result is a zoning based on a spatial (or spatial-temporal) clustering, the conceptual aspects of which deserve a better definition.

Knox (1989) in his studies on spatial relationship of epidemic phenomena gave a seminal definition of spatial clustering: a spatial cluster is a non-usual collection/aggregation of real or perceived (social, economic) events; it is a collection of spatial, or spatial/temporally delimited events, an ensemble of objects located in contiguous areas.

From a statistical point of view, in this case, the clustering can be based on the identification of areas where a group of points shows the maximum incidence inside, and at the same time leaves the minimum incidence outside, referring to a given phenomenon. Such operation is obtained by locating a circular window of arbitrary radius, by calculating the probability (risk) p_1, inside the circle, or the probability (risk) p_2, outside the circle, and finally by rejecting the pointless hypothesis:

$$\begin{cases} H_0: & p_1 \leq p_2 \\ H_1: & p_1 > p_2 \end{cases}$$

or rejecting the pointless hypothesis:

$$\begin{cases} H_0: & p_1 \geq p_2 \\ H_1: & p_1 < p_2 \end{cases}$$

if the aim is to identify minimum risk areas. Of all windows, the minimum *p*-value (probability of critical region referring to the test) corresponds to the most important cluster. The identification of a special area can be based on the intensity of a statistical attribute, instead of the number of attribute-characterised elements.

In the field of epidemiological studies many research groups have developed different typologies of software; these are all based on the same approach, but usually differ from each other in the shape of the window.

Among the various methods of zoning, there are SaTScan (Kulldorff 1997) that uses a circular window, FlexScan (Takahashi et al. 2004), that uses contiguity to build the window, the Upper Level Scan Statistics (ULS: Patil and Taillie 2004), that underpasses the question of geometric shape of the window including aggregate points and finally AMOEBA (A Multidirectional Optimal Ecotope Based Algorithm: Aldstadt and Getis 2006), that uses a similar approach to SaTScan, without the constraint of a circular window.

In this work, the zoning method used is the SaTScan. This method in some cases can produce an imprecise zoning, due to the circular shape of the window, especially in peripheral urban areas, or other areas that are wider than the given size of the radius inside of which is defined the homogeneity of the considered attribute. The research we report in this paper on social-residential problems, based on socio-economic indicators, has led to the identification of small areas with high indexes of poverty although quite heterogeneous in the observed urban context: namely *hot spots*. Regarding this specific aim, SaTScan seems to be quite efficient (release 7.03, freely available at `http://www.satscan.org`).

4 Determination of the Variable for Classification

4.1 The Fuzzy Approach

The different scientific research pathways are consequently directed towards the creation of *multidimensional indicators*, sometimes going beyond dichotomized logic in order to move towards a classification which is "*fuzzy*" in nature, in which every unit belongs to the category of poor with a range from 1 to 0, where the value 1 means definitely poor, 0 means not poor at all, and the other values in the interval reflect levels of poverty. Classifying populations simply as either *poor* or *non-poor* constitutes an excessive simplification of reality, negating all shades of difference existing between the two extremes of high level well-being and marked material impoverishment. Poverty is certainly not an attribute which can characterize an individual in terms of presence or absence, but rather is manifested in a range of differing degrees and shades (Cheli and Lemmi 1995).

The development of *fuzzy theory* stems from the initial work of Zadeh (1965), and successively of Dubois and Prade (1980) who defined its methodological basis. Fuzzy theory assumes that every unit is associated contemporarily to all identified categories and not univocally to only one, on the basis of ties of differing intensity expressed by the concept of degrees of association. The use of fuzzy methodology in the field of "poverty studies" in Italy dates back only a few years, thanks to the work of Cheli and Lemmi (1995) who define their method "*Total Fuzzy and Relative*" (TFR) on the basis of the previous contribution from Cerioli and Zani (1990).

The TFR approach consists in the definition of the measurement of a *degree of membership* of an individual to the fuzzy totality of the poor, included in the interval between 0 (with an individual not demonstrating clear membership to the totality of the poor) and 1 (with an individual demonstrating clear membership to the totality of the poor). Mathematically such a method consists of the construction of a function of membership to "the fuzzy totality of the poor" continuous in nature, and "able to provide a measurement of the degree of poverty present within each unit" (Cheli and Lemmi 1995; Lemmi and Pannuzi 1995). Supposing the observation of k indicators of poverty for every family, the function of membership of i_{th} family to the fuzzy subset of the poor may be defined thus (Cerioli and Zani 1990):

$$f(x_{i.}) = \frac{\sum_{j=1}^{k} g(x_{ij}).w_j}{\sum_{j=1}^{k} w_j} \qquad i = 1,.....,n \tag{1}$$

The w_j function in the function of membership are only a *weighting system* (Cheli and Lemmi 1995), as for the generalization of Cerioli and Zani (1990), whose specification is given:

$$w_j = \ln(1/\overline{g(x_j)}) \tag{2}$$

The weighting operation is fundamental for creating synthetic indexes, by the aggregation of belonging (to the ensemble of the poor) functions of each single indicator of poverty. An alternative, by Betti, Cheli and Lemmi (2002) starts from the conjoint use of the coefficient of variation as the first component of the set of weights, with the correlation coefficient, as the second component. The new set of weights, which is proposed for continuous variables, takes into account two factors, described in the following multiplicative form:

$$w_j = w_j^{(a)} * w_j^{(b)} \tag{3}$$

where:

$w_j^{(a)} = \frac{\sigma_j}{\mu_j}$ is given from the coefficient of variation of X_j

$w_j^{(b)} = 1 - \frac{\sum_{l \neq j} \rho(X_j, X_l)}{\sum_{l=1}^{k} \rho(X_j, X_l)}$ is given from the complement to one of the ratio between the sum of all correlation coefficients, left out the j array, and the whole sum of correlation coefficients referring to X_j.

4.2 The Result of the Fuzzy Approach

The TFR method has been applied to the values of the described sets of indicators in paragraph 2. From this application we derive average values of ownership functions $g(x_{ij})$ and the corresponding weights w_j (Table 2).

The value of weights w_j according to the basic method, varies according to the degree of importance in determining the level of poverty. Taking for example the set of indexes of housing difficulty, since there is more property with heating than property with parking place, it is appropriate to give a more important weight for the first indicator ($w_i = 2.045$), than for the second one ($w_i = 0.739$), because it is supposed that the

Table 2. Results from the TFR method as regards repartition function and corresponding indexes

Measure of poverty	$\overline{g(x_j)}$	Weighting system w_j (2)	New weighting system w_j (3)
Social difficulty:			
Index 1	0.578	0.548	0.208
Index 2	0.354	1.040	0.351
Index 3	0.348	1.055	0.209
Housing difficulty:			
Index 4	0.431	0.842	0.486
Index 5	0.258	1.354	0.508
Index 6	0.129	2.045	0.821
Index 7	0.478	0.739	0. 903

Source: Our elaboration of the data from the Population and Housing Census, 2001.

Table 3. Composition of absolute values and percentage values of the census sections for conditions of poverty in 2001

	Absolute values		Percentage values	
Fuzzy Value	Social difficulty	Housing difficulty	Social difficulty	Housing difficulty
0.0 ┤0.2	583	643	44%	49%
0.2 ┤0.4	49	361	4%	27%
0.4 ┤0.6	370	145	28%	11%
0.6 ┤0.8	6	73	1%	6%
0.8 ┤1.0	304	90	23%	7%
Total	1,312	1,312	100	100

Source: Our elaboration of the data from the Population and Housing Census, 2001.

more widespread positive condition identifies a more discriminating factor when the same condition is not verified in determining estate poverty. Notice that in the new system of weighting the definition of the level of poverty is less discriminating than the former approach both for social and housing difficulty.

As regards the distribution of results deriving from the analysis of 1,312 census sections, the more fuzziness is closer to 1, this identifies the condition of social and housing difficulty; on the contrary, the more fuzziness is closer to 0 the more the value identifies the condition of social and residential welfare (Table 3).

Regarding to the set of *social difficulty indexes*, 23% of observed census sections show fuzzy values in the range (0.8-1.0), representing a clear condition of poverty, counterbalanced to 44% of census sections belonging to fuzzy cluster of non-poor, identified by the range (0.0-0.2).

The extreme conditions of *housing difficulty* are less widespread: more specifically, 7% of observed sections belong to the range (0.8-1.0), representing the condition of unquestionable poverty, and 49% of the observed sections belong to the range (0.0-0.2), representing the non-poor.

5 The Identification of Hot Spots of Social and Housing Difficulty

5.1 The Clustering of Social Difficulty

As reported above, the core question of this paper derives from the need to identify hot spots presenting conditions of social and housing difficulty in the urban area of Bari, on the basis of data emerging from a set of indicators. With the use of the SaTScan method a possible identification of hot spots of discomfort has been obtained from the data generated by a fuzzy analysis starting from two sets of indicators (the first for social character, the second for residential character of difficulty).

The use of SaTScan on variables referring to *social difficulty*, from the TFR method, leads to the zoning of hot spots representing extreme poverty areas. In detail we have identified four clusters, composed of a different number of census sections, for a total number of 491, where the identification of difficulty is given by the mean inside; the higher the mean value, the higher is the level of poverty. A further aspect of interest is given by the *p*-value, which is the probability of the critical region of the test, where the lower the values shown, the better defined is the cluster (Table 4).

Table 4. Composition and description of cluster referring to social difficulty sets

Cluster	Number of cases	Mean inside	Mean outside	Standard deviation	p-value
1	8	0.92	0.39	0.33	0.0620
2	64	0.76	0.38	0.33	0.0010
3	268	0.62	0.34	0.32	0.0010
4	151	0.59	0.37	0.33	0.0010
Total	491				

The interpretation of data analysis shows that the value of mean inside (included in the interval 0 - 1, that is to say "no poverty - definite poverty") are very high. Optimal values are shown also by p-values of the four clusters.

The four clusters are shown on a map by grey shades ranging from maximum social difficulty (the darkest grey) to minimum social difficulty (the lightest grey) so that the represented reality is immediately understandable (Figure 1).

The dark shades denote a more depressed condition, located in such peripheral areas that can be defined "central peripheries" (Pace 2006) identified by the central popular quarters of the past. The first risk area for poverty (mean inside 0.92) is identifiable in a part of the Madonnella Quarter, where there is a public housing estate (The "Duca degli Abruzzi" Estate). The second area (mean inside 0.76) is represented by the historic mediaeval town centre called San Nicola, that is still characterised by phenomena of social marginalisation. The third cluster is composed of the largest number of sections (268, with a mean inside corresponding to 0.62), represented by central peripheries of the past, like Libertà, and popular peripheries of the 1960s (San Girolamo, San Paolo) or outlying neighbourhoods, like Palese, that have been less interested by urban renewal (Rotondo and Selicato 2006).

The situation of the fourth group (mean inside 0.59) is represented again by three neighbourhoods that have been neglected by urban policies of renewal, in spite of the presence of a large number of public housing estates.

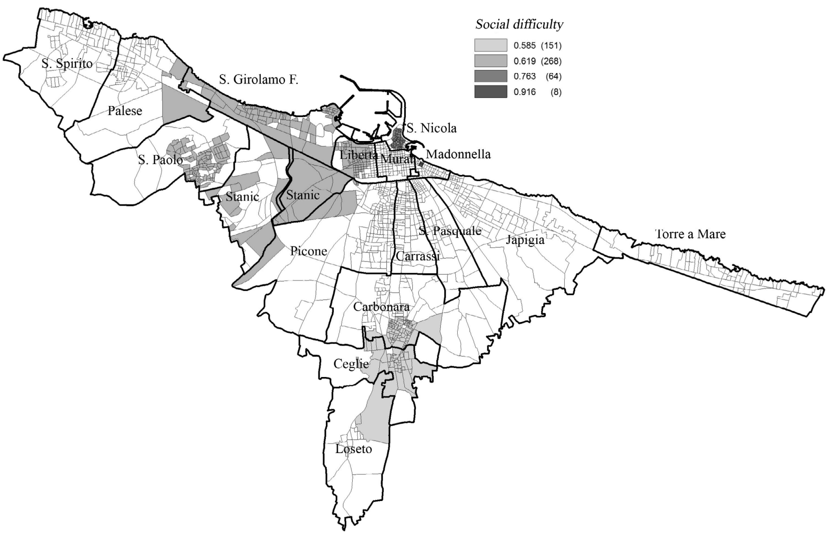

Fig. 1. Geographical representation of hot spots of social difficulty in the City of Bari

5.2 The Clustering of Housing Difficulty

The individuation of hot spots of *housing difficulty* shows a higher level of selectivity than social discomfort. The four identified clusters (Table 5) consist on a total of 286 census sections. Among the four clusters, the first and the third are mainly discriminating, since the second and the fourth cluster, although they show high values of means inside, have a high *p*-value (about 0.5).

Table 5. Composition and description of cluster referring to the set of housing difficulty

Cluster	Number of cases	Mean inside	Mean outside	Standard deviation	p-value
1	65	0.71	0.24	0.23	0.0010
2	8	0.64	0.26	0.25	0.5150
3	129	0.46	0.24	0.24	0.0001
4	84	0.38	0.26	0.25	0.5500
Total	286				

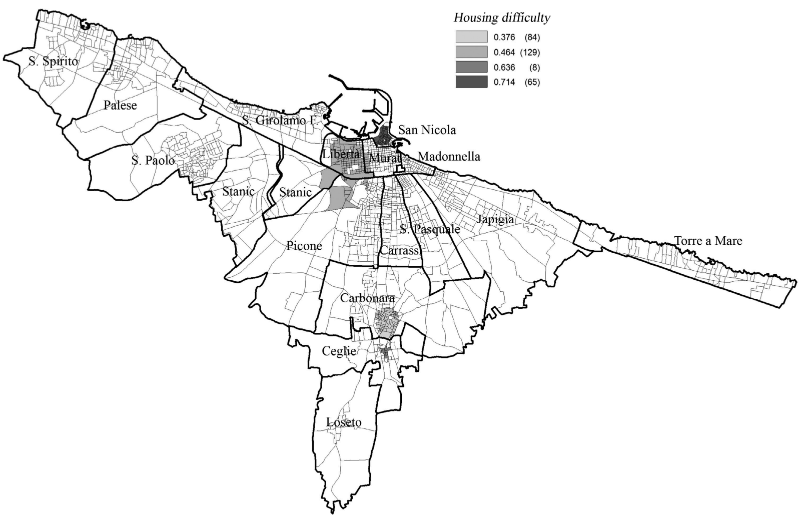

Fig. 2. Geographical representation of hot spots of housing difficulty in the City of Bari

As regards the spatial mapping (Figure 2), the darkest grey areas represent the highest level of housing difficulty, and include the old town centre of San Nicola (mean inside 0.71), and a piece of Ceglie (mean inside 0.64).

The secondary cluster (characterised by high mean inside and high *p*-value), identify as areas with housing problems Libertà, Stanic and Picone areas (129 census sections, mean equal to 0.46) and Carbonara (84 census sections, mean equal to 0.38).

6 Interpreting Housing Difficulty in the Light of the Property Values in the Real Estate Market

6.1 Housing Market Segmentation and Multidimensional Ranking

The fuzzy analysis carried out on the Census Sections utilizes a wide number of spatial elements in the light of selected clusters according to an appropriate statistical identification. At the urban level, at least two further levels of spatial classification exist, which can be helpful to describe a relationship between the urban poverty and spatial-physical attributes of the urban estates. The first one corresponds to the division of the city in quarters and neighbourhoods, which are the result of the urban development during the time. The second one is the classification of the real estates, in the light of their owning to a cluster of the housing market, according to those socio-economic (Bayliss 1968), architectural, spatial and situational (Rosen 1977) attributes that generate their market value. Urban poverty in this case could represent an indirect way to identify urban areas characterized by low-price housing estate. This relationship considers that the availability of high-price estate is obviously limited for poor.

Property value is added according to the supposition that the value of a dwelling represents the greatest indicator of limitation in terms of market availability to residential services. Indeed, this addition is the basis for the shift in the geographical dimension of the analysis from census sections to localities.

The quality of residential services, and consequently the price, is further associated with physical aspects and external quality, in addition to recognisable aspects of the social context which may be aligned with the significance of intrinsic relative and variable marginal prices which appreciate according to the social and environmental context.

A main difficulty is to make the spatial window referring to urban poverty corresponding with a well identified spatial contest, such as a quarter. Cities are historically subdivided in quarters that are not well bounded according to their physical characters, and the social status of its inhabitants. In this case the interesting question is about how to connect the urban and architectural characters of housing estate with the socio economical data deriving from the analysis of social and housing difficulty.

In our experiment, the attempt is to test the correspondence between a possible ranking of the urban quarters, in the light of their attributes of social and housing difficulty, with a market segmentation implicitly represented by estimated real estate values. The experiment has been carried out by the application of a fuzzy multicriterial ranking, with the consciousness that the spread of values in a quarter, as above reminded, is to be considered imperfectly bounded.

6.2 The Method for a Fuzzy Ranking of the Urban Quarters

The fuzzy multidimensional evaluation proposed by Munda (1995), involves the construction of a discrete evaluation with multiple criteria to which relative value judgements can be expressed through levels of verbal and quantitative grading.

The components of a discrete multi-criteria valuation can be described in the following way: E is a finite set of n elements; m is the number of different criteria considered relevant in an evaluation problem, where: the element X is assessed as preferable than Y (both belonging to the set E) according to the m-th point of view if $\mathrm{Rank}_m(X) > \mathrm{Rank}_m(Y)$, or, alternatively, the element X is assessed as indifferent respect to Y according to the m-th point of view if $\mathrm{Rank}_m(X) = \mathrm{Rank}_m(Y)$.

The rank of the m-th criterion Rank_m is expressed in our case by a quantitative intensity of preference g_m; therefore if $\mathrm{Rank}_m(X) > \mathrm{Rank}_m(Y)$, this means that:

$$g_m(X) - g_m(Y) > s \tag{4}$$

and, if $\text{Rank}_m(X) = \text{Rank}_m(Y)$, this means that:

$$g_m(X) - g_m(Y) \leq s \tag{5}$$

s is a positive number, the so-called "indifference threshold". This implies that a grey area exists in the interval $(0,s)$, where, in spite of a preference $g_m(X) > g_m(Y)$, we obtain as result of a pair wise comparison, the collocation in the same rank of two generic elements X and Y. This is the representation of non perfect transitivity of such kind of rankings, which was historically evidenced by Luce (1956).

In order to give a better definition of such area of indifference, some authors introduce the dual concept of "strong preference" and "weak preference" (Roy, 1985). The "strong preference" and "weak preference", are represented by a couple of thresholds of indifference, instead of one: in this case, if $\text{Rank}_m(X) > \text{Rank}_m(Y)$, this means that:

$$g_m(X) - g_m(Y) > s_1 + s_2 \tag{6}$$

or this can mean as well that:

$$g_m(X) - g_m(Y) > s_1 \tag{7}$$

In the first case we speak of "strong preference", represented by the overcoming of the sum of two thresholds (s_1 and s_2, representing the weak and strong preference thresholds); in the second, we speak of "weak preference" (s_1, representing only the weak preference threshold). The final result of the application is that in the two-level preference the intensity of preference g is associated to a pseudo-ranking of a set of element ordered by pseudo-criteria. We speak of pseudo-criteria to put on evidence that the ranking is affected by a special kind of uncertainty.

In a second step, other authors (Munda 1995) identify the possibility that the preference of an alternative with respect to another can be formulated through a fuzzy measure of the difference between the value judgements expressed for the alternative in question; leading to a quantitative transposition for the evaluation of credibility, or rather, the value of the function of the fuzzy membership.

In order to provide a further control of the stability of the ranking, it will be possible to assess the "semantic distance" (Munda 1995). The semantic distance has a general expression of which in our case we use an appropriate reduction.

Let's give a j-th quantitative criterion of a set of m criteria; let's suppose that $f_j(X)$ and $g_j(Y)$ represent the value functions of the criterion to express $\text{Rank}_j(X)$ and $\text{Rank}_j(Y)$.

In the most general case f_j and g_j can be crisp numbers (this means that the function gives a certain result), probabilistic values (this means that f_j and g_j represent expected values), or fuzzy numbers.

In this latter case (that is our case) we deal with fuzzy numbers represented by the area bordered by the function f_j and g_j (e.g. a left-right number could be related by a pseudo-Gaussian integral of value equal to 1), as the number "about 1800" and "about 2400", represented in Figure 3, that have a non empty intersection.

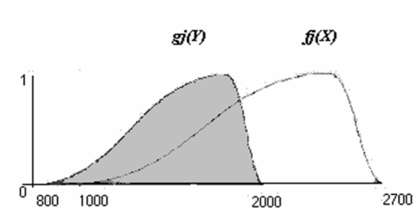

Fig. 3. The fuzzy numbers "about 1800" and "about 2400", has a non empty intersection

The fuzzy number and $g_j(1800)$="about 1800" has a domain of the ownership function corresponding to the interval (800, 2000), while the fuzzy number $f_j(2400)$="about 2400" has a domain of the ownership function corresponding to the interval (1000, 2700); the maximum value of "about 1800", that is 2000, is bigger than the minimum value than about 2400, that is 1000.

Table 6. Characteristics of fuzzy number "Real Estate Value" values (thousand of liras/m^2, year 2001) and stability indexes of the Neighborhoods of the city of Bari

Neighborhoods	*Property value, year 2001 (1000 Italian £/m2)*			*Average of stability index*
	Lowest	Peak	Highest	
Carbonara	800	1,800	2,000	0.72
Carrassi	1,000	2,400	2,700	0.64
Ceglie	900	1,300	2,000	0.74
Japigia	1,000	2,200	2,400	0.65
Libertà	1,300	1,800	2,800	0.66
Loseto	700	1,500	2,000	0.73
Madonnella	900	1,900	3,000	0.61
S.Girolamo	800	2,500	1,400	0.66
Murat	1,900	3,500	3,800	0.98
Palese	800	2,400	3,000	0.62
Picone	1,000	2,800	3,200	0.82
S.Nicola	700	1,100	1,500	0.88
S.Paolo	700	1,500	2,000	0.72
S.Pasquale	1,000	2,000	3,200	0.63
S.Spirito	800	2,500	3,000	0.58
Stanic	800	1,000	1,500	0.88
Torre a Mare	800	1,400	2,500	0.65

Source: Our elaboration of the data from Data of the Chamber of Commerce of Bari.

The “Semantic Distance”, in this case, is represented by the sum of two double integral:

$$S_d(f_j(x), g_j(y)) = \int_{-\infty}^{+\infty}\int_{X}^{+\infty} |Y - X| g_j(Y), f_j(X) dYdX + \int_{-\infty}^{+\infty}\int_{-\infty}^{X} |X - Y| f_j(X), g_j(Y) dYdX \qquad (8)$$

In case of empty intersection the hypothesis $f_j(X) < g_j(Y)$ is not proved, and the Semantic Distance is represented by $|\max(f_j(X)) - \max(g_j(Y))|$, that coincides with the expected value of $|X-Y|$ (Munda 2005).

Our multidimensional ranking is based on the calculation of the values of the fuzzy variable $\mu(X,Y)$ and of the semantic distance *Sd* for each couple of quarters, referring to each criterion of social/housing difficulty, and to the property value of housing estates.

Table 7. Expected value of the difference $f_j(X)$ - $g_j(Y)$ between neighborhoods according: $f_j(X)$ is the fuzzy number “real estate value” of *X* and $g_j(Y)$ is the fuzzy number “real estate value” of *Y* (thousand of liras/m^2, year 2001)

Y / X	Torre a Mare	Stanic	S.Spirito	S.Pasquale	S.Paolo	S.Nicola	Picone	Palese	Murat	S.Girolamo	Madonnella	Loseto	Libertà	Japigia	Ceglie	Carrassi
Carbonara	20	479	-458	-491	154	466	-825	-541	-1554	21	-362	154	-379	-341	179	-512
Carrassi	533	992	54	21	666	979	-312	-29	-1041	533	150	667	133	170	691	
Ceglie	-158	300	-637	-670	-24	287	-1004	-720	-1733	-158	-541	-24	-558	-520		
Japigia	362	820	-116	-150	495	-808	-483	-200	-1212	362	-20	495	-37			
Libertà	400	858	-79	-112	533	845	-445	-162	-1175	400	16	533				
Loseto	-133	324	-612	-645	0	312	-979	-695	-1708	-133	-516					
Madonnella	383	841	-95	-129	516	829	-462	-179	-1191	383						
S.Girolamo	0	458	-479	-512	133	445	-845	-562	-1575							
Murat	1575	2033	1095	1062	1708	2020	729	1012								
Palese	562	1020	83	50	695	1008	-283									
Picone	845	1304	366	333	979	1291										
S.Nicola	-445	12	-924	-958	-312											
S.Paolo	-133	324	-612	-645												
S.Pasquale	512	970	33													
S.Spirito	479	937														
Stanic	-458															

Source: Our elaboration of the data from Data of the Chamber of Commerce of Bari.

Table 8. Semantic distance between neighborhoods according to the criterion “real estate value” (thousand of liras/m2, year 2001)

Y	Torre a Mare	Stanic	S.Spirito	S.Pasquale	S.Paolo	S.Nicola	Picone	Palese	Murat	S.Girolamo	Madonnella	Loseto	Libertà	Japigia	Ceglie	Carrassi
X																
Carbonara	328	523	579	540	320	493	809	677	1582	328	464	320	395	429	316	557
Carrassi	655	1050	476	448	694	1004	531	501	1052	655	458	694	383	396	744	
Ceglie	348	326	742	695	270	329	1063	826	1762	348	595	270	558	583		
Japigia	500	860	450	420	543	833	572	489	1237	500	396	543	313			
Libertà	482	848	443	432	524	862	618	472	1224	482	404	524				
Loseto	339	401	722	648	310	383	979	711	1705	339	550					
Madonnella	533	866	534	486	569	871	660	558	1219	533						
S.Girolamo	384	471	644	611	333	488	943	724	1620							
Murat	1620	2080	1105	1132	1706	2035	785	977								
Palese	731	1118	520	500	730	1049	514									
Picone	952	1378	624	611	984	1319										
S.Nicola	478	161	974	989	379											
S.Paolo	339	401	722	648												
S.Pasquale	610	986	529													
S.Spirito	659	1023														
Stanic	478															

Source: Our elaboration of the data from Data of the Chamber of Commerce of Bari.

In the following tables the expected value of $f_j(X)$- $g_j(Y)$ (Table 7) the semantic distance *Sd(X,Y)* (Table 8), and the ratio between the absolute value of the expected value of $f_j(X)$- $g_j(Y)$ and the semantic distance *Sd(X,Y)* (Table 9) are represented as an example, as regards the criterion “real estate value”.

In our assessment the real estate value is a Left-Right fuzzy number, expressing the possible market price per square meter of the housing property.

Data are referring to the year of the last housing census (2001) and measured in the old monetary unit (thousand of liras per square meter, Table 6).

As above explained, a partial correspondence is supposed to exists between quarters and market segmentation, due to the partial homogeneity of urban and architectural characters of the context, together with the presence of available facilities inside the neighborhood.

If we suppose that the accessibility to the market is therefore partially identifiable with the love price, Table 7 evidence that quarters Loseto, Ceglie, San Nicola and

Table 9. Ratio between the expected value of the difference $f_j(X)$ - $g_j(Y)$ and semantic distance *Sd* according to the criterion “real estate value”

Y	Torre a Mare	Stanic	S.Spirito	S.Pasquale	S.Paolo	S.Nicola	Picone	Palese	Murat	S.Girolamo	Madonnella	Loseto	Libertà	Japigia	Ceglie	Carrassi
X																
Carbonara	.06	.92	.79	.91	.48	.95	1.02	.80	.98	.06	.78	.48	.96	.79	.57	.92
Carrassi	.81	.94	.11	.05	.96	.98	.59	.06	.99	.81	.33	.96	.35	.43	.93	
Ceglie	.45	.92	.86	.96	.09	.87	.94	.87	.98	.45	.91	.09	1.00	.89		
Japigia	.72	.95	.26	.36	.91	.97	.84	.41	.98	.72	.05	.91	.12			
Libertà	.83	1.01	.18	.26	1.02	.98	.72	.34	.96	.83	.04	1.02				
Loseto	.39	.81	.85	1.00	.00	.81	1.00	.98	1.00	.39	.94					
Madonnella	.72	.97	.18	.27	.91	.95	.70	.32	.98	.72						
S.Girolamo	.00	.97	.74	.84	.40	.91	.90	.78	.97							
Murat	.97	.98	.99	.94	1.00	.99	.93	1.04								
Palese	.77	.91	.16	.10	.95	.96	.55									
Picone	.89	.95	.59	.55	.99	.98										
S.Nicola	.93	.07	.95	.97	.82											
S.Paolo	.39	.81	.85	1.00												
S.Pasquale	.84	.98	.06													
S.Spirito	.73	.92														
Stanic	.96															

Source: Our elaboration of the data from Data of the Chamber of Commerce of Bari, year 2001.

Stanic shows frequently a negative difference of their expected value, while Murat usually prevails, evidencing the differences between its expected value and the values of other quarters is always positive.

The semantic distance is always positive, as shown in table 8. Therefore the ratio between the difference of expected values and the semantic distance is as well measured in absolute value.

In this case, as shown on Table 8, the ratio represents the degree of stability of the discriminating potential of real estate value differential among a quarters pair.

The stability is high when the value of the ratio approximates unity, while the more the ratio between expected value and semantic distance is far from unity, the more the stability is low.

The major stability is identifiable in quarters Stanic San Nicola and Murat. Those neighbourhoods show respectively the worst peak, the second worst peak and the best peak of the property value in their Left-Right ownership function above all (Table 6).

The correspondence between hot spots of difficulty appear to be realistically evidenced.

A possible interpretation seems to indicate pathways of further investigations. The first consideration is that a peripheral historic centre is evidenced in the city of Bari, at least according the condition of year 2001.

This frequent phenomenon accompanies the progressive marginality of residential historic centre not interested by gentrification (Fusco Girard and Forte 2001).

In fact as explained in the below pages the current condition of San Nicola Quarter seems to be quite different.

The second is that stability of demand/availability of housing property is more immediate in homogeneous physical/social context, having special identities. It is possible to affirm such consideration for all the three considered cases.

The third is that property values correspond pretty well with a measure of urban poverty or urban difficulty when the characters of property are homogeneous in an “a priori” defined context, as in the case of quarters.

7 Results for Urban Planning

7.1 Introduction

Using the SaTScan methodology to find the hot spots of social and housing hardship, provides certain considerations for future research in the social field and for urban planning of regeneration areas, now relevant in the European Union policies agenda.

Starting from information obtained by the cluster intersection of social and housing hardship, it could be possible to obtain useful indications for planning urban regeneration policies, making decisional process more transparent and scientifically supported.

7.2 Cluster Intersection of Social and Housing Hardship to Identify the “Target” Areas to Which Urban Regeneration Policy Should Be Directed

It could be obvious that social difficulty and housing physical degradation present some intersections, places where there are the highest relations between social and cultural characteristics of residents and their housing conditions. In the case study there are 195 Census sections (the darkest areas) in which there are a critical situation in terms of social and housing conditions, as shown in Figure 4. In the city of Bari there are three areas where urban poverty could be measured in both of its two principal facets of social difficulty and physical degradation. They are the old centre of the city, called “San Nicola”, and the two peripheral areas “Libertà” and “Carbonara”.

As represented in Figure 4, the emerging areas are very few. In these areas the urban poverty level measured in terms of social and housing difficulty is the highest.

The representation is clear and the smooth gradualism shown in Figures 1 and 2, mixed in Figure 4, expresses fairly small differences between different clusters, all characterised by a high level of social and housing difficulty (as shown by the mean inside values of Tables 4 and 5).

Comparing results with previous works (Perchinunno et al. 2008), where we used the same data but we have applied a fuzzy model to evaluate the urban poverty

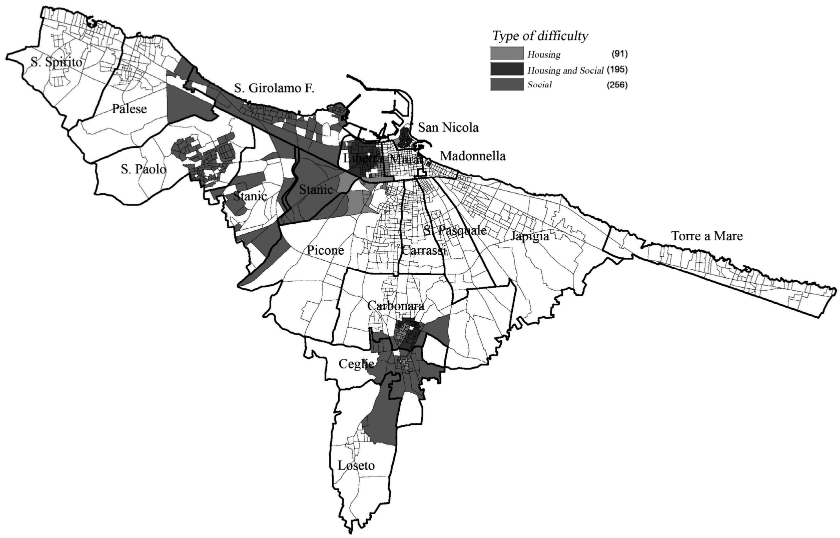

Fig. 4. Geographical distribution of social and housing difficulty hot spots, in the city of Bari. The darkest Census sections represent the Cluster intersection of social and housing hardship.

indexes distributed on the Census sections, the benefits of using the SaTScan model appear immediately. In fact, comparing the social and housing difficulty distribution obtained in the previous work with the same representation shown in Figures 1 and 2, we can see a better "resolution" of the urban poverty image achieved in a simpler way, highlighting immediately the more significant areas interested by the phenomenon.

7.3 Directions for Urban Regeneration Policies

The preliminary question leading towards the identification of town planning and architectonic solutions to the problem of urban regeneration, at a time when there is a lack of public resources for investment, focuses on the identification of areas with the highest level of urban poverty in order to direct the choices of political decision-makers in a transparent, well thought-out and objective manner.

The authors believe that the model used in this study is able to provide relevant data for the identification of such areas.

The present study provides certain considerations for the future. The first stems from the importance of in-depth research based on methods which privilege groups of indicators of a limited number, as demonstrated above. The effectiveness of such a method is to some degree demonstrated by the specific case which can only lead to the wish to widen the investigation. In future studies these indicators could be integrated with further relational elements of, for example, the availability of social services provision by the city council to families in need or the number of requests for support in rent payments for those most at need. This type of data is, however, available at a different level of aggregation from that analyzed here, being available by street and house number of requesting families rather than from ISTAT census sections and, therefore would need to be made homogenous with ISTAT data prior to use.

The second consideration regards the possibility of using this model as a form of evaluation “ex post” of the effectiveness of urban policy, to verify the consequences of urban regeneration on areas characterized by high levels of poverty, examining the nature of the variations measured according to the same statistical indicators used, between the Census period.

The most interesting case regards the San Nicola area, which has been the object of intervention as part of the URBAN programme, and has changed its appearance during the last six years (Gerundo 2000). The development process which that area has been involved in has, on the one hand, brought about new economic activity within the old town, but has also created relevant debate on the question of making a large differential in property between the nucleus and the edges of the area, and furthermore, on the reduction in its residential character, leading to a large-scale “gentrification” (Smith and Williams 2006). Likewise, it would be of similar interest and use as a form of evaluation “ex post” of the effectiveness of urban policy, to verify the consequences of urban regeneration on areas characterized by high levels of poverty, examining the nature of the variations measured according to the statistical indicators used.

Finally, it is useful to underlining the ease of reading information offered by the SaTScan model compared to different urban poverty models. As shown in this study, the model used has a great capacity of identifying the principal places of urban poverty, where the two types of social and housing difficulty have the highest values. In this way it offers a simple possibility to policy makers to localize places where to concentrate urban regeneration interventions, with a scientific selection of areas, useful to integrate the participation results.

In conclusion, the SaTScan model employed in this study would appear to be useful in the identification of what the European Union defines within the sphere of regional politics as the target areas for urban regeneration and focused urban planning programming to be supported with economic and financial resources, both public and private. The model appears to be of even more use through the application of further statistical indicators of poverty as have already been mentioned, providing further objectives for the development of the research in progress.

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The Town at the End of the Town: Integration and Segregation in Suburbia

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Abstract. The paper is concerned with a thematic issue, that is the segregation of social housing in urban peripheries, and with a methodological discussion, regarding the configurational approach to the analysis of urban settlements. Different techniques based on such method are here applied on social housing areas located in the edge of towns, in order to account for the effects of the configuration of the urban grid on their condition of segregation and marginality. The purpose is to test the configurational techniques on several case studies, so as to prove them as a reliable and useful tool to analyse and understand such areas, but, even more, to support town planning both in the project of new housing estates and in redeveloping and rehabilitating the diseased ones.

Keywords: Social housing segregation, configurational analysis, urban peripheries.

1 Introduction

The present paper can be assumed, as a matter of fact, both as a methodological treatment and as a thematic discussion. The specific theme is the edge of the urban settlements, with the widespread condition of disease and demotion we are so used to observe, and the attempt of finding a way for understanding, describing, and even measuring their actual level of segregation and marginality, in order to avoid the effects of periphery in new urban developments and to indicate guidelines in the efforts for rehabilitating the existing ones. The theme is anything but new and original, as it lasts since the beginning of urban growth and the appearance of the first effects of suburban sprawl; the edge of the growing settlements (generically and roughly defined as periphery) is the very issue in the urban debate of the last decades. Yet, we ought to admit that previous attempts in such sense have not provided significant results, as the periphery still remains the most neglected and suffering part of urban settlements, the focus of social, economic, environmental and architectural diseases. So far, the approach has been mostly qualitative, and it has gone mainly focusing on the morphological and aesthetical issues (the typology and shape of buildings, the condition of open space and urban furnishing, etc.), or on socio-economic aspects (the density and distribution of population, its social composition, etc.). On the other hand, the quantitative territorial models so far introduced and still frequently used typically present some grossness, which make them incapable to provide detailed results at a microscale level and to account for morphological aspects (Lee 1973). What nearly takes any attention on these areas away from town planning, committing it to other disciplines, such as economics, sociology, politics, criminology, and so on.

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On such bases, it's not possible to explain why some edge areas do remain peripheral even when are not exclusively inhabited by low social classes, or why such areas do frequently remain segregated (poorly attracting, lacking in appeal, actually marginal) even if they have been subjected to rehabilitation and local renewal plans, which operate on buildings and open spaces. In other words, what essentially seems still lacking is a commonly shared notion of periphery, based on unequivocal data, and recognized as univocally depending on objective elements: and all that requires a methodological change of view over the edge areas and, more in general, over the whole space of urban settlements.

The methodological issue does instead regard the way of working out the analysis of urban settlements, in that the edge areas will be analysed by means of configurational techniques that is by a different kind of approach based on the configurational theory. Just this kind of approach is here expected to give original and useful outcomes, so as to provide new and reliable tools for supporting the planners in the development and in the renewal of diseased peripheral areas.

The idea is that only if we focus the analysis on the configuration of the urban grid (that is on the relations which connect all the spatial elements of the settlements) we can somehow account for the effects that the urban space itself determines on the distribution of centrality from the inner core of the settlements towards its extreme edges. More in particular, such techniques are expected to allow to overcome the limits of the evaluations so far around the edge areas: to appraise the condition of periphery as a result of the configuration of the urban grid of the whole settlement, and not only on the base of social, economic and architectural elements, that here we are going to set aside: all in all, to appraise the periphery as a spatial pattern, deriving from the configuration of the urban grid. In other words, summing all up, the thesis is that the way the urban grid is arranged and its paths are disposed and mutually connected are rich in effects on the internal geography of the settlements, influencing both its material variables (the location of activities, the distribution of movements, etc.) and the immaterial ones (land values, attractiveness, etc.).

2 The Theme: The Social Housing in the Edge of Italian Towns

In the first postwar years, between 1945 and 1965, Italy had gone facing two different and hard problems: on the one hand, an extraordinary demand of low cost housing, due to the greatest urban migration Italy has ever known; on the other hand, a widespread condition of poverty, mainly due to very high unemployment rates. Those two problems were faced by a massive production of social housing, intended for the lower classes and financed by means of deductions from the regular pay of subordinate workers. Such effort had gone providing outstanding results, materialized in the construction of millions of cubic meters intended for social housing, widely spread all over the country, from the biggest cities to the smallest villages. The negative aspect with such an operation (or at least one of the most relevant) was that the need of control the expenditures (without worsening the intrinsic quality of buildings) induced to economize in land purchasing, hence pushing social housing towards the far edges of the settlements, into their growing suburbia. Consequently, the result of this strategy, though highly positive if referred to the problems it was called to resolve (quantity of built houses and employed workers), yet left all the Italian social housing areas (and, what's more negative, its inhabitants) segregated along the boundaries of the towns, in their extreme peripheries. That's the reason why in Italy the issue of urban peripheries does actually coincide with the issue of social housing, and at present the most dramatic cases of urban disease (the Zen in Palermo, Secondigliano in Naples, Corviale in Rome, just to name a few cases) once were actually welcomed as some of the most ambitious and illuminate social and architectural realizations. At a distance of over forty years from their birth and after their plainly recognized failure, generally those areas still present such features, despite lots of theoretical theses, projects and concrete renewal and rehabilitation interventions on buildings and spaces.

It's worth specifying that problems like that are not only Italian, and that several countries appear to share this singular coincidence of social housing estates and diseased peripheries: as a well known example, we cannot but mention the American case of Pruitt Igoe, in the edge of St. Louis, whose demolition in 1972 is still commonly identified as the epilogue of modern urbanism. This coincidence actually determines some noxious confusion, with social problems (in particular the homogeneous composition of inhabitant population, which reminds the image and the idea of modern social ghettos), environmental problems (in primis the lacking of amenities and public facilities), and architectural problems (enormous and anonymous buildings, designed according to tremendous typologies which do not facilitate social relation and human integration) which do mix each other, so as to compose the typical scenario of the diseased and segregated periphery: a dangerous no man's urban land, ugly and vague boundary between the town and the rural areas around. And that scenario often doesn't change, even if the social composition of the inhabitants gets modified and more variegated, even if schools, parking and green areas are worked out, even if different and smaller buildings are located beside the existing ones. A question does hence arise: what really is a periphery? Is there any element that concurs in making an urban area a peripheral one, other than the social, environmental and architectural issues? If we set aside all those aspect, the idea is that space actually does matter, and that the geometry and the morphology of the paths and the open spaces which compose the urban grid do influence the intrinsic geography of a settlement, providing a variegated distribution of the levels of centrality, as well as a distribution of the levels of periphery in the whole area of a settlement.

On such basis, we have decided to use the configurational techniques to analyse a wide selection of social housing areas, in order to find, in the results, recurring aspects as well as variable elements.

3 The Urban Space and the Configurational Approach

As we have underlined so far, the theme of urban diseased periphery is not new nor original; new and somehow original, instead, does actually appear the method for approaching the edge areas, analyzing them by means of configurational techniques; such techniques actually allow a different point of view over any urban phenomenon, assigning a primary relevance to the grid of the paths of the urban settlements. What exactly we need, in our attempt to analyse the geometry and the morphology of the peripheral areas.

The origins of configurational theory, as well as its genetic code, can be recognised in Hillier's preface to The Social Logic of Space, written in 1984 with Julienne Hanson: "*By giving shape and form to our material word, architecture structures the system of space in which we live and move. In that it does so, it has a direct relation – rather than a merely symbolic one – to social life, since it provides the material preconditions for the patterns of movement, encounter and avoidance which are the material realization – as well as sometimes the generator – of social relations*" (Hillier, Hanson 1984). Such an assertion defines the new notion of urban space, which is assumed as the primary element of urban processes, rather than the inert backdrop on which they occur.

The effect of such a radical change of view is worth highlighting and briefly discussing.

The importance of the spatial consistency of an urban settlement and its influence on the distribution of land use are certainly anything but new: since the first urban age, the location of the prominent activities was indicated by the geomorphological condition of the settlement, so that its inner geography was somehow influenced by its geometric pattern. From a sociologic point of view, such an influence was underlined by several authors, and among the others we ought to mention Hägerstrand and Giddens, and their assumption that spaces are not mere and inert containers of activities and functions, but that they interact with them and do influence the way they actually work and mutually interact (Hägerstrand 1975, Giddens 1984). The new element introduced by Hillier can be pointed out in the role configurational theory assigns the urban space, with regard to the urban phenomena, and, even more, in the actual possibility of measuring such effects by means of quantitative models.

The urban grid is then to be regarded as the primary element in the urban processes; such assumption, on its turn, is based on the fundamental hypothesis of the existence of "natural movement" (Hillier 1996a), that is defined as the portion of movement which is produced by the configuration of the grid itself. Therefore, it does not depend on the presence, on the position and on the consistency of the located activities, which obviously do attract movement thanks to their mutual interaction. In other words, within the movement along the paths of an urban grid we can distinguish a portion determined by the grid configuration (called natural movement) and a portion which is attracted and specifically connected to the presence of the located activities. This does not means that the natural movement will result bigger than the attracted one: in most cases, on the contrary, the attracted movement is fairly relevant, so as to be preponderant with respect to the natural portion. All the same, the natural movement still retains the role and the function of a primary factor in urban process, an interface between them and the paths of the grid. (Hillier et al. 1993).

In a configurational vision, we can associate the pattern of urban paths (that is the streets which compose the grid) to a distribution of natural movement which determines privileged locations (paths with higher densities of movement) and disadvantaged ones (where the movement flows are poorer). Activities which, in a free market, can select their position, will aim at locating in the most favourable places, in order to take benefit of denser flows and then intercept more people. On the other hand, such location will determine some further movement, attracted just by their presence; and this movement, on its turn, will determine a further positional advantage, making the appeal of those locations to increase and attracting other activities. This dynamics is evidently exponential: the more appealing locations attract activities, whose presence, on its turn, makes both movement and appeal to increase. Briefly, that allows recognising the located activities as the multiplying factor of the effect (movement) caused by the urban grid according to its configuration (Hillier et al. 1993).

On such basis, we can easily notice the potential of configurational models: by means of them, we can go back to the urban space, in terms of the way its blocks, its streets, its open spaces are morphologically shaped, elements of central importance, so as to recognise in its features the essential elements, or, at least, some of them, of the diseases of the peripheral areas. Even more, we could release the notion of urban periphery from the ambiguity of the several meanings, all negative, which are used to be referred to the urban edge: marginalization, segregation, lacking of facilities and amenities, social disease, architectonic uniformity, etc. On the contrary, we aim at defining the periphery as the result of a specific spatial pattern of an urban settlement: that means the periphery as a spatial pattern.

We can better understand this aspect if we conceptualise an urban grid as the factor that produces potential of movement. This potential can (or cannot) be actually realized according to the location of functions, buildings and facilities. In other words, the grid works as "*a mechanism for generating contacts*" (Hillier 1996b), therefore as aimed at optimise the movement and to maximise the interactions between couples of activities. Such contacts will result more frequent in specific areas (we call them central) and rarer in others (we call them marginal). We cannot exclude that the spatial vocation of any urban places will not be contradicted by the actual land use: for instance, shopping centres in segregated areas. Discordances between land use and configuration, or say between natural movement and attracted one, does not hence prove the lacking of influence of the grid on the urban phenomena. It rather shows the poor use of the potential movement economies the grid provides by means of its configuration, and that the configurational analysis can easily highlight (Hillier 1996b).

This paper will hence sketch the conceptual bases of the configurational approach and will discuss the main operational techniques so far introduced and their respective potential and limits; finally, going back to the theme of peripheral social housing, here we report the results of some significant applications on peripheral and segregated urban areas. The final aim is to pinpoint some recurring configurational aspects that appear to attest periphery not only as a social, morphologic and functional matter, but, prominently, a spatial pattern. This is what configurational techniques can help to analyse, to better understand and to manage.

4 The Configurational Approach: Conceptual Bases and Operational Techniques

We still ought to clear out how the consistency of the urban space has to be appreciated, or, in other words, which are the significant element with reference to the production of movement and to the location of activities. On this regard, the configurational theory is characterised by the strong relevance it assigns to the spatial relations between the parts of a settlement. More in detail, analysing the configuration of an urban grid means determining the spatial value which competes to each single element thanks to the spatial relation between it and the others. Strictly speaking, the measure of those relations will stand for the very configuration of the urban grid.

A small abstract example will certainly help the understanding this definition and the consequent kind of approach. Let us consider a minimal urban settlement, composed of 9 square elements, here represented in figure 1 as cells; in such representation, a "door" in the segment dividing two adjacent cells stands for the presence of an interaction between them. In order to determine the configurational state of the settlement, it is useful to represent it by means of a tree graph, transforming the spatial elements (the cells) into nodes and their relation, if existing, into arcs. Such representation makes clear the effects of a variation of the relations betweens cells which does not modify the morphological layout of the settlement. A similar transformation is represented in figure 2b, where the position of the cells remains unchanged while the mutual relations do vary.

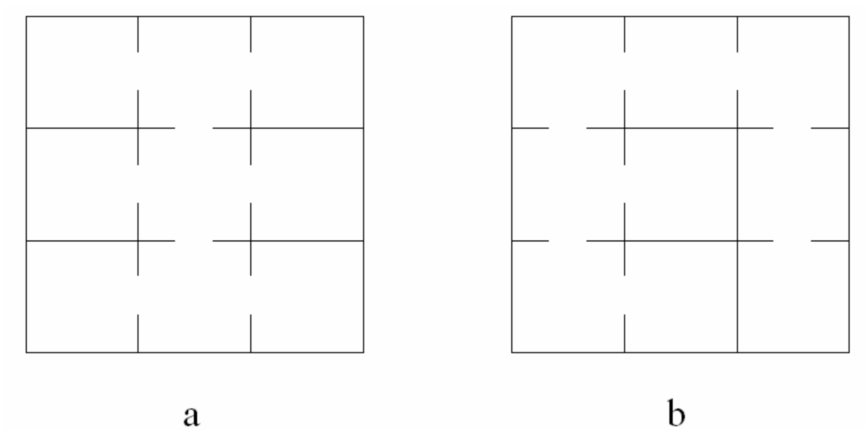

Fig. 1. Transformation of the spatial relations between urban elements. Planimetric cells layout.

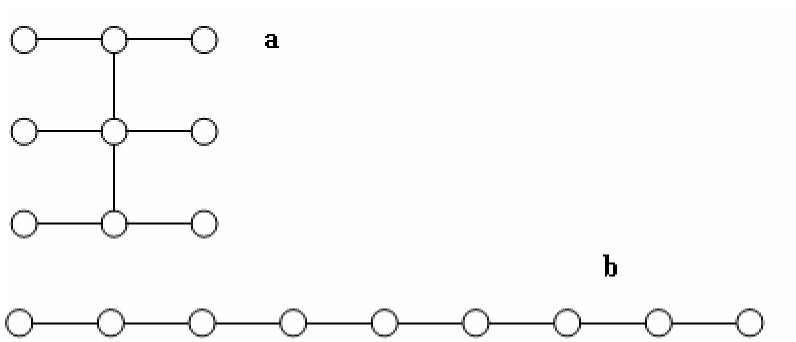

Fig. 2. Transformation of the spatial relations between elements. Representation by tree graphs.

Let us compare the two layouts above with their representations by means of tree graphs, in figure 2, which point out the radical transformation of the relations pattern of the settlement.

On such basis, the configurational analysis starts with applying a minimum paths algorithm to the graph; some elements will result on a larger number of paths, so as to stand for preferential locations, appealing for the activities which take benefit from a dense through movement. Other activities, like housing, prefer locations with poorer traffic flows and hence are likely to locate in the least used nodes of the graph.

Summing all up, we can point out four fundamental elements of the configurational theory:

- The prevalent (if not exclusive) interest towards the spatial relations between the parts of the grid.
- The assumption of the urban grid as the primary element of urban processes.
- The hypothesis of the existence of the natural movement, mere function of the grid configuration, as a link between the grid itself and the activities location.
- The essential role the visual perception assumes in the relation between the grid elements.

For what concerns the grid, two aspects are still to be cleared and specified. First, the way the urban grid is to be discretised, so that its continue space gets transformed in a set of discrete elements, connected by a mutual relation. Such operation will allow a systemic approach to the space of the settlement and associate to each single elements a set of state variables. Second, we ought to define these configurational indices as the quantitative parameters able to describe the configurational features of the elements. By their means we will be able to build a hierarchy of those elements according to their respective capability in attracting movement (and hence activities) thanks to their spatial configuration.

On this regard, the configurational theory is far from appearing unitary and monolithic. Several different approaches have been so far arising, and, summarily, they may be referred to two different ways of analysing the urban space, that is the so-called *Linear Analysis* and the *Visibility Graph Analysis*. On the one hand, those methods share the fundamental bases of the configurational theory (here briefly sketched); on the other hand, the specific way of reducing the urban space into a system appears as the essential distinctive element (Hillier and Hanson 1984, Turner et al. 2001).

4.1 Operational Techniques: The Linear Analysis

Two main operational techniques appear to refer to the *linear analysis*: the *axial analysis* and the *angular* one. The axial analysis is based on the assumption of the line as the fundamental element in the perception of the urban space: an observer perceives it by means of his own viewsheds, which lead him and make him to move along the intermediate segments composing his path. On such basis, the line is assumed as the key element in the comprehension of phenomena depending on movement (Hillier and Hanson 1984).

Down to the facts, the axial analysis reduces the urban space into a system by means of the construction of the axial map, that is the complex of the longest and fewest segments which cover the whole grid, connecting its convex spaces (Hillier, Hanson, 1984). Since each convex space is composed of mutually visible points, the axial map can be regarded as the grid of the visual connection between the single perception unities of a settlement. The configurational indices of each line are determined computing the spatial relations between it and all the other lines of the system. The most significant parameter is the integration index, defined as the mean depth between the lines and all the other lines of the axial map.

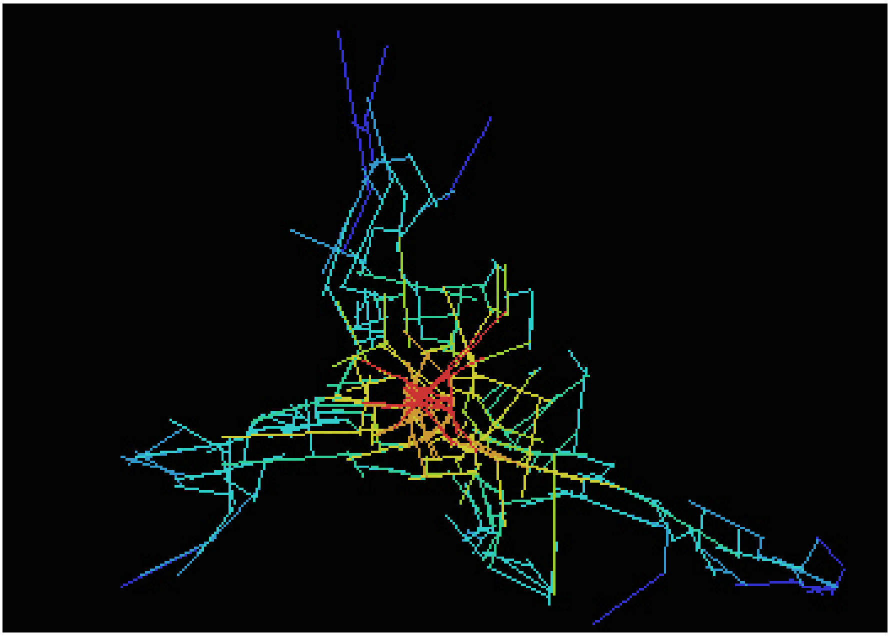

Fig. 3. Distribution of integration in the axial map of Siena

As an example, here we present in figure 3 the graphic representation of the results of the configurational analysis of Siena, showing the distribution of integration in the lines of its axial map.

4.2 Operational Techniques: The Angular Analysis

The *angular analysis* (Turner 2001a) can be said to recently derive from the axial analysis, importing into it the results of some studies of perception psychology (Sadalla and Montello 1989; Montello 1991). Based on the conviction that wide angle intersections appear less impedient than acute angle ones, the depth dividing a couple of lines is computed taking into account the angle of each intersection and measured providing them with different values according to it. Down to the facts, a turn with a 165° angle (and over, of course) is not appreciated as a turn and hence is not computed in the measure of the depth, and so on (Turner 2001a). Obviously, the difference in the results of the angular analysis with respect to the axial one will be expected wide as the wide (> 90°) intersections are actually frequent in the specific urban settlement, while the two different method are likely to provide similar results in most cases, where angles are generally around 90° wide. The technique is supported by the following analytic expression of the integration index:

$$Md_i^{\alpha} = \Sigma_{j\in V(L)}\, d_{ij}^{\ \alpha} / \Sigma_{k\in E(L)}\, w_k \qquad (1)$$

where $d_{ij}^{\ \alpha}$ is the angular depth between the lines i and j,, V(L) is the complex of all the lines of the axial map, E(L) is the complex of all the connections and w_k is the wiight (direct function of the intersection angle) of those connections.

4.3 Operational Techniques: The Visibility Graph Analysis

Around the last Nineties a new technique has gone arising from the common configurational root, the *Visibility Graph Analysis*. What strongly distinguishes the VGA from the other techniques is the radical different way of constructing the system; it derives from the urban grid covering its whole extension with a mesh of points, so as to obtain the so-called visibility graph (Batty 2001). The single element of the system is then the point, here called vertex, the relation between couple of vertices we have to assume is their mutual visual interaction (Turner et al., 2001), and their spatial impedance, or depth, is measured in the number of interposed vertices along their minimum connection path. The VGA contains several advantages with respect to the axial one.

First, an absolutely objective construction of the system, which derives from an automatic operation and doesn’t allow any choice: the only discretionary of the

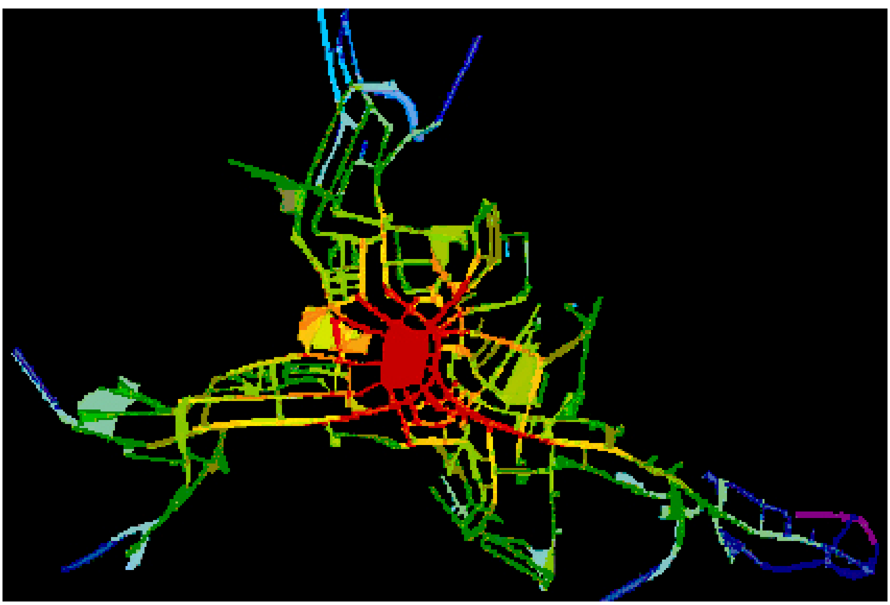

Fig. 4. Distribution of integration in the visibility graph of Siena

operator is the selection of the density of vertices, which is related to the width of the streets in order to cover their whole space. Besides, the variability of the configurational parameters of a single linear street, which can change continuously along its path. Moreover, the visibility graph analysis provides the distribution of the configurational parameters within a single wide open space (that is a square), so as to allow the evaluation of the configurational features of such urban elements. And finally, in that the vertices can be drawn out so dense as one prefers, at an infra-urban scale the technique, sensitive towards any detail, is available for analysing the morphology of small areas and the profile of blocks and buildings. Aiming at highlighting the most evident differences between the methods sketched above, here we present in figure 4 the distribution of the integration value in the vertices of the visibility graph of Siena, so as to compare it with the representation of figure 3.

4.4 Operational Techniques: Potential and Limits

So far, we have gone describing the techniques and the results, but, what's more important, their actual use and usefulness have not yet shown, and they are worth discussing.

All the methods sketched above provide the integration value as their most significant output variable.. Several studies of our did prove this parameter a reliable indicator of natural movement, in that the distribution of its value appears to correspond narrowly to the distribution of pedestrian movement (Cutini 1999a; Cutini 1999b). Successive researches (Cutini 2001a) attested that local configurational indices (such as radius 3 integration) can even better reproduce the distribution of movement at an infra-urban scale, within a whole limited urban area.

Moreover, other studies did show a correspondence like that existing between the integration value and the density of the located activities along the streets (Cutini 2000). On such basis, we are allowed to assert integration as a significant indicator of centrality, and in such sense we can even define it as a "pure accessibility" parameter; the attribute "pure" means that accessibility is here computed taking into account only the configuration of the grid, and not (as in traditional town planning models) the presence, the position and the consistency of the located activities.

It is worth specifying that not always the distribution of integration actually coincides with the distribution of movement and activities; that's to the presence of monopolistic activities (such as, for instance, public offices and facilities, monuments and amenities), which can be located setting aside the configurational pattern of the settlement, but obviously do attract movement and other activities (Bortoli and Cutini 2001).

All the same, the configurational techniques, by means of its integration value, can describe the pure accessibility, and then the "pure" distribution of centrality, that it their hypothetic distribution ceteris paribus; at the same time, we can easily understand that those techniques clearly point out the relevance of the monopolistic activities, and their role in deforming the configurational vocation of the grid. Beside, the location itself of the monopolistic activities can be used as a strategic tool, aimed at deforming the configuration centrality in order to enhance or just to modify the centrality of a portion of a settlement, making it to shift somewhere else in the urban area (Cutini 2001b).

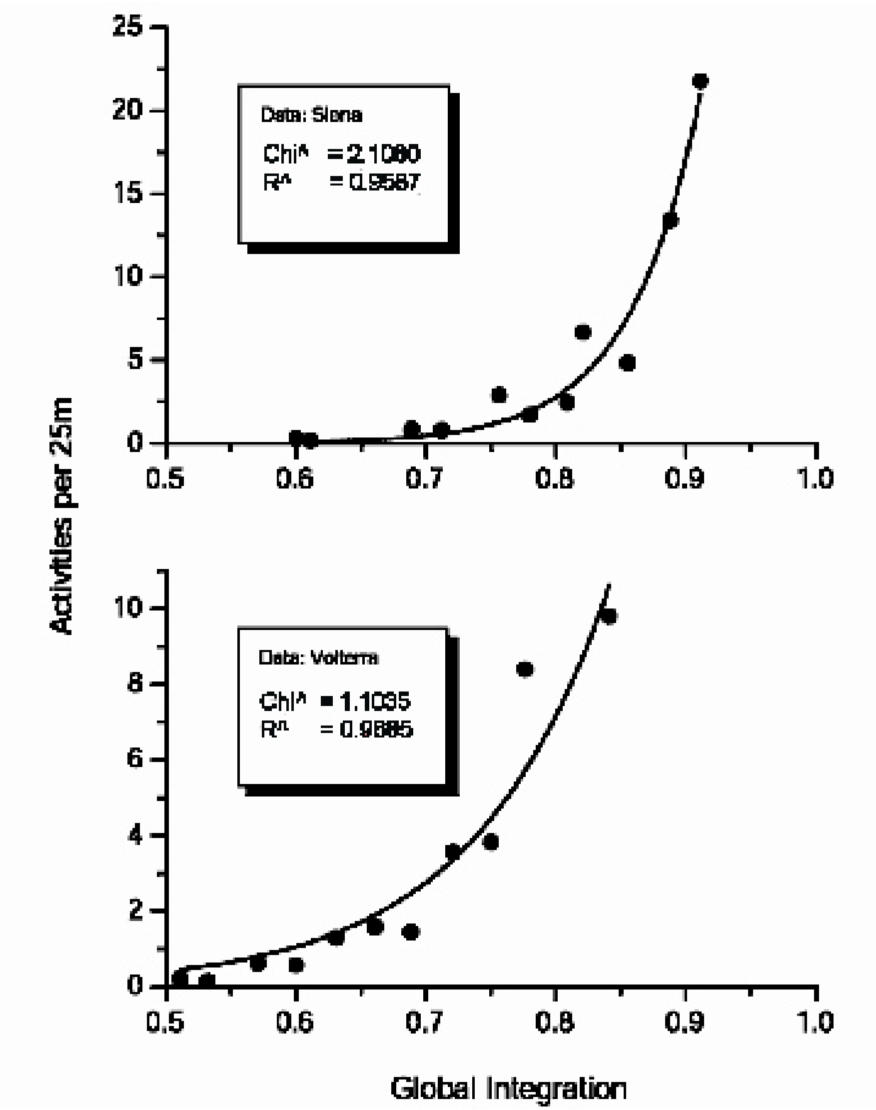

Fig. 5. Regression analysis between integration value and density of activities in the lines of the axial maps of the historic centres of Siena and Volterra

As an example of those studies, here we present in figure 5 the results of the correlation analysis of integration versus density of activities in the urban grids of the historic centres of Siena and Volterra; in those studies, the correlation of the configurational parameter versus the actual distribution of activities was proved so outstandingly narrow (in both cases R^2 well over 0.95) as to attest the reliability of the thesis at the basis of the configurational theory: the primary role of the urban grid on the making of urban phenomena.

With reference to the faults of the configurational techniques, that at present still do limit their actual use, in the exposition above we have shown how VGA allows to overcome some limits of the axial analysis. Yet, also the visibility graph analysis appears affected by some significant faults. First, there is not a univocal correspondence of the elements of the system (the vertices) with the elements of the grid (streets and other spaces). Besides, the dimension of the system (that is the visibility graph) is generally enormous, what makes it hard its processing, even by a powerful computer, and, even more, makes it difficult to export his results in an affective way, so that they can be read, interpreted, represented and used in other applications.

Aiming at overcoming these limits, in 2004 we have introduced a different technique, the Ma.P.P.A. (Mark Point Parameter Analysis), which stands on the same configurational bases of the others, but provides a different way of constructing the system: the Ma.P.P.A. system is composed of elements which consist in singular points (the mark points) spread all over the space of the grid, selected as follows (Cutini, Petri and Santucci 2004):

- Intersection points between a couple of streets;
- Central points of wide open spaces;
- Access point to wide open spaces;
- Maximum length points on a single linear street;
- Slope change points on a single linear street.

All these points can be easily recognised within an urban settlement, so as to provide a univocal correspondence between the elements of its actual grid and the derived system; but, what's more important, their definition allows to easily and automatically import them into the model from an existing GIS, taking any discretionary operation away from the construction of the system. In the same way, the results of the processing of the model can be exported, again easily and automatically, into a GIS; what evidently allows a better understanding of the results, their clearer representation and managing, and, above all, the possibility of using them as input variables of other models.

Furthermore, recent studies (Turner 2007) have introduced other indices, such as the betweenness centrality, in order to predict the distribution of movement by means of a metric approach.

5 Our Case Studies

The feature of configurational analysis makes its models capable to operate up to an infra-urban scale; this capability, as well as the possibility of taking into account morphological matters (the shape of blocks and buildings, the layout of streets and squares), allows them to overcome the traditional limits of quantitative urban modelling, and induces to experiment them on the most recurrent issues of the present debate. This research focuses on urban peripheries, assuming as case studies a set of development plans worked out around the edges of Leghorn, Grosseto and Pisa. As the essential criterion for the selection of the urban plans, we focused on the second half of XX century, and mainly on public housing plans. Such plans do generally result much more organically planned than private operations, so that it is easier to pacifically identify and circle them. Some of those urban contexts are well known for their bad urban quality and for their present condition of degrade (both urban and social). On the contrary, some others are commonly appreciated as nice and appealing urban areas. The thesis of the research is that some spatial features can account for the urban quality (good quality or bad one) of such areas, and hence that by configurational analysis it is possible to point out (identifying and measuring them) those spatial features. In other words, we could be able to identify the spatial features which determine the level of degrade of an urban area, so as to provide an indicator (or, better, several indicators) reproducing the level of marginality of a context. Even more, this thesis would open new ways for the definition of redevelopment plans, focused on the mitigation of the factors of marginalization which affect them. As we can easily observe in the following pictures (figures 6, 7 and 8), in all the selected urban cases the location of social housing estates in the postwar years was clearly oriented towards the far edges of towns, in order to save money and to preserve other more accessible locations for private housing development plans.

In Pisa, we have selected the housing areas called CEP, Gagno and I Passi, which are all located in the western and northern edges of the urban settlement. All these areas, worked out by public housing plans, were urbanized and built in the first postwar years; more in particular, CEP was worked out in the late Forties, and renewed in the following decades, while I Passi and Gagno date back to the first Sixties.

Similarly, in Leghorn we have selected the area named Corea and La Rosa, and respectively located in the north-eastern and in the south-eastern urban edge. Corea, well known and often criticised for its demoted and degraded condition, was urbanized in the late 40s, while La Rosa was built in the first Sixties. It's worth noticing that in the common sense the CEP and The La Rosa, despite their segregated position,

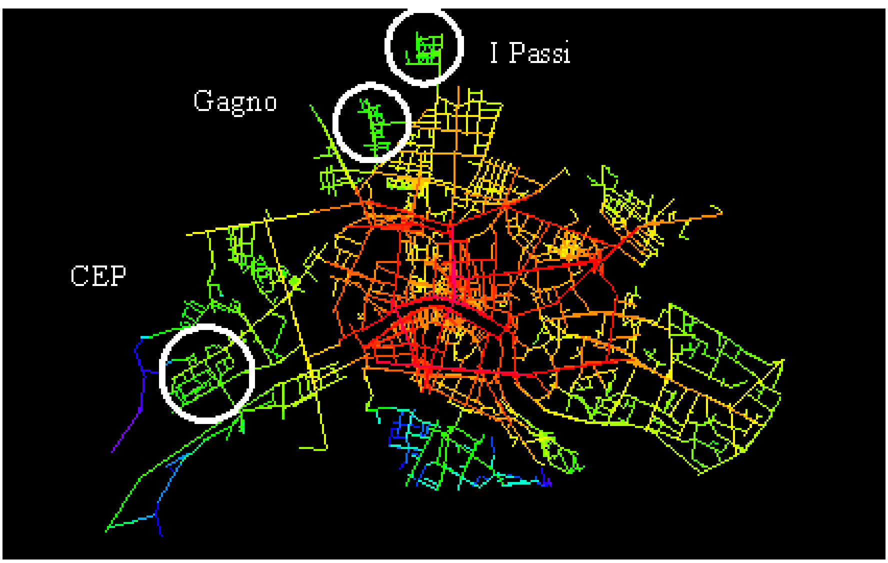

Fig. 6. Distribution of global integration in the lines of the axial map of Pisa; circles highlight the position of the selected public housing areas

are recognized as quite appealing urban residential areas, as it's proved by their rather high land values; the other areas, on the contrary, are commonly regarded as demoted areas, with poor economic values: around such areas in these last few years many redevelopment plans have been presented and discussed.

In Grosseto, our attention has been focused on the social housing estates of Barbanella and Gorarella, respectively located in the south-western and in the south-eastern edge of the settlement, and worked out in the first '50s and in the first Sixties by public housing plans.

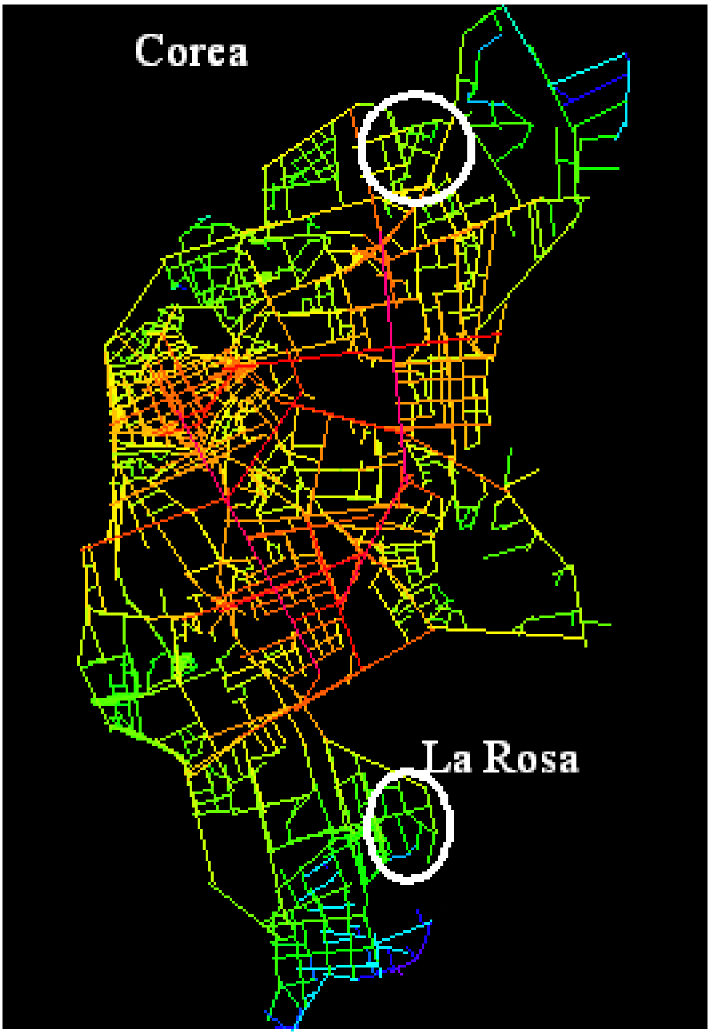

Fig. 7. Distribution of global integration in the lines of the axial map of Leghorn; circles highlight the position of the selected public housing areas

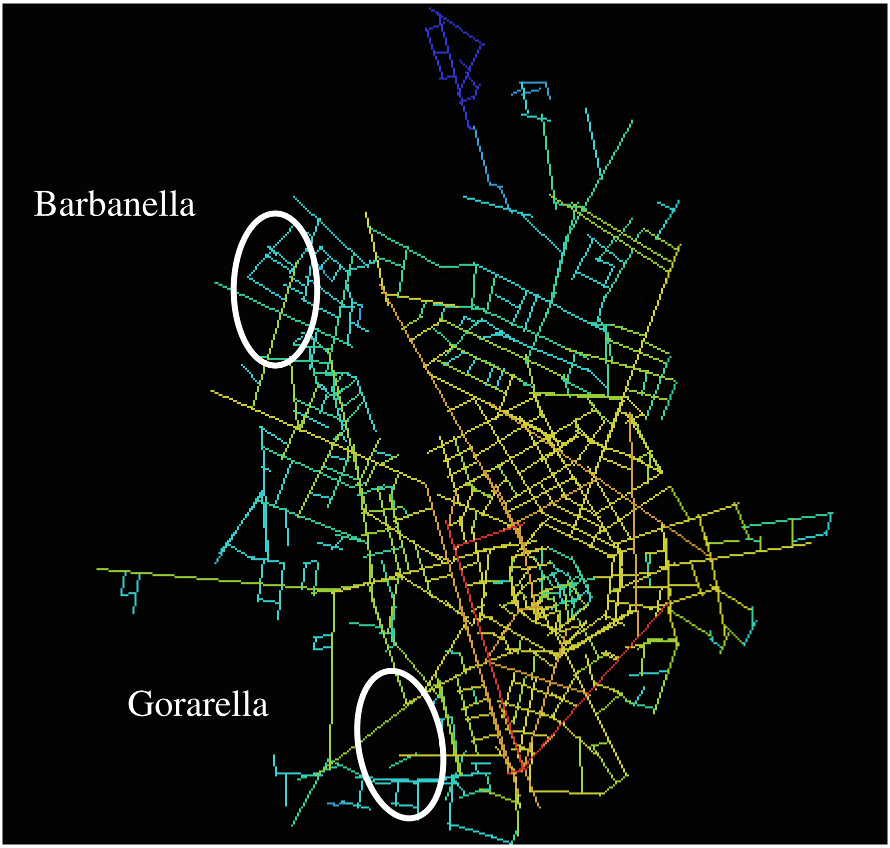

Fig. 8. Distribution of global integration in the lines of the axial map of Grosseto; circles highlight the position of the selected public housing areas

The configurational analysis of the settlements has been worked out by means of the axial analysis of the urban grids of Leghorn, Grosseto and Pisa, aimed at determining the distribution of the configurational parameters (especially the global and the local integration values) in the respective whole urban area. In figures 6 and 7 we respectively represent the distribution of the global integration value in the axial maps of Pisa, Leghorn and Grosseto, as well as the position of the selected public housing estates.

Later, locally and in a more detailed scale, we have focused on the seven selected areas, whose grid has been analysed by means of visibility graph analysis.

The results of the axial analysis on the whole urban grid of the three settlements show, in almost all the seven selected housing estates, areas characterized by poor global integration values. This parameter, which is particularly high in the central areas of Pisa, Grosseto and Leghorn, dramatically decreases as we go outward, around the edges of the settlements; more in detail, in the selected areas its value appears particularly poor. Only in the case of the Grosseto estate of Gorarella, the area is characterized by medium values of global integration. Yet, another significant aspect arises from the axial analysis: some of the most degraded areas (Gagno and I Passi at Pisa, Corea at Leghorn) are characterized by poor values of local integration too, while the others (CEP at Pisa and La Rosa at Leghorn) area characterized by the presence of a strong local integrator. On the contrary, at Grosseto, Barbanella is characterized by very low global integration values and by medium local integration ones. On the other side, in the Grosseto area of Gorarella we can observe medium values of both global (as we have mentioned above) and local integration.

Going to the urban microscale, analysed by means of VGA, the results are obviously much more detailed. In particular, it is worth noting that three of the four demoted areas (again Gagno and I Passi at Pisa, Corea at Leghorn) are characterized by two recurring configurational elements: the uniformity of poor values of local integration (as it appears shown in figures 9 and 10) and the poor values of the interaction index.

The other diseased area (Barbanella at Grosseto) takes its own marginality from the very low value of global integration, which makes it a strongly segregate area despite its medium level value of radius 3 integration.

Summing all up, the results of the experimentations on the selected case studies lead to identify the configurational state of the degraded and marginalised areas as characterized by the following elements: at the wider scale of the whole urban areas, poor values of global integration and absence of strong local integrators; at the smaller scale of each single local context, poor values of interaction and absence of a clear hierarchy of local integration.

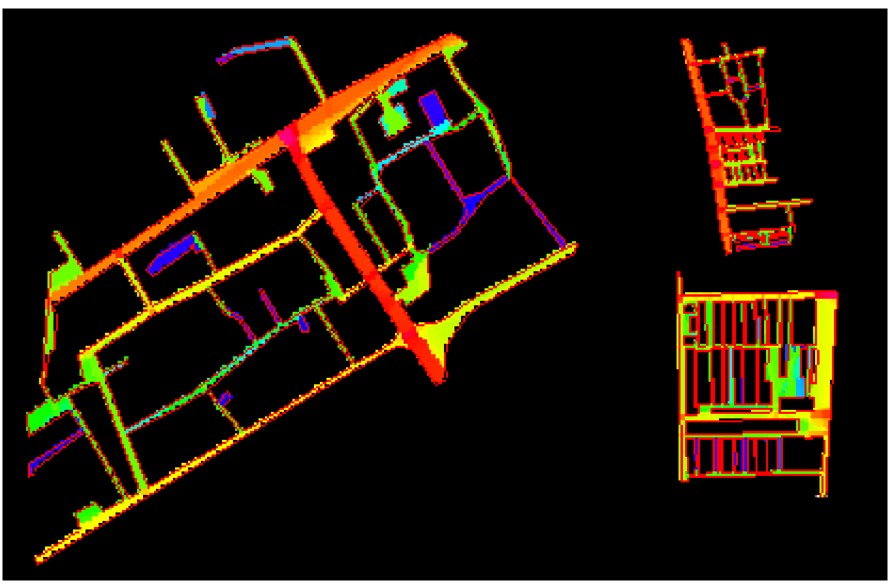

Fig. 9. Distribution of the local integration value in the visibility graph of CEP (on the left), Gagno (on the upper right) and I Passi (on the lower right)

Fig. 10. Distribution of the local integration value in the visibility graph of Corea (on the left) and La Rosa (on the right)

A brief analysis of such results is certainly needed. Obviously, we cannot but recognize such an analysis as merely qualitative, since we actually could not find any reliable quantitative indicator of the level of "periphery", except the rough and aleatory land values we have assumed at the local market; and hence we could not compare our configurational values with any other numeric index. Despite this undeniable limit, all the same some results do arise as clear and significant. First, the poor values of global integration is a typical configurational feature of the urban edge areas: since it is defined as pure accessibility (Cutini 2001b), the global integration does reproduce the distribution of centrality, translating into the configurational mode the mean value of spatial impedance with respect to the rest of the settlement. So, that result could be easily predicted. Far less predictable is, on the contrary, the absence of strong local integrators: in such diseased areas we do not find a local centre which can appear as an attractive places for commercial activities with a limited range. At the same time, those areas lack in urban spaces suitable for favouring interaction, meeting and encounter, which are generally characterized by high values of interaction index (Cutini 2003). Finally, the uniformity in the values of local integration describes a flat and disorienting scenario, characterized by the absence of an evident hierarchy among the paths: that is the typical scenario of an urban periphery, as we are used to know and as it is settled in the collective imagery.

At first glance, the results hence appear to confirm what we already knew. Nevertheless, the original and outstanding aspect with this result is that such scenario, so well known, does not derive from a discretionary reading of an urban settlement, but it rather arises from a quantitative and objective analysis, which could even be applied to planning hypotheses in order to simulate their effects and to avoid phenomena of segregation and marginality in the new development areas. Beside, the same results allow to propose some guidelines aimed at mitigating, by the planning of spaces, such aspects of marginality, i.e., increasing the level of global integration of the analysed areas, enhancing their accessibility; providing spaces with good values of local attractiveness, so as to be used as local centres; articulating the hierarchy of urban paths; introducing wide open spaces, suitably shaped, so as to favour the interaction of people. All these strategies, exclusively focused on the configuration of urban space, can be usefully taken, beside the more usual interventions on different (other than spatial) aspects. In particular, we refer to interventions on the functional pattern (integration of residential areas and economic activities, location of monopolistic activities, developments of parks and gardens, parking areas and other facilities, etc.) and on the social composition, such as the co-presence and the mutual interaction of different social classes. Such strategies and the configurational ones can usefully concur in managing (what fundamentally means improving) the segregated residential areas spread all over the edge of our settlements.

6 Conclusions

The different perspective offered by the configurational approach to the analysis of urban settlements does hence provide the expected results, even if some limits still remain, so as to call for further studies and developments. In general, this approach allows overcoming some typical limits of classic modelling, making possible to operate at a microterritorial scale, focusing on small infra-urban areas, and to account for morphological issues. More specifically, the assumption of the urban grid as the primary element in the making of urban phenomena allows appreciating the effects of the inner urban geography, both at global and local scale, on the actual condition of marginality and segregation of each analysed peripheral area. Besides, the operational models based on configurational theory are capable to provide quantitative results that can be easily used to reproduce the levels of marginality and to map their distribution all over the whole settlement. In such operation, the different configurational techniques so far introduced distinguish each other for their own specific advantages and faults, all them anyhow revealing capable to provide the main useful of the results of configurational analysis, that is the possibility of describing the distribution of centrality within an urban settlement from its inner core towards the extreme edges.

Down to the social housing areas, here assumed as our subject, the configurational techniques have been applied so as to identify, in the configurational variables, those which appear recurring in the degraded and segregated areas. The results appear significant and encouraging. They made us to define the configurational pattern of the analysed contexts, what allows a careful and detailed understanding of the actual causes of marginality of the segregated areas; and, even more, it provides planners and decision makers with tips and guidelines, in order to support the definition of the redevelopment plans of the degraded peripheral areas. The main fault with this study can be singled out in the merely qualitative character of the correlation analysis, depending on the lack of existing and reliable indicators of urban disease (socio-economic disease, as well as architectural and environmental one) in the selected areas, what undoubtedly weakens the significance of the correspondence with the numeric distribution of configurational parameters. In such lack we cannot but identify the opening of further developments of our research, whose results induce to expect as wide ranging and highly promising.

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Planning Evacuation by Means of a Multi-modal Mesoscopic Dynamic Traffic Simulation Model

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Abstract. In this paper analysis of a transportation system in emergency conditions due to an hazardous events is considered. To assess the effects on the transport network analysed, extension to a mesoscopic dynamic traffic assignment (DTA) model was developed in order to determine quantitative indicators for estimating the exposure component of total risk incurred by the transport networks in an area. In particular, the ability to allow for multi-modal (user) flows and network reliability was introduced. To give a practical example of the proposed model, it has been applied to a real case, studying evacuation in the hypothesis that in the event of a calamity, population in the area follows the instructions proposed by the municipal civil protection plan. The work shows that adequate quantitative methodologies based on a dynamic approach can be a useful tool to support the process of evacuation planning at several regional scales.

Keywords: disaster management, mesoscopic traffic assignment, evacuation.

1 Introduction

Few models have been specifically designed for emergency conditions in transportation systems developed since this task has received only marginal attention in the literature. Only specific aspects concerning large-scale emergencies are treated, such as the occurrence of a nuclear event (Goldblatt, 1993), urban systems on the occurrence of general hazards (Russo and Vitetta, 1996; Goldblatt, 2004) and buildings or transportation modes during fires (University of Maryland, 2005; Di Gangi et al., 2001; Galea, 2001; Vassalos et al., 2001).

Except for some very particular cases (e.g. CCPS, 1995), specific studies on the application of general risk theory in transportation systems have not yet been systematically carried out, and vulnerability and exposure concerning transportation systems are very often considered as similar entities; in other cases exposure variables are treated as vulnerability variables.

On the basis of definitions stated in a recent paper (Russo and Vitetta, 2004), system vulnerability can be defined as the resistance of infrastructures (material and non-material) when the emergency occurs. We are only dealing with resistance of infrastructures to the hazardous event and there is no dependence on demand since it is a supply characteristic. Vulnerability can be direct or induced: it is direct when it concerns resistance connected to the main event (e.g. the resistance of a bridge when a seismic event occurs); it is induced when it concerns resistance to events, possibly

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generated from the main one (e.g. the vulnerability of an area due to a discharge of hazardous goods from a vehicle travelling on a bridge during the hazardous event).

Exposure of a system can be defined as the equivalent homogeneous weighted value of people, goods and infrastructures affected during and after the event. By definition, exposure is a demand and demand/supply interaction characteristic. An example of exposure is number of people in the involved area who could die if not evacuated when a hazard occurs (e.g. with reference to the same example as above, exposure is also the value of the bridge and/or the buildings which collapse on road surface and also the number of people on the bridge or inside the buildings and who can be evacuated). According to these definitions, connectivity of two points in terms of topology or of free flow travel time can be used as a proxy indicator of vulnerability characteristic, since it does not depend on demand, while congested (true) travel time between two points in the considered area, as it results from a demand/supply interaction, can be used as a proxy indicator of exposure. In emergency conditions, congested travel time is completely different from free flow travel time and it is this congested time which has to be considered (Goldblatt and Weinisch, 2005). In order to verify the effects of an evacuation strategy, experimentation in a real system is very often conducted; although this approach yields results which closely approximate real conditions, it is expensive in terms of resources needed (money, organization and people involved). Moreover, modified scenario configurations cannot be implemented during experimentation and require new trials to be organized. Hence the use of simulation models in this case can be very helpful.

When an event occurs in a system or it is expected to happen in the short term, evacuation measures must be applied and in some cases have to be designed in real time. Models and algorithms specified and calibrated in ordinary conditions (Ben Akiva and Lerman, 1985, Sheffy, 1985; Train, 2003; Cascetta, 2001) cannot be directly applied in emergency conditions. Indeed, during the evacuation of an area, flow (and network) conditions are subjected to strong variations in time and a static approach does not allow a reliable representation of the dynamic evolution of demand profiles within a reference period; in this case an intra-period dynamic approach (within-day dynamics) is more suitable, since it can give a satisfactory representation of both over-saturation and queue formation and scattering phenomena; it can also take into account time variations in the configuration of supply.

Many studies (Ben Akiva, 1985; Friesz, 1985; Cascetta, 2001) highlighted the limits of static assignment models in analysing phenomena connected to temporal variations, in terms of both demand and supply, such as rising and scattering of queues due to temporary peaks of demand and/or capacity reductions of infrastructures. Thus, in order to comply with these phenomena, it is necessary either to use static models in pseudo-dynamic assignment procedures (Russo and Vitetta, 2000), or to remove intra-period stationarity hypothesis and choose within-day dynamic assignment models (Dynamic Traffic Assignment - DTA).

In general, a classification of DTA models can be made according to the representation of traffic variables (continuous or discrete) and on the aspect of the variables representing network performances (aggregate or disaggregate). So-called macroscopic models, or flow-based analytical models (Merchant and Nemhauser, 1978/a and 1978/b; Ben Akiva et al., 1984, 1986; Janson, 1991; Carey, 1992; Papageorgiou and Korsialos, 1998), simulate network performances by means of aggregate variables (speed, density, flow) with explicit capacity, as in static models, and use a continuous representation of traffic; generally, in formulating macroscopic models, fluid-dynamic analogies of traffic are adopted. A second type of models, named mesoscopic (or packet-based models: Smith and Van Vuren, 1993; Ben Akiva et al., 1994, 1997, 1998; Cascetta and Cantarella, 1991; Di Gangi, 1992, 1996), is similar to the previous one in the way it simulates network performances (aggregate variables with explicit capacity are used), but it differs in terms of traffic representation; the peculiarity of mesoscopic models consists in a discrete flow representation for groups of vehicles/users. A third type is made up by microscopic models, where individual trajectories of all vehicles are simulated by using disaggregate variables with implicit capacity, and a discrete traffic representation.

The dynamic assignment model developed in this paper is mesoscopic, i.e. flow characteristics depend on link conditions defined within discrete time intervals and time evolution of each vehicle's (or group of vehicles') movement is explicitly traced following some individual rules introduced; using this approach both evacuation time and temporal evolution of flow conditions can be evaluated. It is based on the model proposed by Cascetta and Cantarella (1991) and subsequent developements (Di Gangi et al., 2001; Di Gangi, 2002; Di Gangi and Velonà, 2003; Di Gangi et al., 2003): it consists of an evolution of the dynamic approach developed for evacuation purposes in the last two cited papers, presenting both multi-user and multi-modal features.

This paper is developed as follows: section 2 describes the formulation of the proposed model, where some specific issues on the formulation of path design problem within the general evacuation problem are reported; in section 3 an application, where the model is applied to simulate a stretch of a multi-modal transportation system, is conducted in order to show the sequence of operations performed by the model during simulation. Some conclusions and indications for research developments are then given in section 4.

2 Model Description

In this section features of DTA model introduced here are reported. The approach used refers to discrete time intervals, supposed of constant length (without any loss in terms of generality). Let δ be the length of the generic interval t and τ the current time within the interval, $\tau \in [0, \delta]$.

Outflow characteristics are calculated at the beginning of each interval and are assumed homogeneous along a link; for sufficiently short lengths of the interval, they can be considered approximately constant for the entire duration of the interval, avoiding the need to allow for the inner fixed point problem that would arise. Once outflow characteristics on links for a generic interval are known, movement of vehicles can be traced on the link, depending on the definitions of the link model and on the adopted movement rules described below.

2.1 Demand Model

Demand is described in terms of *travellers* (i.e. passengers) moving on the network using a *modal facility*; modal facilities sharing the same characteristics are grouped into a *class*. In other words, a *modal facility* defines a type of vehicle, and differences among vehicles of the same type are expressed by the definition of a *class*. As an example, considering two modal facilities, say car and bus, classes for car can be ‘fast car’ and ‘slow car’ while for bus they can be ‘small bus’ and ‘large bus’.

A set of modal facilities of the same class u departing at the same time η and following the same path k (and consequently related to the same origin/destination pair connected by path k) can be grouped together to form a *packet* $P \equiv \{\eta, k, u\}$ which represents a punctual entity moving on the network. Characteristics shared by each class of modal facility are expressed by means of parameters related to movement rules, occupancy, storage and grouping capability of the modal facility of the class; with reference to a class u of modal facilities, parameters used to define the class are:

- *Speed parameter* ζ_u: this represents the speed at which modal facilities belonging to class u move on the running segment of the link. The speed parameter is expressed relative to the speed of a reference class, that is the class which the adopted speed-density function is referred to.
- *Occupancy parameter* ξ_u: this indicates the occupancy rate of the modal facility which class u represents.
- *Equivalence parameter* ε_u: this indicates the equivalence, in terms of utilized arc capacity, between the modal facility that class u represents and a reference class, which is the one adopted as the unit in the definition of arc capacity.
- *Filling parameter* φ_u: this indicates the maximum number of travellers that can be accommodated by modal facilities belonging to class u. It is defined as an integer number.
- *Grouping parameter* γ_u: this indicates the maximum number of modal facilities of the class which can be grouped together to form a packet. It is defined as an integer number.

As an example of the meaning of parameters defined above, let us consider the two modal facilities (car and bus), and the two classes both for car (fast car, slow car) and bus (small bus, large bus) introduced above. This situation, using the notation defined above, can be reproduced by means of parameters shown in Table 1.

On interpreting values contained in the example of Table 1, it can be seen that modal facility (vehicle) belonging to class #1, which in this example represents the class

Table 1. Parameters of two exemplificative modal facilities

Modal facility	class U	ζ_u	ξ_u	ε_u	φ_u	γ_u
car	#1 - fast car	1.0	0.2	1	2	5
car	#2 – slow car	0.8	0.2	1	2	5
bus	#3 - small bus	0.75	0.12	2	18	2
bus	#4 - large bus	0.75	0.08	3.5	45	2

referred to by the speed-density function, has a lane occupancy of 0.2 veh/m, represents the unit used to express arc capacity, can contain a maximum of 2 passengers and can be grouped, together with other modal facilities of the same class sharing the same path and departure interval, in packets containing no more than 5 modal facilities (vehicles). Analogously, speed of class #4 is 75% of that computed for the reference class, has a lane occupancy of 0.08 veh/m, is equivalent to 3.5 cars for the evaluation of arc capacity, can contain a maximum of 45 passengers and can be grouped, together with other modal facilities of the class sharing the same path and departure interval, in packets containing at most 2 modal facilities (vehicles).

Hence, let $d_i(\eta, u)$ be the origin/destination demand flow made up by those travellers wishing to move between the *i*-th origin/destination (in the following o/d) pair departing at time η and using a modal facility belonging to class u; let $K(i, u)$ be the set of paths connecting the *i*-th o/d pair followed by the modal facility belonging to class u and let π_k be the choice probability associated to each path $k \in K(i, u)$. The number of packets $P \equiv \{\eta, k, u\}$ to be generated depends on demand flow $d_i(\eta, u)$, choice probability π_k, filling parameter φ_u and grouping parameter γ_u of class u. To simplify notation, from now onward the set $\{\eta, k, u\}$ identifying a packet will be implicit.

Packet P will then consist, at most, of a number $n_e(P) \leq \gamma_u$ of elements of modal facilities belonging to class u departing at time η following path k, each with a number $n_t(f) \leq \varphi_u \;\; \forall f=1,.., n_e(P)$ of travellers inside. The number $n_e(P)$ of elements of modal facilities composing a packet is considered integer and, after distributions due to path and departure time choice adopted models, demand flow conservation in terms of travellers, within each departure interval h, must be respected, i.e.:

$$\Sigma_{\eta\in h}\, \Sigma_{k\in K(i,u)}\, \Sigma_{f=1,\, n_e(P\equiv\{\eta,k,u\})}\, n_t(f) = d_i\,(h, u)$$

To respect this conservation condition, an appropriate repartition of possible discards obtained after the distribution of packets among paths and time must be carried out.

Packet P can consist of only one element of modal facility class u, that is $n_e(P) = 1$; in this case the number of generated packets coincides with the number of generated modal facilities (vehicles) belonging to class u.

2.2 Supply Model

2.2.1 Arc Model

The transport network is modelled by means of a graph $G(N, A)$, with N representing the set of nodes and A the set of arcs, where nodes generally represent junctions, whilst arcs represent road sections with homogeneous characteristics. In order to define performances associated to arc a of the graph, whose length is L_a, two arc segments are introduced, *running segment* and *queuing segment*, whose difference consists of the adopted outflow rule; in particular, running segment is crossed with a fixed speed, while in queuing segments a deterministic queuing approach is considered and outflow depends on the capacity of the final section of the arc. The edge between the two segments is located at a section S whose abscissa, x^S_a, can assume values between 0 and L_a, as shown in figure 1. Thus the *running segment* is the part of the arc with $x \in [0, x^S_a[$, while the *queuing segment* is the other part, with $x \in [x^S_a, L_a]$. The abscissa of section S is determined at the beginning of each evaluation interval and depends on outflow conditions, on links computed by means of the loading model, as described below.

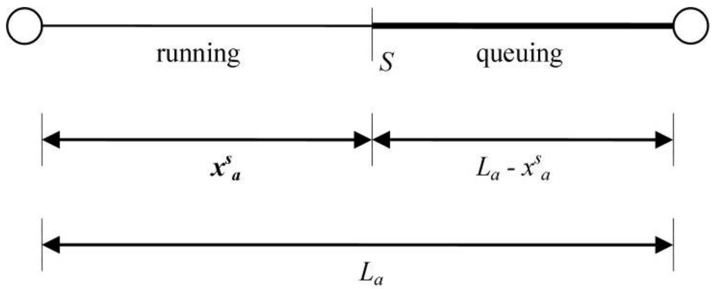

Fig. 1. Functional scheme of an arc

2.2.2 Arc Performance (Reliability)

In the event of evacuation, path evaluation should take into account the different kinds of vulnerability which can be related to each arc of the network in order to select, within a set of effective paths, those reducing the level of risk. In the present work this selection is done by modifying the valuation of generalised transport costs, so that conventional path search algorithms can be used (Di Gangi, 2006).

A *failure level indicator* (a probability value) $r_a \in [0,1]$ can be associated to each arc $a \in A$, depending on the vulnerability of the arc vis-à-vis, the occurrence of the hazard in question, and a *safe probability* s_a can be defined as $s_a = 1 - r_a$.

To allow for risk associated to an arc, its generalized cost (i.e. travel time) can be weighted by means of a factor w_a depending on *safe probability* which, for example, can be defined as:

$$w_a = \alpha\,[\ln(1/s_a)]^{\beta}$$

where α, β are parameters to be calibrated; in this particular example, parameter α can be used to take into account the nature of the hazard (i.e. in the case of a pollutant, for the same risk level associated to an arc, effects potentially produced depend on the type of contaminant).

2.3 Loading Model

2.3.1 Packet Movements

Let, at time τ of interval t, packet P leaving at time η of interval h [with $h \le t$; if $h = t$ then it is $\eta < \tau$] be represented on the graph by a point located at abscissa x of arc a belonging to path k. Let v_a^t be the current speed on the running segment of this arc during interval t, Q_a the capacity of the final section of the arc expressed in terms of the selected unit (capacity that could also depend on t) such that $1/Q_a$ is the service time and ρ^{a}_{max} the maximum density on the arc. Remembering the definition of δ as the time length of an interval, so that $\tau \in [0, \delta]$, referring to the arc model described above, if $x < x^{S}_{a}$, (point representing) packet P moves on the running segment at speed v_a^t and, within interval t, reaches at least abscissa x^{S}_{a} . Hence, the distance which can be covered on the running segment is given by: $min\{ x^{S}_{a} - x, (\delta - \tau)\cdot v_a^t \}$. If it occurs that $x^{S}_{a} - x < (\delta - \tau) \cdot v_a^t$, packet P enters the running segment of arc a, at time $\tau' = \tau + [(x^{S}_{a} - x) / v_a^t]$.

If $x \geq x^{S}_{a}$, packet P moves on the queuing segment; outflow on this segment is ruled by capacity of the final section of arc a. The queue length covered by packet P to the end of the interval is given by $\delta = [(\delta - \tau)\cdot Q_a] / \rho^{a}_{max}$. If $x + \delta > L_a$, then packet P exits arc a during interval t at time $\tau'' = \tau + [(L_a - x) \cdot \rho^{a}_{max}] / Q_a$.

2.3.2 Spill-Back Management

Once packet P reaches abscissa L_a, before the end of the interval (either $\tau'' < \delta$ if $x^{S}_{a} < L_a$ or $\tau' < \delta$ if $x^{S}_{a} = L_a$), then the length of the running segment of the arc a^+ following arc a on path k is not null, i.e. $x^{S}_{a+} > 0$. If this is true, packet P can enter arc a^+. Otherwise, it means that the whole length of arc a^+ is occupied by a queue and packet P remains on arc a until the queue length on arc a^+ is lower than the whole length of the arc, i.e. for all the time until condition $L_{a+} - x^{s}_{a+} < L_{a+} \rightarrow x^{s}_{a+} > 0$ occurs.

Behavioural operating conditions of the junction corresponding to the initial node of arc a^+ depend on the adopted implementation in terms of graph representation. As an example, refer to the simple case outlined in figure 2.

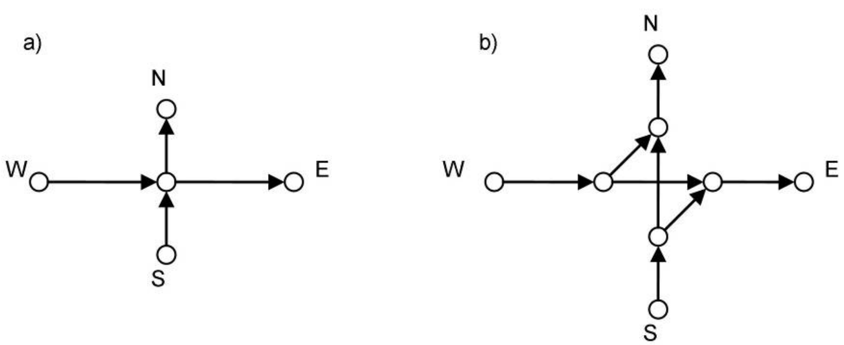

Fig. 2. Implementation of behavioural operative conditions of a junction by means of different graph representations

In this example, considering two different path flows, one following direction W-E and the other following direction S-N of the depicted intersection, using a simple graph implementation (a) spill-back of queue generated by path flow in direction W-E obstructs the intersection also for path flow in direction S-N, while the use of a graph implementation with the explicit representation of all the possible manoeuvres (b) keeps away from this occurrence.

2.3.3 Overtaking

Mesoscopic models do not need to satisfy any kind of FIFO constraints, since they are not based on a fluid approximation. Anyway, since the presence of the above-defined speed parameter in the model presented in this work introduces different flow rules for each class (modal facilities belonging to different classes may move on the same link with different speeds), the FIFO rule is respected among modal facilities belonging to the same class, since they have the same speed, while overtaking, within the running segment, may occur only between two modal facilities belonging to different classes.

Such a behavioural rule may be accepted in most cases (e.g. a link representing a motorway with 2 or more lanes), but there are some circumstances for which it is not acceptable (i.e. link representing a one-lane road section). In such cases it is possible to go beyond this drawback algorithmically, by explicitly defining the sequence of the operations to be conducted within the loading model.

In order for FIFO to be respected also by modal facilities belonging to different classes, the main rule is that packets belonging to different classes of modal facilities have to be moved starting from that belonging to class *u* with the lower value of speed parameter ζ_u and then moving packets belonging to other classes in increasing order of speed.

Let modal facilities classes be defined in terms of increasing order of speed ($\zeta_u > \zeta_{u-1}$) and let *P* be a packet made up by modal facilities belonging to class *u*. At a generic time, let packet *P* be on link *L(P)*; let *X(P)* be the abscissa of link *L(P)* where packet *P* is located and *T(P)* the time at which packet *P* entered link *L(P)*.

In general, as explained in section 2.3, a packet *P* entering link *a* at time τ can potentially cover a maximum distance x_{max} equal to the length of the running segment, that is $x_{max} = x^S_a$. If there is a packet *R* made up by modal facilities belonging to class *v* such that: $v = u - 1$; $L(R) = a$; $T(R) < \tau$, (i.e. on link *a* a packet *R* is located, made up by modal facilities belonging to class *v* with speed parameter lower than that of class *u* and entered on the link in a previous time with respect to time τ), then $x_{max} = X(R)$ and packet *P* moves following rules (speed) of its own class on the running segment of link *a* until abscissa x_{max} is reached, then packet *P* tags on behind packet *R* positioned on the link and which has exhausted its time to be moved for the present interval.

In general, packet *P* at time τ can potentially cover on the running segment of link *a* a maximum distance equal to:

$$d_{max} = x^S_a - X(P)$$

$$if\ \exists p : v < u\ ;\ L(R) = a;\ T(R) < \tau \rightarrow$$

$$\rightarrow d_{max} = min\ \{[x^S_a - X(P)], [X(R) - X(P)\ ]\}\quad \forall R: v< u\ ;\ L(R)=L(P);\ T(R)<T(P)$$

The value of the abscissa of the link which can be reached is given by:

$$y = min\ \{[x^S_a\ , X(R)\}\quad \forall R: v< u\ ;\ L(R)=L(P);\ T(R)<T(P)$$

and, if the value of the reachable abscissa within the residual time is greater than *y*, then:

$y \geq x^S_a \rightarrow$ packet P enters the queuing segment;
$y < x^S_a \rightarrow$ packet P tags on behind packet R positioned on the link that has no more residual time to be moved for the present interval; it reaches abscissa y and its residual time is set at zero.

2.3.4 Modal Change

Modal change consists in an operation that, if starting from a packet P made up by modal facilities belonging to class u, with a grouping parameter γ_u, it generates a set of packets R made up by modal facilities belonging to class v with a grouping parameter $\gamma_v < \gamma_u$ or, vice-versa, aggregates in a packet P made up by modal facilities belonging to class u with a grouping parameter γ_u, a set of packets R made up by modal facilities belonging to class v with a grouping parameter $\gamma_v < \gamma_u$. By definition both packets P and R share the same path k and departure time η.

Such an operation takes place by means of a *bi-modal arc*, introduced in the graph representing the network, where travellers, who can be defined as a modal facility belonging to class u which can be aggregated in a packet P, embark on (or disembark from) a modal facility belonging to class v that can be aggregated in a packet R.

Let us consider travellers as the modal facility belonging to class u, and small buses, as defined in Table 1, as the modal facility belonging to class v; let us also, for the sake of simplicity, group parameters $\gamma_v = \gamma_u = 1$; the two separate bi-modal arcs which can be defined represent either boarding or alighting operations at a bus stop (each operation must be represented by a separate arc), as schematically shown in figure 3. Following this example, in the case of boarding, a packet composed of one bus (since $\gamma_v = 1$) is generated once 18 packets composed of one traveller (since $\gamma_u = 1$) reach the arc; on the other hand, in the case of alighting, 18 packets composed of one traveller are generated once a packet composed of one bus reaches the arc.

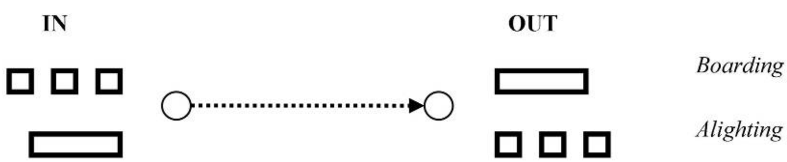

Fig. 3. Schematic example of operations carried out in a bi-modal arc

In general, in this type of arc, the entry of a packet P, made up by a number $n_e(P) \leq \gamma_u$ of elements of modal facilities belonging to class u, each with a number $n_t(f)$ $[f=1, n_e(P)] \leq c_u$ of travellers inside, is matched by the exit (at most) of a number γ_v / γ_u made up by a number $n_e(P) \leq \gamma_u$ of elements of modal facilities belonging to class u of packets R, each made up at most by γ_v modal facilities belonging to class v.

For the sake of simplicity, without any loss in terms of generality, let grouping parameters of packets be considered equal to 1 (i.e. each packet is made up by only one modal facility); in this case modal change rules depend on values assumed by filling parameters φ_u and φ_v of the modal facilities belonging to class u forming packet P and class v forming packet R, respectively, as described below.

If the $\varphi_u < \varphi_v$ operation corresponds to carrying out bunching, then a packet *R* is generated every $m = \varphi_v / \varphi_u$ packets *P*. Let $\tau_{m(u)}$ be the time at which the last of *m* packets made up by modal facilities belonging to class *u* enters the bi-modal arc. The time τ_v at which the packet made up by modal facilities belonging to class *v* generated by bunching the *m* packets exits the bi-modal arc is given by:

$$\tau_v = \tau_{m(u)} + \Delta t(u \rightarrow v)$$

where $\Delta t(u \rightarrow v)$ is the time corresponding to the current operation represented by packets bunching (referring to the example where class *u* represents travellers and class *v* buses, $\Delta t(u \rightarrow v)$ corresponds to the boarding time). Since an integer number of packets has to be generated, if the value of *m* is not integer, the number of packets made up by modal facilities belonging to class *u* needed to form a packet made up by modal facilities of class *v* is given by $m = INT\,[\varphi_v / \varphi_u]$.

If $\varphi_u > \varphi_v$ corresponds to carrying out a split-up, $m = \varphi_u / \varphi_v$ packets made up by modal facilities belonging to class *v* are generated for each packet made up by the modal facility belonging to class *u*. Let τ_u be the time at which packet of class *u* enters the arc, the time $\tau_{v(1)}$ at which the first of the *m* packets, made up by modal facilities of class *v* generated by splitting the entering packet made up by modal facilities of class *u*, is given by:

$$\tau_{v(1)} = \tau_u + \Delta t(u \rightarrow v)$$

where $\Delta t(u \rightarrow v)$ is the time corresponding to the current operation corresponding to packet splitting (referring to the example where class *u* represents buses and class *v* travellers, $\Delta t(u \rightarrow v)$ represents alighting time). Also in this case, splitting must generate an integer number of packets. Hence, if the value of *m* is not integer, the number of generated packets is given by $m = INT\,[\varphi_u / \varphi_v] + 1$.

In both cases conservation in filling level among source and generated packets must be respected, i.e. $\Sigma_{j=1,\, ne(Q)}\, n_t(j) = \Sigma_{i=1,\, ne(P)}\, n_t(i)$.

In the present model a peculiarity of bi-modal arcs is that one of the two considered modal facilities must be made up by travellers, which means that every modal change must pass through a pedestrian phase. Such a constraint can be relaxed by defining an appropriate cost function for $\Delta t(u \rightarrow v)$ expressing the time needed to operate modal change. Due to this specification, if a path contains more than one bi-modal arc, modal continuity must be assured within the path; this means that if *l* and *m* are two successive bi-modal arcs belonging to the same path, where *l* comes before *m* in the path (they must not necessarily be consecutive), and *u(i)* and *v(i)* are the classes of modal facilities of packets, respectively entering and exiting from generic arc *i*, then *v(l)* cannot be different from *u(m)*. This definition is necessary to assure that the fraction of path between arcs *l* and *m* is covered with packets made up by the same class of modal facility.

2.3.5 Flow Estimation

In general, considering multi-modal assignment models, both flows of passengers using different modes and corresponding vehicle flows should be specified by introducing, with reference to each arc, a couple of vehicle and passenger flow variables for each mode (Cascetta, 2006). Under some particular hypotheses adopted in practice, it is sufficient to consider only passenger flows; in particular it is assumed that vehicle flows of individual modes are linearly related to passengers by means of an occupation rate and, considering transit flows, they are predetermined (obtained by the scheduled service) and expressed in car-equivalent. Both of these components concur in determining costs on the arc.

It is simple to introduce multi-class (e.g. informed vs. non-informed traveller) by introducing a set of behavioural parameters in the definition of modal facility.

Within the proposed model it is possible to explicitly consider both the flows of passengers using different modes and corresponding vehicle flows only by examining packets crossing a specific section of the arc within a reference interval. Indeed, by identifying the class and value of actual filling it is possible to know both modal and passenger flow. Moreover, mode facility cannot be overloaded since, by construction, a new element is generated once the maximum number of accepted travellers (defined by the filling parameter) is reached.

Also, in the present model it is not necessary to introduce a car-equivalency for different classes of modal facilities since the contribution of each class in terms of occupancy (linearly or on the surface) is explicitly defined.

3 Experimentation

The application of the proposed model was made taking advantage of a real experiment in the urban area of Melito Porto Salvo in the province of Reggio Calabria (Italy), in relation to a research project, organized by the LAST - Laboratory for Transport Systems Analysis and funded by the Calabria Regional Authority (EU Structural Funds 2000-2006), named SICURO. The study area is 42990 m^2 and was subdivided into 11 traffic zones, which included 23 residential buildings, 1 school, 1 town hall, 1 court, 3 public facilities and 28 mixed buildings. Data were recorded and developed by laboratory analysis. During the experiment, information was collected with manual/automatic tools, 30 video cameras and by interviewing evacuees.

For the application of the proposed procedure, the considered building consists of a primary school located within the CBD area selected for the drill. The school has its own evacuation plan which, for the sake of this drill, was correlated to the evacuation plan of the whole town. The school evacuation plan stipulates that everybody must gather at a site in front of the building (below called *first assembly point*); according to the town evacuation plan, the school's staff and pupils will be led to the safe place on a bus service, starting from another gathering place (below, *second assembly point*) which must be reached in order to completely evacuate the area (see figure 4).

Hence, evacuation of the school was schematized in the following five main phases:

1. evacuation of the building reaching first assembly point;
2. roll-call of pupils at first assembly point;
3. transfer to second assembly point;
4. boarding on bus.
5. transfer to refuge area.

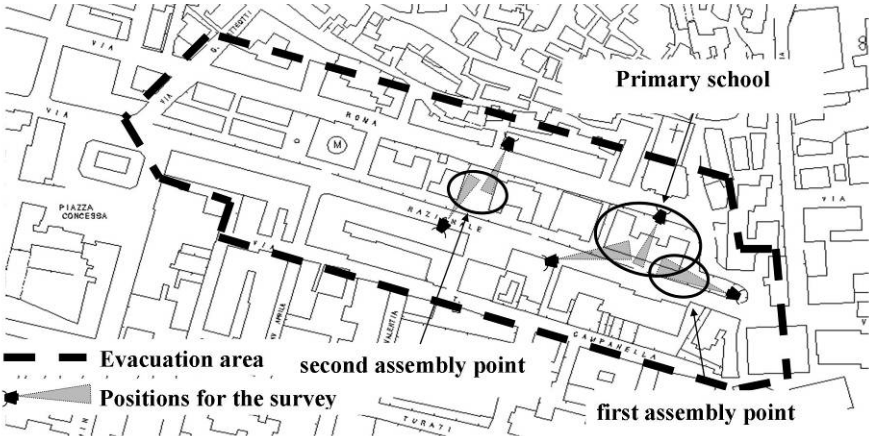

Fig. 4. Locations of assembly points and external cameras used for the survey

3.1 Data Acquisition

Prior to experimentation, data were gathered concerning supply (building plan, evacuation paths) and demand (number of classrooms, school population); during the drill a monitoring system was arranged, with manual/automatic tools and 12 video cameras (external and internal), in order to acquire data concerning pedestrian outflow (times, densities) both inside and outside the building until the gathering places were reached.

The obtained videos (see figure 5 for an example of images taken from evacuation videos) were analyzed in the laboratory to extrapolate data needed for model calibration. Time required per flight of steps, from the reference section upstream to the downstream one, was measured for each user and, to identify density, the average number of users on the stairs during this time was counted.

Stairs

Fire escape

Fig. 5. Example of images obtained from the survey

From observations, as also shown in figure 5, stairs were used differently. Hence, for the inside staircase, a perceived width equal to half the real one was assumed. In all, 73 users were counted for the inside stairs and 52 for the external fire escape.

Same data acquisition method was used for boarding time, where both the number of boarding users and time needed to board were obtained by videos.

3.2 Performing Simulation

As an application, a computer simulation of the observed evacuation was performed. Referring to the test site, Table 2 reports the number of nodes and arcs of the graph to simulate school evacuation. Paths were obtained from the school evacuation plan. As regards the cost functions adopted, for fictitious links a constant speed function was considered; for corridors we considered a relationship between speed and specific flow specified and calibrated in Di Gangi and Velonà (2007).

Table 2. Characteristics of network topology

Node classification	nodes	Link classification	links
origin centroid	22	fictitious link	23
destination centroid	1	corridor	85
real	99	descending flight	9
Total	122	Total	117

Demand values used in the simulation were obtained from school attendance on the experimentation day, and users were located in offices and classrooms following the real distribution. Demand value to be evacuated consists of about 150 users. The first three steps identified in the previous section were simulated with a dynamic approach. The assignment model implemented within the DSS built for this research project allows pedestrian outflow to be simulated with two different hypotheses on distribution of departures:

- departures uniformly distributed in a defined interval;
- departures concentrated at the start of the first simulation interval.

From these considerations, two different kinds of time interval can be defined:

- time interval within the (distributed) departure, whose length is indicated as LID;
- time interval between two successive updates of outflow conditions within the simulation model, whose length is given by LIS.

3.3 Simulation Results

By tracking the movement of each point representing a packet, along the followed path during each interval, several link characteristics (flows, densities, queues) related to the interval can be computed by means of the described model; such data are not reported. For every o-d pair it is possible to know the time needed for all travellers belonging to the pair to clear the network.

Evacuation time is thus defined as the difference (whatever the origin-destination pair) between the starting time of the first traveller and the time the last traveller leaves the network to reach his/her destination (refuge area).

Figure 6 describes the evacuation time up to the second assembly point (the time needed for the last user to reach the second assembly point) depending on LID, considering a fixed value of LIS equal to 30 seconds. It is worth noting that evacuation time in the case of concentrated departures remains constant and higher than that obtained with distributed departures.

This happens since users are all introduced into the network at the same time, slowing down at the nodes with lower capacity. In the case of distributed departures, evacuation times increase since users are constrained to put off departures and times are lower since generated outflow conditions avoid queue scattering.

Table 3 reports variations obtained by comparing simulated vs. measured components of evacuation time.

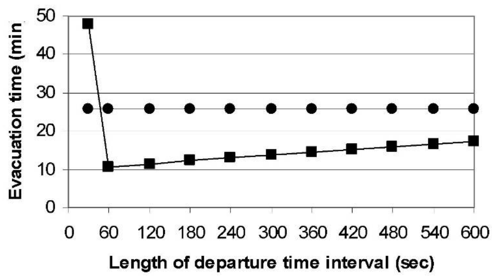

Fig. 6. Evacuation time (end of phase 3)

Table 3. Analysis of results

Phase	Description	Simulated vs. Measured time
1	Reaching first assembly point	+ 1' 33"
2	Waiting at first assembly point	- 0' 07"
3	Reaching second assembly point	- 0' 17"
4	Boarding on bus	- 0' 02"
5	Reaching refuge area	- 0' 31"
	Total time	+ 0' 36"

4 Final Remarks

To manage and control those events greatly modifying the way in which a transportation system works in an urban area, it is necessary to use tools and procedures able to acquire information through the simulation of several scenarios, representing the feasible alternatives to tackle the problem. Dynamic assignment models appear those most suited to conduct effective simulations of transport networks in emergency conditions.

The proposed mesoscopic dynamic approach appears a flexible tool able to simulate a complex event such as the evacuation of an urban area taking into account the connected flow phenomena like the build-up and avoidance of queues.

The application of the model to a real case experimentation conducted in a school of the town of Melito Porto Salvo yields to computed components of evacuation time very close to the measured ones.

Furthermore, it not only allows exogenously defined scenarios to be simulated, but can also be used to define optimal distribution of starting times and/or modal choice proportion to reduce the time needed to evacuate the area.

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Improving Moran's Index to Identify Hot Spots in Traffic Safety

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Abstract. This chapter aims at identifying accident hot spots by means of a local indicator of spatial association (LISA), more in particular Moran's I. A straightforward use of this LISA is impossible, since it is not tailor-made for applications in traffic safety. First of all, road accidents occur on a network, so Moran's I needs to be adapted to account for this. Moreover, its regular distributional properties are not valid under the circumstances of Poisson distributed count data, as is the case for accidents. Therefore, a Monte Carlo simulation procedure is set up to determine the correct distribution of the indicator under study, though this can be generalized to any kind of LISA. Moran's I will be adapted in such a way, that it can overcome all the previously stated problems. Results are presented on highways in a province in Flanders and in a city environment. They indicate that an incorrect use of the underlying distribution would lead to false results. Next to this, the impact of the weight function is thoroughly investigated and compared in both settings. The obtained results may have a large impact for policy makers, as money could be allocated in a completely wrong way when an unadjusted LISA is used.

Keywords: Traffic safety, Moran's I, Monte Carlo simulation.

1 Introduction

Over the past decades, traffic safety has become a topic of increasing interest by the media, as well as for policy makers. The States General of Traffic Safety (Staten Generaal, 2007) has set the ambitious goal to reduce the number of individuals killed in traffic per year from 1,000 in 2006 to 500 by 2015. As opposed to most of our neighboring countries, Belgium's score concerning traffic safety is still below par. The number of people that had a fatal accident per 1 billion vehicle kilometers equaled 11.1 in Belgium in 2006 (International Traffic Safety Data and Analysis Group, 2008). This figure is about 31% higher than the number in France, 44% more than in The Netherlands and even 50% higher when compared to Germany. Putting these figures in an international context only confirms Belgium's poor performance (The United States have a figure of 9 persons killed per 1 billion vehicle-kilometer, Australia has a value of 7.9 and Japan of 10.3). Therefore, it only seems logical that traffic safety has become top priority in the National Safety Plan.

A key issue in traffic safety analysis is determining the reason for a site to be hazardous, also referred to as hot spot analysis (HSA). In general, HSA can be split up into four phases. The first step is to identify the dangerous locations. Next, a ranking

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of these locations needs to be established. The severity of the accident, determined by the severity of the injuries, can be taken into account here (Brijs et al., 2006; Brijs et al., 2007; Miaou and Song, 2005; Vistisen, 2002). Consequently, one tries to come up with an explanation why some sites are hot spots and others are not (i.e. profiling of hot spots). This can be verified through an analysis of maneuver diagrams, information from traffic accident records, characteristics of environment, of infrastructure, etc. (Pande and Abdel-Aty, 2007; Geurts et al., 2005). Finally, one needs to select the hot spots to be treated (Miranda-Moreno et al., 2007). Very often, this turns out to be a policy decision and the choice may be based on different aspects: e.g. based on limited financial supplies, or on a cost-benefit analysis (Banihashemi, 2007; Kar and Datta, 2004). Only the first phase, identification, will be discussed in this chapter, although the technique could be applied for the purpose of ranking as well.

There exists no univocal definition of a hot spot (Hauer, 1996). Sometimes the number of accidents per vehicle-kilometer driven (VKD) or per number of vehicles is used to identify hot spots; other researchers use an absolute figure (accidents per km/year or per year), and some use a combination of both. Since the definition of a hot spot is already very broad in itself, there also exists a wide range of methods and techniques in the domain of traffic safety to identify hazardous locations on a road network, ranging from simple models based on the observed number of accidents, to more advanced statistical models based on the expected number of accidents. Hot spot safety research encapsulates localizing and treating crossroads and road segments with an unexpected high number of accidents. In order to reduce this number of collisions, it is important to know where concentrations of accidents occur. Therefore, the geographical aspect is highly important to determine and to handle the most unsafe traffic sites in a scientifically sound and practical way. Although one acknowledges the importance of this geographical aspect, very often statistical – non-spatial – regression models are used to model the number of accidents.

Analyzing hot spots always occurs within a certain time frame and a large number of locations will show no accidents for that period of time. This is recognized in the literature as sparseness. This abundance of zeroes causes estimation problems in most prediction models. Negative binomial models have been developed to solve this problem and in the recent past this was often countered by using Zero-Inflated Poisson (ZIP) models (McCulloch and Searle, 1989). It is assumed that a location can find itself in two conditions: either the location is inherently safe (state of zero accidents), or there is a chance that an accident occurs at that location (i.e. the location has a strictly positive mean number of accidents, but the probability of having zero accidents at that location is larger than zero). Modeling accident data by means of this type of models often yields better results than using an ordinary Poisson regression model. Though, recently this was criticized in the literature (Lord et al., 2005; Lord et al., 2007), because there is no theoretical underpinning to believe that there exists a location that is inherently safe. Namely, an accident is not necessarily caused by infrastructural characteristics, the state of the driver (inattention, drunk driving, etc.) often plays a very big role. Because of this, it is unrealistic to believe that there exists even just one inherently safe location. The abundance of zeroes will be very often caused by a low exposure (low traffic volumes) and/or by an ill-considered selection of accidents in time and/or space. This can be solved, on the one hand, by enlarging the time frame or the geographical window, or by using a better set of explanatory variables and/or by taking non-observed heterogeneity effects into account to explain the model, or by applying methods for small area estimation (e.g. Poisson-lognormal models).

Next to applying a frequentist's approach, traffic safety researchers are inclined to use Bayesian models, since they can make use of prior information in an efficient way. An example that is widely used in traffic safety literature is the Poisson-gamma model (Brijs et al., 2006; Brijs et al., 2007; Hauer, 1996; Hauer, 1997; Hauer et al., 2003; Cheng and Washington, 2005; Li and Zhang, 2007). Researchers tend to prefer it to the Poisson regression model, because this model can handle the problem of overdispersion (Lord, 2006). The Poisson distribution, underlying the regression model, assumes that the mean and variance are equal to each other and since the mean number of accidents usually is very low, accident data often show a larger variance. Very recently (Lord and Miranda-Moreno, 2007; Park and Lord, 2007), research was conducted on the effect of low means and small sample sizes in traffic safety and this has led to the conclusion that the Poisson-lognormal model often achieves better results than the Poisson-gamma model.

The advantage of using regression techniques is that one has a 'normal' number of accidents for a certain location at one's disposal and as a consequence one can determine the effect of treating that specific location (i.e. safety potential, (Persaud et al., 1999). This is expressed in terms of the difference between the expected number of accidents according to the (Bayesian) model and the number of accidents that is judged to be 'normal' for a similar location, i.e. the *potential of accident reduction (PAR)*. This leads us to what is judged to be the model-based definition of a hot spot (Sørensen and Elvik, 2007): a hot spot is a location with an observed number of accidents that is higher than expected, in comparison with similar locations as a consequence of local risk factors.

Most of the techniques discussed above ignore the existing geographical relationship between different locations. However, it seems only logical that structure of underlying road network can play an important role in determining hazardous locations. For example crossroads, on and off ramps on a highway, the existence of one-way streets, all may have direct implications on the number of accidents on a location nearby. Next to that, there is a recent trend to examine road segments instead of dangerous locations, because of the obvious spatial interaction between accident locations that are close to one another. Spatial techniques allow to account for this. These spatial methods usually exist in one and in two dimensions, but often they are not suited to be used alongside a network. This chapter displays the use of Moran's Index (I) to identify hot spots on highways and on regional roads, hereby taking into account the structure of the road network. However, as indicated above, due to the nature of road accidents (sparseness), a straightforward use of the indicator has serious flaws and adaptations are required to apply it in this context. Section 2 gives a background on spatial autocorrelation in general and it explains the use of Moran's I. The second part of this section denotes the required adaptations and the changing distributional properties when Moran's I is applied to a traffic safety context. The impact of using different weight functions is also discussed. Section 3 gives a description of data, together with the results on highways in Flanders on the one hand and on regional roads in a city context on the other hand. Conclusions and some ideas for future research are given in Section 4.

2 The Method: Moran's I

2.1 Background on Spatial Association

Recently, there is a tendency to use spatial data analysis techniques in association with statistical (Bayesian) regression models in HSA (Flahaut et al., 2005). This enables to account for the spatial character of a location. In this chapter, a spatial autocorrelation index is used. It aims at evaluating the level of spatial (inter-)dependence between the values x_i of a variable X under investigation, among spatially located data (Levine, 2000). If the idea of temporal autocorrelation is extended, then a simple representation of spatial dependence can be formulated as follows:

$$x_i = \rho \sum_j w_{ij} x_j + u_i \, ,$$

where ρ measures the spatial autocorrelation between the x_i's, w_{ij} are the weights representing the proximity between location i and j and u_i are independent and identically distributed error terms with mean zero and variance σ^2. However, in contrast to temporal autocorrelation, spatial neighborhood is multidirectional, making it more complex and leading to specific indices for spatial autocorrelation. Specifically, spatial correlation analysis determines the extent to which the value of the variable X at a certain location i is related to the values of that variable at contiguous locations. This assessment involves analyzing the degree to which the value of a variable for each location co-varies with values of that variable at nearby locations. When the level of co-variation is higher than expected, neighboring locations have similar values (both high or both low) and autocorrelation is positive. Opposite, when the level of co-variation is lower than expected, high values of the variable are contiguous to low values and the autocorrelation is negative. The lack of significant positive or negative co-variation suggests absence of spatial autocorrelation (Flahaut et al., 2005).

Global measures of spatial autocorrelation have been applied for several decades and mainly stem from the work of Moran (Moran, 1948) (see e.g. Griffith, 1987; Haining, 1990). Moran's I is most often used and its usefulness for transport fluxes and traffic accident analysis has been thoroughly discussed in the literature (Black, 1992; Black and Thomas, 1998). Next to the global measure that gives an idea about the study area as a whole, it may also be interesting to limit the analysis to a smaller part of it. It might happen that smaller parts of the study area show spatial autocorrelation, but that it has not been picked up by the global measure. Nevertheless, also when global autocorrelation is present, local indices can be useful to point at the contribution of smaller parts of the investigated area. The use of these local indices is more recent (Flahaut et al., 2005; Getis and Ord, 1992; Anselin, 1995). Each location is now characterized by one value of the index denoting the individual contribution of the location in the global autocorrelation measure.

These local indices are considered to be *Local Indicators of Spatial Association* (LISA) if they meet two conditions:

- They need to measure the extent of spatial autocorrelation around a particular observation, and this for each observation in the data set;
- The sum of local indices needs to be proportional to the global measure of spatial association.

2.2 General Use of Moran's I

The global version of Moran's I was first discussed in Moran (1948), however, in this chapter its local version will be applied. The LISA version of Moran's I satisfying the two requirements as stated in 2.1 can be written down as follows:

$$I_i = \frac{n}{(n-1)S^2}(x_i - \bar{x})\sum_{j=1}^{n} w_{ij}(x_j - \bar{x}) \tag{1}$$

with

- x_i representing the value of interest of variable X for point i,
- $\bar{x}$ the average value of X,
- w_{ij} representing the proximity of point i's and point j's locations, with $w_{ii} = 0$ for all points,
- n representing the total number of points, and
- $S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$, the variance of observed values.

A nice property of Moran's I is the fact that it looks relative with respect to an average value. Because of computational issues, it is often impossible to compute the index for the study area as a whole in one time, and it needs to be split into smaller parts. By plugging in the average of the entire study area as $\bar{x}$ (instead of just the average of the smaller part), all results can easily be combined. So, $\bar{x}$ might serve as a reference value for the study area under investigation (see also 2.3).

Anselin (1995) derives the mean and variance of I_i under the randomization assumption for a continuous X-variable. The expected value of I_i is, for example (Schabenberger and Gotway, 2005):

$$E[I_i] = \frac{-1}{n-1}\sum_{j=1}^{n} w_{ij} \text{ .}$$

The exact distributional properties of the autocorrelation statistics are elusive, even in the case of a Gaussian random field. Gaussian approximation tends to work well, but the same cannot necessarily be said for local statistics (Schabenberger and Gotway, 2005). Anselin (1995) recommends randomization inference, e.g. by using a permutation approach. However, Besag and Newell (1991) and Waller and Gotway (2004) note that when data have heterogeneous means or variances, a common occurrence with count data such as accidents, the randomization assumption is inappropriate. Instead, they recommend the use of Monte Carlo testing.

2.3 Adaptations

It can be observed that some kind of proximity measure w_{ij} is used to denote the distance between location i and location j in the calculation of Moran's I. In general, geo-referenced x and y coordinates are attached to each location and distances are determined by means of a bird's-eye view. However, accidents take place on a road network, and it may happen that locations are very close to each other in space, though, via the network, they cannot be reached easily (e.g. because one of them is located in a one-way street). A logical step is then to consider the distance traveled alongside the road network. Every location can be pinpointed at the road network map and distances can be determined via the network. This also takes care of junctions and on and off ramps in a proper way and encapsulates the whole network structure in its measure. This is the first extension that is used in this chapter in comparison to the 'normal' use of LISA.

Four other adaptations to previous uses of local Moran's I in traffic safety have been proposed here. First of all, it is important to use the index in a correct way. One needs to account for zero observations, as well (instead of only taking into account locations with at least one accident, see e.g. Flahaut et al., 2005). Otherwise, the average value would clearly be overestimated. Moreover, all locations with accidents would be judged to be of a too high importance.

Second, as already indicated in the previous paragraph, any reference value can be used for $\bar{x}$. In normal use of the index, this is just the average of the area under study, however, if - e.g. for computational purposes - the area needs to be split up, the average of the total area can still be used here, so that comparisons between small parts are straightforward. If one wants to compare different countries to each other, a global average can be computed and in this way all countries can be compared to that global average. From a traffic safety point of view, it might be interesting to compare the average of a region or a country e.g. to the average for that type of road.

Third, this local measure of spatial association can be regarded as being a traffic safety index, since for each basic spatial unit (BSU) of road the local Moran's I can be regarded as a measure of association between the BSU under study and the neighboring BSUs which are similar to the one under study concerning the number of accidents. A negative value of the local autocorrelation index at location *i* indicates opposite values of the variable at location *i* compared to its neighboring locations. A positive value, on the contrary, points at similar values at location *i* and its neighborhoods. This means that location *i* and its weighted neighborhood can both have values above the average or both can have values below it. In the application area of traffic safety, however, one is only interested in locations having:

1. high number of accidents in regard to the total average number of accidents (i.e. $x_i - \bar{x} > 0$),
2. and where the neighborhood also shows more accidents than was expected on average (i.e. $\sum_j w_{ij}\left(x_j - \bar{x}\right) > 0$).

It might be argued that it is also important to look at locations with a high number of accidents at location *i* and a very low number in the surrounding area (i.e. a spike). In this case, very negative values of Moran's I would occur. However, although conceptually appealing, this gives very contradictory effects as illustrated by the following example. Let us suppose that the global average over a certain area equals one accident ($\bar{x}=1$). Then, if 7 accidents occurred at location *i* and none in its surrounding, this would lead to a negative value of Moran's I and possibly a significant negative autocorrelation. However, adding one accident to every surrounding point of location *i*, hence making the surrounding area more hazardous, would lead to a Moran's I of zero, indicating no significant autocorrelation. This would mean that a more dangerous location has a less significant Moran's I when compared to a more 'safe' location. This is really counterintuitive, therefore it was opted to look only at points where a high number of accidents is contiguous with high values in the neighborhood (the location and its surrounding area reinforce each other in a positive way).

Finally, since the distributional properties of Moran's I are intangible, as suggested by Besag and Newell (1991) and Waller and Gotway (2004), a Monte Carlo approach was applied to arrive at cut-off values for the local Moran's I above which a location can be considered to be a hot spot. On this purpose, the total number of accidents for the study area will be spread randomly over the total available locations. Note that locations are allowed to have more than one accident, otherwise high concentrations of accidents cannot be determined. For each location, local Moran's I is then calculated. This simulation will be repeated 500 times to end up with an approximate distribution of the local Moran index for the particular situation at hand. Next, to determine hot spots, it has been decided upon to filter out the locations with a high number of accidents contiguous with high neighboring values. For this subsample of locations, 95th percentile (P_{95}) of the distribution of remaining Moran values is determined. This value will be utilized as the cut-off value to determine an accident hot spot in the study area. If the local Moran's I value of a location of true data also has similar high values between the location under study and its contiguous locations and it exceeds this 95th percentile (i.e. if $I_i > P_{95}$), then this location is considered to be hazardous, and hence it is a hot spot location.

A real world example for 506 accidents at 3,252 locations is shown in Figure 1. It is obvious that a Gaussian approximation would not work well in these circumstances. The solid curve indicates the simulated density for Moran's I, while the dashed curve shows the Gaussian approximation with the mean and variance as they are expected to be under randomization.

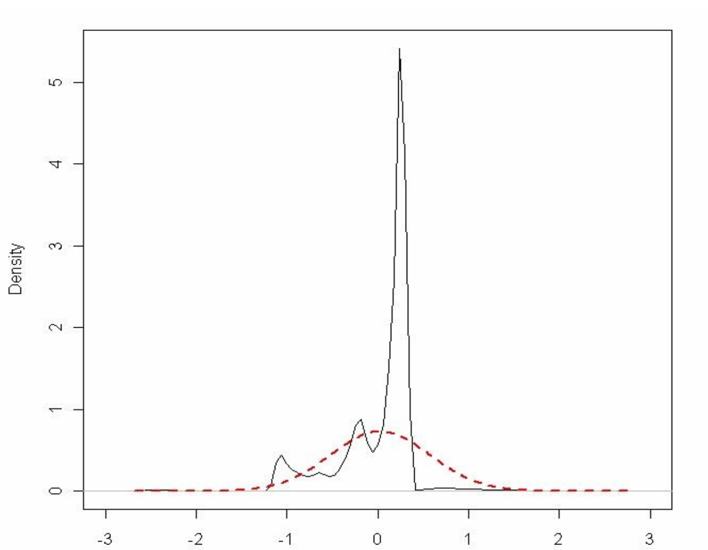

Fig. 1. Simulated density of local Moran's I

2.4 Impact of the Weights

An important disadvantage of spatial autocorrelation in general is that this measure is not uniquely defined. There is no optimal specification for weights and this proves to be one of the most difficult and controversial methodological issues in spatial econometrics (Anselin and Florax, 1995). One needs to consider two different aspects, i.e. *number of neighbors* (level of connection) and *value of weights*. Concerning the level of connection, it seems impossible to define an optimal distance between two BSUs for which both BSUs would still show any connection. This optimal distance will vary with type and characteristics of the road under investigation, but probably also with road configuration, posted speed limit, etc.

Additionally, the choice of weights is not uniquely defined. Getis and Ord suggested (Getis and Ord, 1992) to assign all locations in the neighborhood of a certain location a weight equal to 1 and the remaining locations a weight value of zero, though this does not account for the fact that locations are not uniformly spread. It seems only natural to account for the distance between the locations to determine local autocorrelation. Often the inverse of squared distance is used. This entails that the less nearby a location is to the location under study, the less weight it receives. Note that at the end of a road, one only accounts for the neighbors which exist. In general, weights are row-standardized, meaning that the sum of weights at each location sums up to 1.

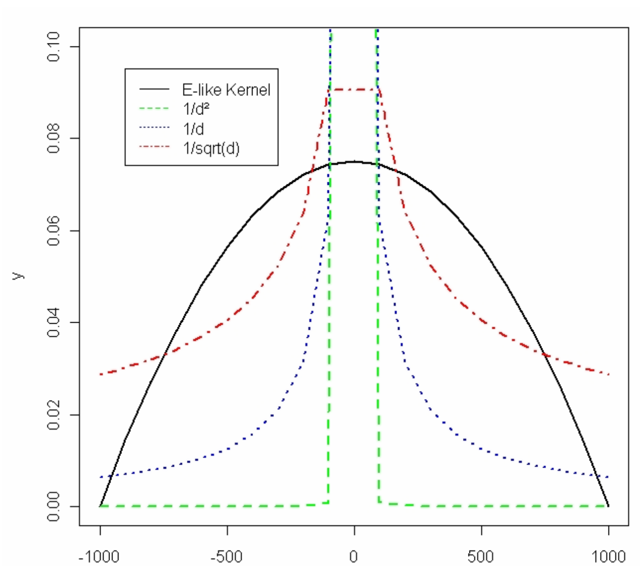

Fig. 2. Impact of different weight functions

Figure 2 shows the impact of using different weight functions. Note that functions are truncated at zero, otherwise three of the four functions would go to infinity. The solid line indicates an Epanechnikov-like kernel (E-like) which is often used in kernel density estimation. This is shown to point at the contrast when compared to powers of distance between locations. The dashed line equals 1 over the squared distance. One may observe that after 150 m weights are almost equal to zero. The dotted line is the inverse of distance, this allows some weight to be given at locations up to about 750 m from the site under investigation.

The dash-dotted line shows 1 over the square root of distance. This clearly gives some weight at all contiguous locations. For the choice of weight function, just as for the choice of the number of neighbors, there does not exist one optimal choice. It preferably changes per setting, depending on road configuration of the area under study and it interacts with the number of neighbors. Perhaps, different simulation settings together with some expert knowledge can help to provide some more insight in this matter. Although not the main focus of this chapter, some results on different weight functions are shown in Section 3.

3 Analyses and Results

This Section illustrates the use of Moran's I for two different configurations. A first application comprises accidents on highways in Limburg, a province in Belgium. A second data set consists of accidents on regional roads in the city of Hasselt (capital of the province of Limburg) and its surroundings. Both data sets are provided by the Belgian Federal Police.

Variability, i.e. the fact that the yearly number of accidents on a road segment varies from year to year, is an important issue for accident analysis. This can be explained by the inherent accident risk of a road segment. Randomness in the number of accidents is typical, because of the nature of accidents and because of unpredictable factors, such as the weather. Therefore, it is of great importance that the study period is long enough to ensure representative accident samples. Based on a large number of studies, it is generally agreed upon that the period of three to five years is sufficient to guarantee the reliability of results (Cheng and Washington, 2005). For both analyses, data on accidents were collected from 2004 to 2006.

3.1 Data

The first analysis is carried out on the province of Limburg in Belgium. Figure 3 indicates the location of the province of Limburg within Flanders (the upper, Dutch speaking part of Belgium).

The second analysis is carried out on regional roads. Figure 4 indicates the road network of the city of Hasselt and its surroundings, together with the BSUs where accidents occurred. Note that many accidents occurred on the inner and the outer ring way of the city and at the arterial roads towards the city. In the upper left corner, one can observe the clover leaf junction of the two highways in Limburg, E314 and E313. This is expected to be a hazardous location, though one needs to take care in which setting. It may be true that this proves to be dangerous when analyzing highways separately, while on regional roads (they actually comprise of provincial roads, regional roads and highways), it may prove not to be a hot spot, after all.

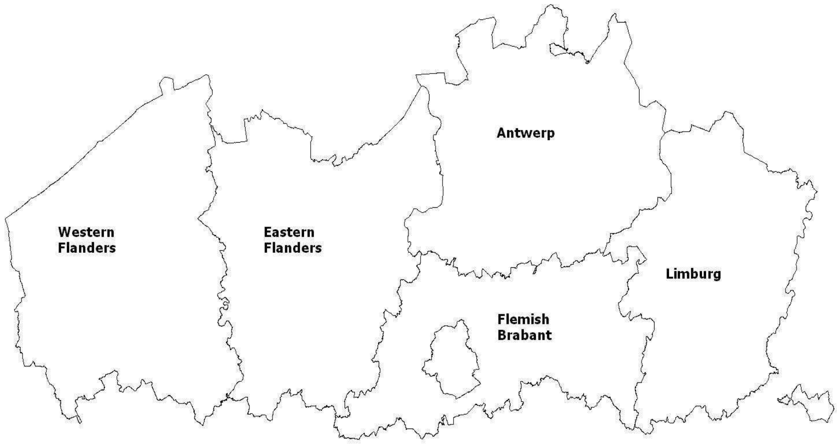

Fig. 3. Limburg within Flanders

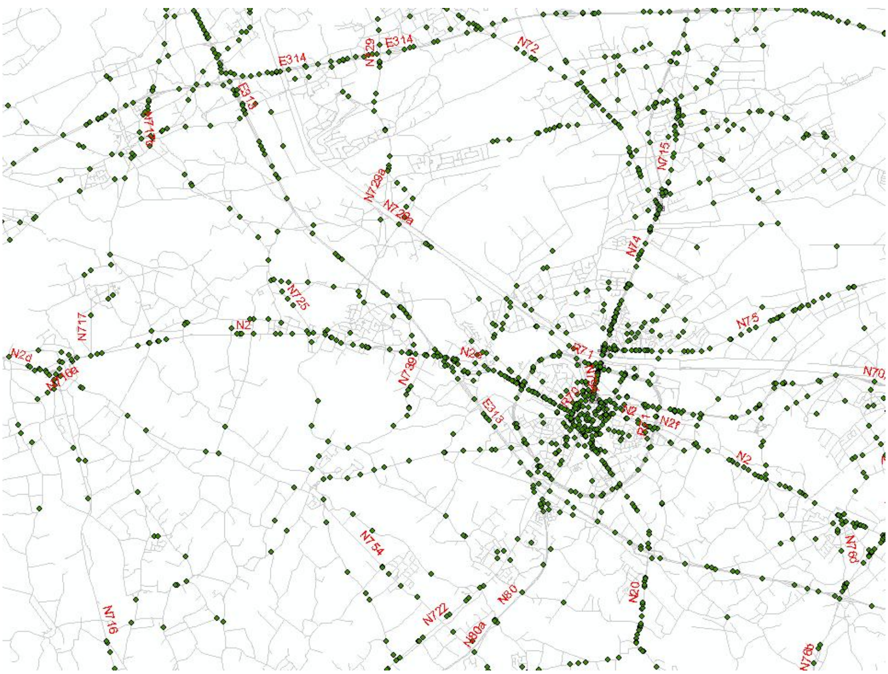

Fig. 4. Road network around Hasselt

For both settings, the basic spatial unit is defined to be about 100 m. Accidents occurring at highways are assigned to the closest hectometer pole, so they are regarded as BSU, both for highways and for regional roads. Initial weights used are the inverse of squared distance, where distance was determined from one BSU to the next one on the network. The number of neighbors is also distance based. For each BSU, BSUs within a 1 km range from BSU under investigation are included as neighbors. So, each point, not located near the end of any highway, has approximately 20 neighboring points (more neighbors are possible for the city environment configuration). Nearby the junction of both highways, it may happen that BSUs from the second highway are within the predefined number of neighbors for a location at the first highway. To account for them in a proper way, distances need to be network-based. In the city environment, this becomes even more important, since there are much more small roads within the neighborhood of each other. Because the idea is to compare the results of Limburg with other provinces in Flanders, the number of accidents for Flanders was set as a reference value ($\bar{x}$) in both analyses. Limburg has 3,252 hectometer poles alongside its two highways (E313 and E314) and 506 accidents occurred on these highways between 2004 and 2006. In the second configuration, 1,678 collisions took place on one of the 3,856 possible hectometer sites. As stated above, since accidents form a Poisson process instead of a Gaussian process and because of sparseness (most locations have a zero accident count), the distribution of local autocorrelation statistics proves to be far from Gaussian. Moreover, count data often suffer from the problem of overdispersion and means and variances tend to be heterogeneous, so as stated in (Schabenberger and Gotway, 2005; Besag and Newell, 1991; Waller and Gotway, 2004). Therefore, the Monte Carlo approach is applied to derive the distribution of local autocorrelation statistics.

3.2 Analyses and Results

For the setting on highways, the 506 accidents are spread randomly over the 3,252 hectometer poles to determine the distribution of the local version of Moran's I. This density is illustrated in Figure 1. Since we decided to look only at locations showing a positive reinforcement with their contiguous locations in the calculation of the local autocorrelation index, these values need to be filtered out of the 500 x 3,252 values. From these remaining values, 95th percentile was calculated and this value, i.e. P_{95} = 4.32, was utilized as cut-off value to determine which location is a hot spot and which is not. Only 5 of the 3,252 locations appeared to be hot spots on highways in Limburg. For reasons of comparison, standard used Gaussian approximation was also applied to investigate difference in results. Using also the 95th percentile (of the Gaussian distribution!) as cut-off value, now 46 locations proved to be hot spots according to this method. The previous 5 are part of them, however about 87% of the points are falsely identified as belonging to the 5% most extreme Moran's I values. From a policy point of view, this might lead to a wrong allocation of funds to ameliorate traffic safety and thus it indisputably shows the importance of using the right distributions.

For the more urban configuration, the 95th percentile proved to be much lower, P_{95} now yields 2.14. 48 sites are determined as hot spots by the local Moran's I, while again more than twice as much (114) locations were pinpointed as hazardous if the Gaussian approximation would have been used.

Figure 5 shows the resulting hot spots for both configurations. The left panel shows the province of Limburg and its two highways, while the right panel shows Hasselt and its surrounding area. Hot spots are indicated as red points, while the underlying road network is drawn in black.

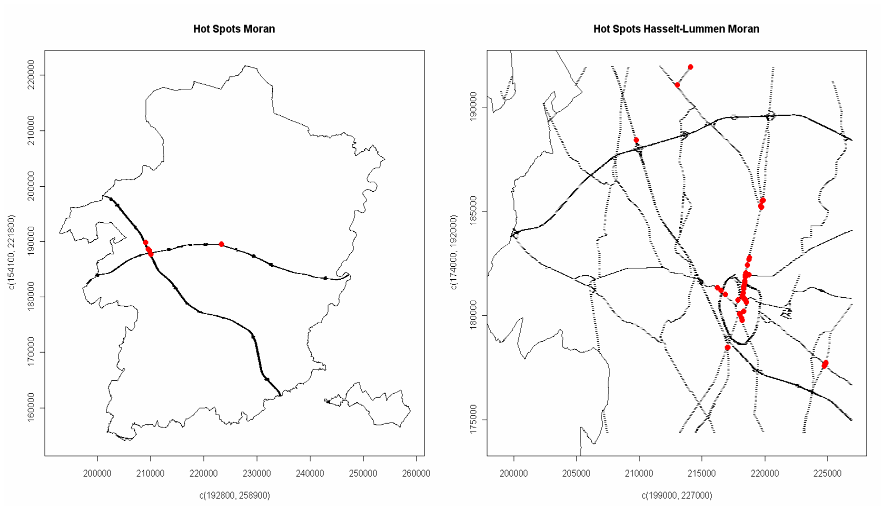

Fig. 5. Hotspots for both configurations

Table 1. Results on highways for different weight functions

Loc. with … ….accid.	Nr. of locations	HS in setting 1	HS in setting 2	HS in setting 3	HS in setting 4
0	2,871	0	0	0	0
1	318	0	4	8	6
2	50	3	8	10	10
3	5	0	0	0	0
4	2	1	1	1	1
5	1	0	0	0	0
7	2	1	1	1	1
8	1	0	0	0	0
14	1	0	1	1	1
24	1	0	0	0	0
Total	**---**	**5**	**15**	**21**	**19**

Next, four different weight functions are compared to each other. The determination of neighbors stays the same. Previously discussed results are denoted as setting 1. Setting 2 indicates the version where the inverse of distance is used as weight function, in setting 3 the inverse of square root of distances is applied and in setting 4 Epanechnikov-like function is used. Tables 1 and 2 display number of locations and their corresponding accident figure over three years and how many of these locations are determined to be hot spots (HS) for each setting. Table 1 shows results on highways, whereas Table 2 gives results in the city environment.

Most locations which proved to be hot spots for the inverse quadratic weight function remain hot spots for all other 3 settings. Furthermore, those locations which are hazardous in setting 2 are almost always HS in setting 3. Hot spots which are retrieved in setting 4 appear to be a mixture of those of setting 2 and 3. It has to be noted that Gaussian approximation leads to at least 3 times as much the 'so-called' hot spots in each of the applied settings. Often this difference is even much larger.

Table 2. Results in city environment for different weight functions

Loc. with … ….accid.	Nr. of locations	HS in setting 1	HS in setting 2	HS in setting 3	HS in setting 4
0	3,064	0	0	0	0
1	494	2	1	0	0
2	163	4	6	11	9
3	62	10	11	12	14
4	23	5	6	6	6
5	15	8	8	7	8
6	9	3	4	4	4
7	10	3	4	4	4
8	1	0	0	0	0
9	2	1	1	1	1
12	1	1	1	0	0
14	3	2	3	3	3
17	1	1	1	1	1
20	1	1	1	1	1
21	2	2	2	2	2
24	2	2	2	2	2
30	1	1	1	1	1
67	1	1	1	1	1
78	1	1	1	1	1
Total	**---**	**48**	**54**	**57**	**58**

This once again emphasizes the necessity to apply the Monte Carlo approach to end up with proper results. The largest difference in the number of hot spots occurs between setting 1 and 2. Although there is a remarkable difference in shape of weight function (concave versus convex) between settings 3 and 4, the resulting hot spot locations do not differ a lot. This is probably due to the fact that differences occur predominantly at locations further away from the investigated BSU. It also shows that for accidents on highways not all locations with a high number of accidents turn out to be hot spots, whereas this does happen to be the case for the city environment. It is obvious that the denser the road network is in the study area, the more these dangerous locations show up in the analysis. Only one highway location turns out to be a hot spot location for the analysis in the city environment, and this is a location at the junction of both highways in Limburg. This clearly indicates that the context plays an important role. When considering an urban environment of this type (city with ring ways and arteries), one might argue that it suffices to consider only accidents at provincial and regional roads to determine the most dangerous locations. However, one needs to be careful in generalizing this result, since it is only based on one particular example.

4 Conclusions and Discussion

The aim of this chapter was to apply a local indicator of spatial association, more in particular Moran's I, to identify hazardous locations on highways and on regional roads. First of all, it needs to be acknowledged that accidents occur on a network, and this should be accounted for by using the correct network-based distances between locations under study.

Moreover, accident data, in general, stem from a Poisson random process, rather than a Gaussian random process and locations with zero counts are very frequent, so the normal use of indicators seems very elusive. To account for these characteristics, a simulation procedure was set up to get at the distribution of Moran’s I, so as to determine the 5% most extreme observations. Two different settings were regarded, highway network of the province of Limburg in Belgium and road network around the city of Hasselt, the capital of Limburg. To construct the distribution of the improved Moran’s I, a Monte Carlo simulation experiment was set up, where reported number of accidents was spread randomly over the population of possible locations to reach the distribution of the local indicator. Sites which showed a local index above the 95% cut-off value of the density have been then regarded as hot spots.

For comparison purposes, the same analysis was carried out using the Gaussian approximation for Moran’s I, instead of the simulated distribution. Now, at least twice as much locations were defined as hot spots, including ones obtained by a correct use. Blindly using the Gaussian approximation is certainly not an option, and one absolutely needs to take into account the nature of data under study. This is a very relevant result for policy makers, since they usually do not have access to an unlimited budget to treat hot spots. To allocate their funds in the best possible way, it is important to know which locations are true hot spots. The impact of different weight functions in both settings has also been investigated. This illustrates that context and density of road network are very important when choosing a good weight function. Further research combined with expert knowledge seems required to come up with some rules of thumb to be used for analyses in the future.

A next step to be taken is to investigate how these hot spots can be combined into hot zones. A possible way forward has been suggested by Loo (2008).

An important issue for future research is to apply and compare results of this and other (spatial) techniques (such as network-based K-function) to identify hot spots on other road types (e.g. local roads).

Acknowledgments

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Visual Impact Assessment in Urban Planning

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Abstract. Nearly half a century has passed since Lynch described visual quality of American cities. Although the issue of visual impact assessment in urban planning is not new, only few experiences exist considering visual aspect when realizing new development zones. Visual aspects are fundamental in urban planning, since each plan choice can generate manipulation or obstruction of urban elements, producing negative effects on the image of the city. Viewshed analysis can help to achieve a more objective and consequently more effective analysis of visual impacts. Traditional viewshed analyses (single, multiple and cumulative) do not show which target is visible from a certain cell. On this purpose, a new viewshed analysis has been developed, the Identifying Viewshed, which shows how many and which objects are visible in several areas. The implemented extension has been tested in three different contexts, Laurenzana and Venosa, in Basilicata Region, and Pisa, in Tuscany.

Keywords: Urban Planning, Visual impact assessment, Viewshed, Cumulative Viewshed, Identifying Viewshed.

1 Visual Impact Assessment and Urban Planning

Two cornerstones in urban planning literature have been written by Kevin Lynch. In his "The image of the city" (1960) Lynch analyzes visual quality of American City by studying its citizens mental image; while in "Good city form" (1984) Lynch synthesizes urban quality according to five main aspects, defined from the citizen point of view: Vitality, Sense, Fit, Access, Control. Sense has been defined as follows: "by the sense of a settlement, I mean the clarity with which it can be perceived and identified, and the ease with which its elements can be linked with other elements and places in a coherent mental representation of time and space and that representation can be connected with nonspatial concepts and values. This is the join between the form and the environment and the human processes of perception and cognition". Lynch considers three main factors in defining the image of city features: identity, structure and meaning. Identity is connected to recognizability of an object relative to other things. Structure is related to spatial relationships between the object and the observer. The meaning accounts for all practical and emotional issues generated in the observer by the object. In case of manipulation or obstruction only identity and structure could be modified.

Lynch coined the term "imageability" as a quality of an object evoking a strong image in any observer and generating a strong relationship between object and inhabitants, which remains engraved in memories and meaning. The concept of the sense of place, based on cultural, social and historical symbols, plays an important role in human perception (Daniel 2001).

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In new development zones or in areas planned for urban renewal programs, only building design criteria have been adopted, like proportions, aesthetic pleasantness, similitude with existing urban patterns, etc.. This is the reason why visual aspect is a crucial topic in urban planning, since each plan choice can generate manipulation or obstruction of these particular objects producing negative effects in the image of the city.

The use of visual impact assessment in urban planning adopts a different approach than other fields. A lot of studies in landscape planning are focused in the attempt to reduce impacts of development, also trying to hide built objects (Gimblett et al 1987). These experiences are based on the definition of a threshold (Shang and Bishop 2000; Cau and Cocco 2004) beyond which visual impacts could be considered. While the main aim in evaluating impacts of a bridge or a wind farm is reducing the dimension of the visibility of these objects, in urban planning the purpose is completely different. In most cases it is important to save the view of monuments, natural areas and all elements considered important for the community. Generally, people don't like to lose the view of these objects, even though they are very far and appear very small; so the use of visual thresholds in urban planning is meaningless. One of the recurring issues of visual aspects in urban planning is "What happens to my view of these important landmarks when all my neighbors raise their roofs to the maximum allowed and I don't?" (De los Rios-Urban and Chasan 2005).

However, evaluating visual impact assessment is not simple, because it is affected by subjectivity. Stamps (1997), analyzing significant and not significant visual impacts, considers three main problems: subjectivity, magnitude of impacts and vagueness of language in design. Since many years, every kind of technology has been adopted in order to improve decision making quality. Visual aspects take into account three main factors (Bishop and Karadaglis 1996):

- observer: any person who can be affected by object perception;
- object: human artefacts to be included in landscape;
- environment: every natural or anthropic element between object and observer and behind the object.

These three aspects are strongly related and can never be considered separately (Laurie 1975). Also Kant (1791) in his "Critique of judgment", considers physical relation between people and environment. Visual impact assessment accounts for relationships between the human viewer and landscape properties. Observer location relative to objects defines if the object is visible and how big it appears (Stamps 1997).

Nowadays computer graphics and GIS can be considered a cornerstone of this analysis in order to increase the level of objectivity. The use of multimedia tools in visual impact evaluation shows the following limits:

- these techniques are strongly related to the aesthetic sense of the designer, affecting the choices by a certain degree of subjectivity;
- they do not give any information about from where the new object is visible and, consequently, if it obstructs the view of town symbols;
- carrying the analysis is onerous, so it is possible to understand if the landmark is visible or obstructed only for a limited number of observation points and for a limited number of design alternatives;

- it is not possible to quantify and compare in a more objective way different planning choices;
- it is not possible to compare visual aspects with other important factors, in new residential zone locations, such as geology, idrology, accessibility, etc..

The use of spatial information in visual impact assessment produces less attractive and suggestive data, but fundamental in more objective evaluations, relative to other tools, as renderings or videos.

This kind of analysis is based on viewshed computation, which identifies every cell visible from one or more observation points (Burrough and McDonnell 1998). Viewshed analysis has been improved realizing multiple viewshed (Ruggles et al 1993; Kim et al 2004) and cumulative viewshed (Wheatley 1995). Multiple viewshed combines all layers achieved for each target point with the union operator. Cumulative viewshed allows to account for many points of view summing all grids by means of map algebra (Tomlin 1990, DeMers 2000), providing further information on how many objects can be seen in a certain zone. In this paper a new viewshed operator, Identifying Viewshed, has been developed in GRASS (Geographic Resources Analysis Support System) GIS software. This extension allows to understand how many and which objects are visible in several areas. This tool could support the urban planning process when Visual Impact Assessment is needed to realize a suitable location of new development zones.

2 Viewshed Analysis

Viewshed analysis is a common method adopted in spatial analysis. In recent times, following the great diffusion of GIS, viewshed analysis has been used in a lot of fields: in several archaeological applications (Fisher et al 1997; Lake et al 1998; O'Sullivan and Turner 2001; Ogburn 2006), in the study of protection of extinguishing species (Camp et al 1997), in visual impact assessment of wind turbines (Kidner et al 1999), in marble quarry expansion (Mouflis et al 2007). Planners adopted viewshed analysis predominantly in landscape planning (Aguilo´ and Iglesias 1995; Hanna 1999; Hernández et al 2005), but also in supporting decisions in urban planning (Lee and Stucky 1998) and in urban design applications (Yang et al 2007).

Viewshed analysis allows to understand which pixel is visible from an observation point, located in a certain area with known morphology. Therefore, in this analysis the input datum is a point pattern, while the output is a grid containing numerical information about the target visibility.

Nevertheless, in most cases, there is the need to evaluate visibility from more than one point, at the same time. For this reason several authors (Ruggles et al 1993; Kim et al 2004), in order to increase viewshed functionality, developed multiple viewshed which produces a binary grid, where 0 means target not visible, while 1 means target visible, from the union of single viewshed rasters (figure 1). Another approach considers cumulative viewshed analysis (Wheatley 1995). This is calculated using the union operator and inserting a counter. Consequently, the final result is a no more binary grid, but it indicates, for each cell, the number of observation points or (inverting the problem), the number of observed objects (figure 1). The same result can be obtained summing single viewshed binary grids coming from each observation point.

Despite the fact cumulative viewshed seems to be a fairly complete analysis, this approach lacks in a fundamental aspect. Cumulative viewshed does not show which target is visible from a certain cell. Evaluating the impacts of a new neighbourhood, it is possible that only one building generates an huge visual impact. It is fundamental to identify the object which generates great part of the obstruction. On this purpose, a new viewshed analysis has been developed, the Identifying Viewshed, which for each cell shows which target is visible (figure 1).

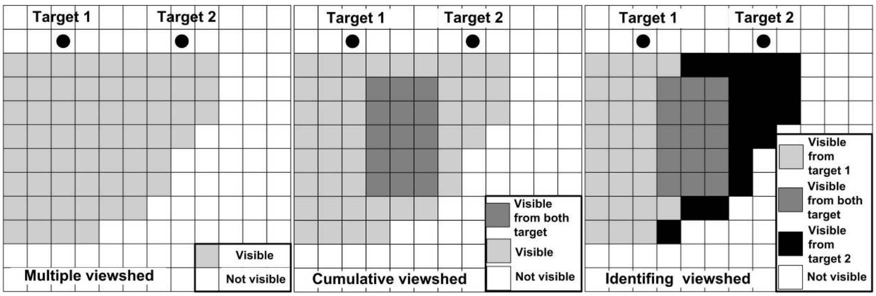

Fig. 1. Main differences among Multiple, Cumulative and Identifying Viewshed in the case of two targets

Clearly, many factors influence the results of visual impact. These can be summarized in three main points (Ogburn 2006):

- observer properties;
- observed object properties;
- environment properties.

For what concerns observer properties, two main aspects should be considered:

1. Limits of human sight. Consequently, there is the need to consider a limited observation radius around the observer to take into account this factor,.
2. Altitude of the observer above the terrain. As the common sense suggests, visibility can change completely, sometimes even only if we consider two differently tall people. When they observe an object, this can be seen only from the taller and not from the shorter one, because of the obstacles to sight which can exist between the observer and the observed object.

Observed object properties are strongly related to geometric properties. Increasing object dimensions, the possibility that the object is visible will grow. Another property which could influence the visibility of an object is related to its colour.

About environment properties, it is important to consider surrounding atmospheric factors, like the presence of humidity and mist, because they can alter the visibility level. But most of all it is important to realize a detailed digital elevation model, closer to reality. On this purpose, it is important to account for the third dimension of land cover and other artefacts as bridges and dams, which could substantially obstruct the visibility.

Other two important aspects in viewshed interpretation could be considered: edge effects and cell size. Wheatley and Gillings (2000) analyzed edge effects in archaeological visibility, showing how results could be affected by a certain degree of inaccuracy in areas close to the edge of the study zone. Particularly, in the case of cumulative and multiple viewsheds, errors could be combined with other errors producing meaningless results. This problem can be solved analyzing a wider zone than the study area. Another problem could be generated by cell size. If the DEM can be generated from a detailed map, it is important to produce a very fine grid in order to increase accuracy level.

3 The Implemented Model

In order to improve a new quantitative approach to visual impact assessment, a model has been implemented in GIS open source software GRASS. In this way it is possible to reduce processing time, increasing the level of objectivity and transparency of analysis.

This model allows to understand:

- Current visibility of city landmarks and natural/landscape resources, from different points of urban areas and access roads. More particularly, it is possible to understand how much and from which observation point each landmark and natural resource can be visible.
- Visibility after urban plan location of a new residential area. It is possible to see if, how much and which are the obstructed observed points, comparing different design alternatives, placed in different zones and with different heights of new buildings which should be constructed.

Intervisibility analysis developed in this application is mainly based on a new viewshed analysis, called “Identifying Viewshed”, because it provides information about which cell is visible from each target.

On this purpose, three modules have been realized; their main properties can be synthesized as follows:

- *v.to.dem.sh* script allows to build a DEM from vector data accounting at the same time for contour lines, spots height, buildings and woods;
- GRASS software adopts *r.los* (line of sight) module to create single viewshed maps. Each pixel of these maps contains the vertical angle (measured in degrees) from which the target is visible. An extension of *r.los* module, *r.visibilità.sh,* has been developed in order to produce: as first step the basic binary viewshed, where the pixel is 0 if the target is not visible and 1 if the target is visible; as second step the Cumulative and the Identifying Viewshed;
- *v.impact.sh* modifies the DEM allowing to include buildings of any new residential area.

3.1 Identifying Viewshed

The developed viewshed has been called "Identifying viewshed" because it is possible to understand, in a univocal synthetic map, how many and which landmarks are seen from each point of the territory, instead to have different maps, difficult to consult and to analyse at the same time.

In order to obtain it, considering *n* binary viewshed maps V_i, respectively calculated for each observation point, the Identifying map **I** can be obtained applying the following expression:

$$I = \sum_{i=1}^{n} V_i \cdot 10^{i-1} \tag{1}$$

In simpler words, if we have three matrixes A, B, C (figure 2), each corresponding to three viewshed maps, the Identifying map **I** can be obtained combining the simple binary viewshed maps according to equation 1. Consequently, in each pixel of the map **I** there will be a binary number, which is formed by 3 digits, each representing the capability to see one observation point; so it allows to understand which point is visible (digit equal to 1) and which is not (digit equal to 0). As an example, considering the pixel highlighted in the picture: the first digit represents the ability that point A has to see that pixel (which is 0), so point A cannot see it; the second digit represents point B (in this case it is 1), so the pixel is visible from B; finally the third digit represents point C (in this case 0), so the pixel considered is not visible from C.

Obviously, the problem can be inverted, the identifying map does not show only which points are visible from each pixel, but also which points can be seen from each pixel. This means that, considering again the highlighted pixel, point B not only can see the pixel, but it can also be seen from it; in the same way points A and C cannot see and cannot be seen from the pixel.

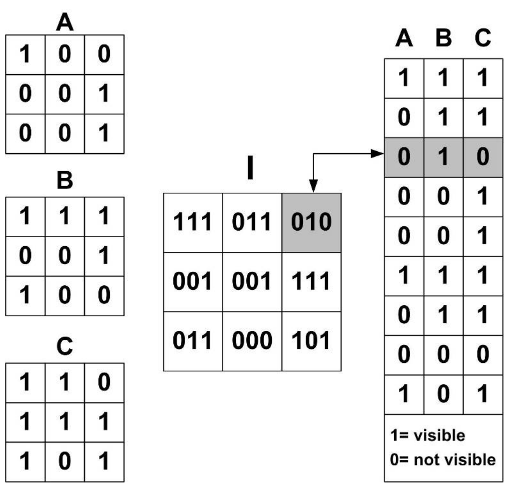

Fig. 2. Scheme of identifying viewshed map implementation

This procedure has been implemented in Grass by creating a main module, called *r.visibilità.sh*, useful to calculate Cumulative and Identifying Viewsheds. This module is supported by two other scripts, called *v.to.dem.sh* and *v.impact.sh.* These modules will be described in the following paragraphs.

3.2 The v.to.dem.sh Script

The *v.to.dem.sh* script was implemented to drive the user in the construction of a Digital Elevation Model, particularly useful for viewshed analysis, because the DEM can be built up not only with contour lines and spots height, but it can choose other elements, which could obstruct the sight of an object. When the user chooses these elements, he/she can select or not a flag, depending on if he/she wants to consider the height of the element above the sea level or not.

Moreover, in this tool it is also possible to choose the more suitable cell size for the working scale considered.

3.3 The r.visibilità.sh Script

This script represents the main part of the built model. It uses *r.los* tool existing in GRASS environment, which carries the simple viewshed analysis for one observation point and calculates the basic viewshed map for each observation point.

The main steps followed in the script are:

- selection of the DEM realized with the v.to.dem.sh tool;
- definition of the dataset with observation points;
- applications of *r.los* tool to calculate each viewshed;
- conversion of the viewshed maps, containing angles of visibility, in basic binary maps;
- combination of all these maps in order to obtain cumulative and Identifying viewsheds;
- possibility for the user to delete or not the single binary intermediate maps.

3.4 The v.impact.sh Script

The last script has been created in order to change rapidly the DEM, simulating planning decisions and evaluating visual impact of different solutions. With this objective, it is possible to load up the vector file containing, for example, new buildings, then the user can choose the preferred height and quickly create a new DEM and recalculate viewshed maps, using *r.visibilità.sh* tool.

4 The Case Study

Visual Impact Assessment has been tested in three Municipalities, Laurenzana and Venosa, in Basilicata Region, and Pisa, in Tuscany.

Laurenzana is a small town located in southern Apennines and completely surrounded by woods and natural reserves. Venosa has been chosen because of its history and its cultural heritage. Pisa is one of the most famous cities in the world and the Leaning Tower is not only a symbol of the city, but of the whole Nation.

Observation points have been located on monuments, cultural heritage areas and road network representing the main access to towns, while an average height of 1.65m has been adopted for the observer.

Vegetation can influence visibility; for this reason other parameters have been chosen in order to account for height values for different types of land uses.

Vegetation does not have a constant height, because it varies depending on the age of the topsoil, with a range included between few meters to 20-30m, but also on environmental factors like altitude, exposure, etc. According to Bernetti (1995) the following mean values have been adopted:

- Conifer woods: 20-30m;
- Broad-leaf woods: 15-25m;
- Bushes: 3-5m;
- Orchards: 5-8m;
- Olive groves: 5-8m;
- Fences: 15-20m;
- Riparian vegetation: 20m.

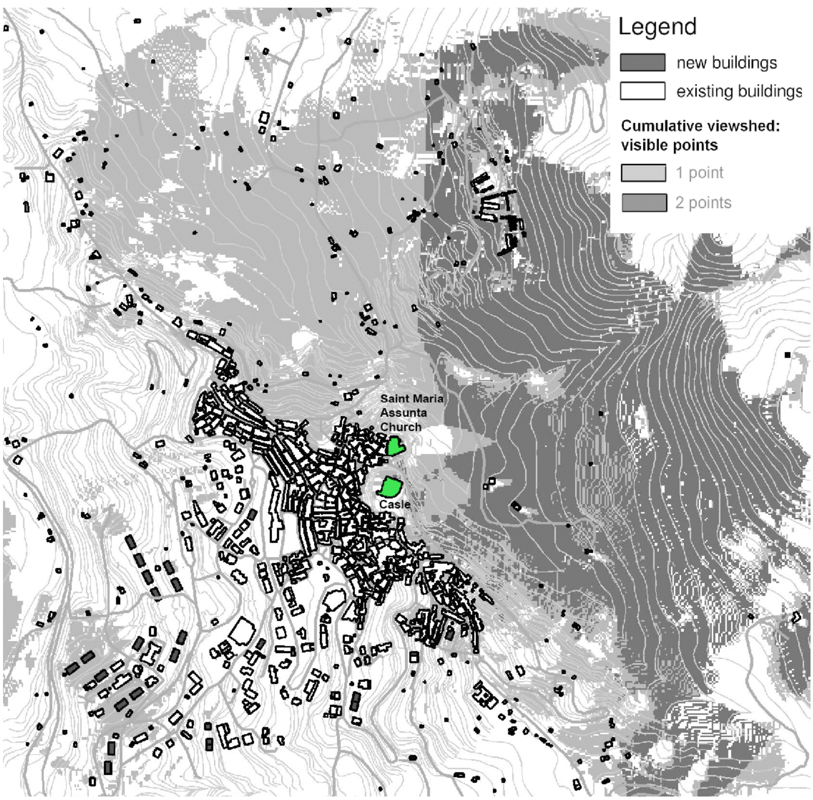

Fig. 3. The cumulative viewshed of Laurenzana

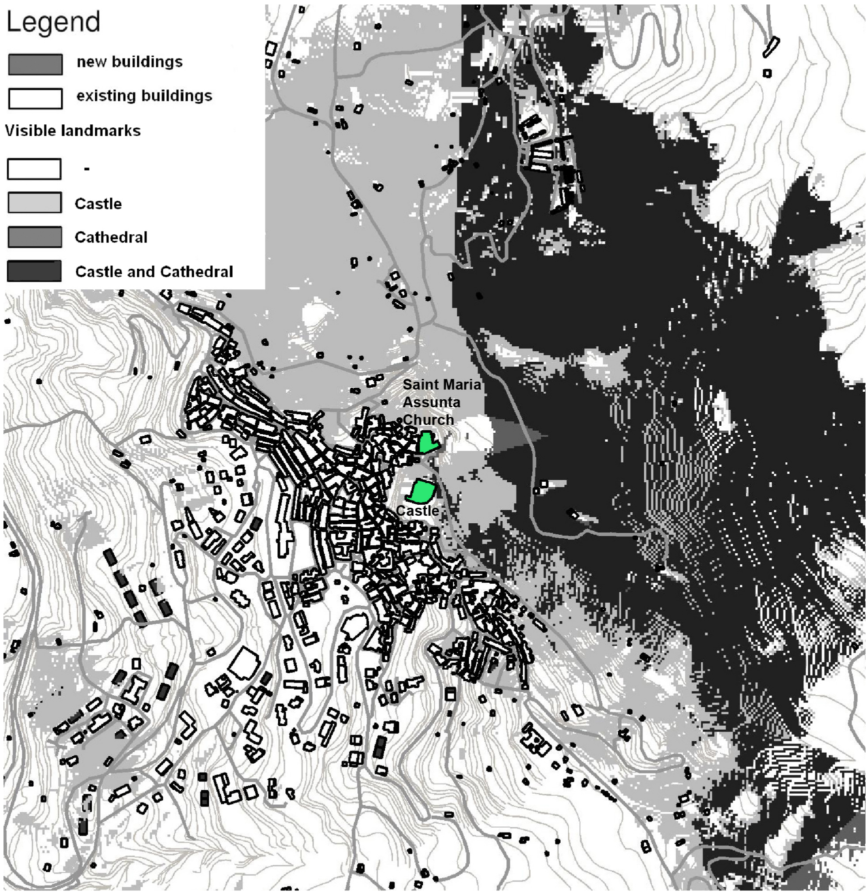

Fig. 4. The Identifying viewshed of Laurenzana

Laurenzana town is located on a ridge and has many old mansions. Among these, the castle and Saint Maria Assunta Church have been chosen as landmarks.

The analysis was first carried out on the current status, in order to evaluate the degree of visibility before the location of a new residential area. So the cumulative (figure 3) and the identifying map (figure 4) have been calculated. Several design alternatives, different locations of the new project and different heights of the buildings located inside the boundary of the new urban plan have been considered, and the results have been compared from visual points of view.

Results show that the location of new residential area, chosen in the plan, does not produce considerable impacts concerning visual aspects. More precisely, the simulation of new neighbourhoods highlights that new buildings do not obstruct either the sight of landmarks, or the sight of the town. Both maps illustrate that the castle is always visible along the principal road which represents the main access to the city.

In Laurenzana, simulation on Visual Impact Assessment has been realized also considering a natural reserve, called Abetina. In fact, it is a very important resource

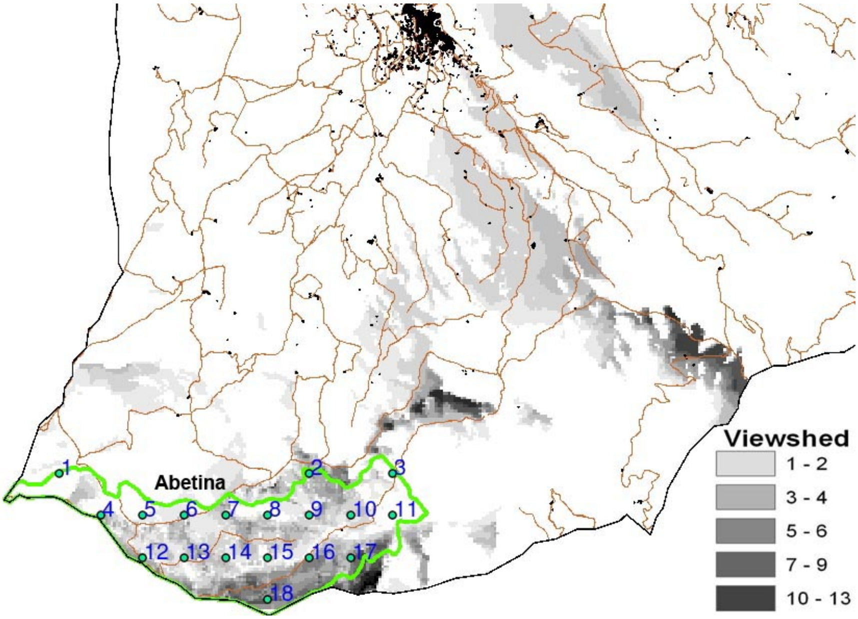

Fig. 5. Visibility of the Abetina from the urban area

Fig. 6. The viewshed analysis of Venosa, calculated in the current status and after the project

for this town, both from the natural and landscape points of view. In order to understand the visibility of the Abetina from the urban area, the natural reserve has been divided in eighteen sub-areas, each represented by a point. In this way, calculating cumulative and identifying viewsheds, it is possible to understand which and how much are large areas visible from each point inside Laurenzana.

A completely different result has been achieved in the case of Venosa municipality. In this town the famous Latin poet Quinto Orazio Flacco was born and it is characterized from the presence of several buildings which can be considered as an important cultural heritage. Therefore the Castle, Orazio's House, the Cathedral and the Trinity Church have been considered as landmarks.

In this municipality a new developed zone has been located in a flat area, suitable from the geological point of view, with a good accessibility.

In this case viewshed analysis shows (figure 6) that the new residential zone designed in the urban plan, with an height of 15m, completely obstructs the sight of these structures from a lot of points of the town and also from the main access road to the city. In this case visual impact assessment, usually ignored in urban planning, could become a crucial factor in evaluating the suitability of this area for a new neighbourhood.

Another kind of morphology characterizes the third study case, Pisa, because of its flat territory. At the same time this city has a great number of famous architectonic and historical heritages, which really contribute to create the image of this city, so the

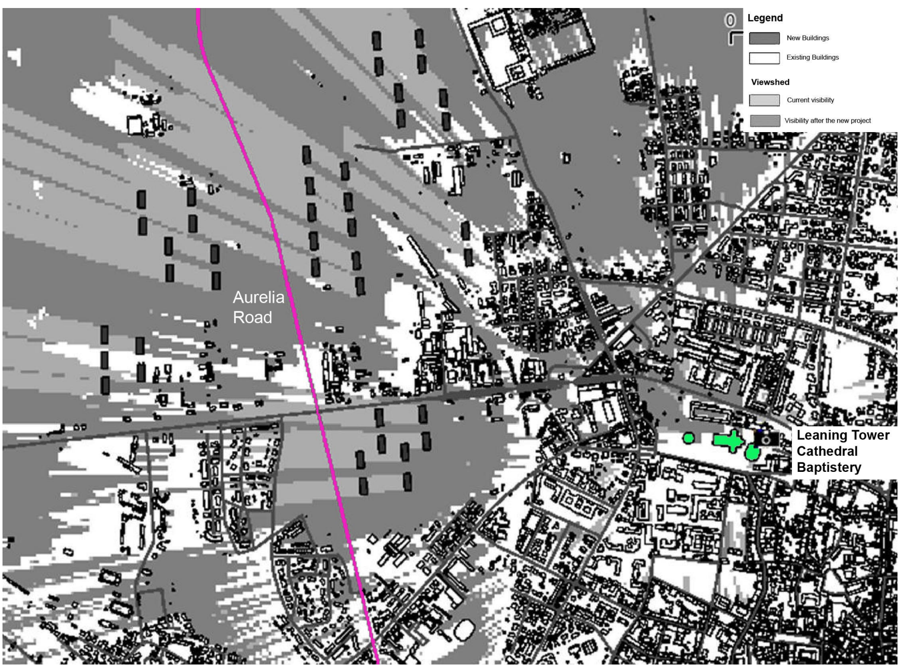

Fig. 7. The viewshed analysis of Pisa, calculated in the current status and after the project

location of any new project must pay a great attention to the visual aspect and to avoid any type of obstruction. In this study we considered, in particular, the viewshed study of the Tower, the Cathedral and the Baptistery.

In this case, the attention is focused on an area close to the town and near to Aurelia road, built during the ancient roman times to improve the connection from Rome to France. This tree-lined road is used by great part of tourists to reach the town. From this road it is possible to see the Leaning Tower.

Considering a land suitability procedure for a new development zone, this zone is suitable from a lot of points of view, geology, flood risk, accessibility, proximity to the town, etc.. Also in this case viewshed analysis is the aspect which can determine in an unambiguous way if an area is suitable or not for a new development zone. It is possible to see (figure 7) which are the effects obtained choosing the wrong area for a new residential zone: a partial, but very meaningful obscuring of the monuments also from Aurelia road, which is the main access road to the city.

5 Conclusions

Even if Visual Impact Assessment is one of the most important issues in Environmental Impact Assessment, it is often neglected, in particular in urban planning, sometimes also due to difficulties and costs that must be paid to obtain results with classical instruments.

The built model, instead, provides a useful tool to analyse and compare different alternatives from the visual point of view in a quick way. For these reasons, it could be successfully used in every other application field, where there is the need to make these evaluations, such as in locations of wind turbines, in particular because the Identifying map makes the user able to understand which is the machine causing the worst impact.

However viewshed analysis shows a limit: it is a good starting point to evaluate visual impact, but it is not enough because it does not consider the case when a new project does not obstruct landmarks, but it is not very well integrated with them or with other characteristic features of the city. On this purpose, the ideal equipment to carry Visual Impact Assessment is composed by quantitative methods improved in GIS, by renderings and virtual reality which can answer these other problems.

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Urban Roughness Parameters Calculation in the City of Rome by Applying Analytical and Simplified Formulations: Comparison of Results

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Abstract. The mesoscale meteorological models are the most used to study air quality and pollutant dispersion processes in urban areas. However they do not have the spatial resolution to directly simulate the fluid dynamics and thermodynamics in and around buildings and other urban structures that can modify the atmospheric characteristics. In order to improve the quality and consistency of mesoscale models the most extensively adopted approach is the "Urban Canopy Parametrization" (UCP) which allows to describe geometric and morphological characteristics of urban agglomerations by a range of parameters derived from analysis of high resolution databases. This work has the aim to analytically determine some of these parameters and an automatic procedure was implemented by Arcgis 9, using as input data the vectorial numerical geodatabase of the city of Rome, coded in 1: 2.000 scale and provided by CARTESIA S.p.A. This procedure was applied to the IX district of the city of Rome, whose full extent is about 8.1 km^2.

Keywords: Urban Canopy Parameter, Roughness Length, Displacement Height.

1 Introduction

1.1 The UCP Parameters

According to the Urban Canopy Parameterization, the urban tissue is characterized by a series of parameters that describe the geometric, morphologic and physical properties of buildings and vegetation and allow to evaluate the city effects on the atmosphere. The most used parameters for the UCP are summarized in Table 1.The analysis of Table 1 shows that for a complete characterization of the city, is important to calculate not only the buildings parameters but even those parameters linked to the vegetation and the urban canopy. As a matter of fact, this is not always possible because the high resolution databases, employed in the urban vegetation covers, are not always available. Some studies (Burian et al. 2002 2004) show the utility to intersect a wider dataset in order to distinguish the verdant areas, for example employing the DEM together with the up-to date digital maps that show the buildings plans.

1.2 Review of the Most Relevant Literature Models

For the aim of the work, the roughness length and the displacement height have been selected among the range of the UCP parameters.

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Table 1. The most used parameters for the UCP (Burian et al. 2002 2004)

Canopy UCPs	Building UCPs	Vegetation, Other UCPs
	Mean building height	Mean vegetation height
Mean canopy height	Standard deviation of building height	Vegetation plan area density
Canopy plan area density	Building height histograms	Vegetation top area density
Canopy top area density	Building wall-to-plan area ratio	Vegetation frontal area density
Canopy frontal area density	Building height-to-width ratio	Mean orientation of streets
Roughness length	Building plan area density	Plan area fraction surface covers
Displacement height	Building rooftop area density	Percent directly connected impervious area
Sky view factor	Building frontal area density	Building material fraction

The objective of this work is to determine these urban roughness parameters starting from a cadastral database relative to the buildings and to the road network of the city of Rome.

There are, in literature, different kind of methods connected to the calculation of the roughness length (z_0) and the displacement height (z_d) for an urban context. Some of the most meaningful methods are described below.

Height buildings method
It is the simplest among the methods available from literature and it is based on the relationship between the aerodinamic parameters and the middle height of the buildings.

Lettau's model
This model (Lettau 1969) considers only the obstacles having the same height and width (perpendicular to the direction of the wind). It assumes that the ratio between the z_0 and the height is proportional to the frontal area density (λ_F), which is defined as the relationship between the surface of the obstacles to whom the wind crash and the total surface on the ground. The model neither reproduce the effect of a "mutual sheltering" situation in a high density of obstacles nor can evaluate the z_d. The model fails for values of $\lambda F > 20\% - 25\%$ when the effect of the interference between the buildings becomes significant.

MacDonald's model
MacDonald (MacDonald et al. 1998) proposes a method that links the roughness lenght to the drag coefficients and to the displacement height. The model uses some coefficients which take into consideration the shape of speed profile, the intensity of accident turbolence, the turbolance scale, the wind incidence angle and the obstacles angles. The sheltering effect is included in the drag coefficient of the obstacles through the introduction of an efficient λ_F.

Duijm's model
This model (Duijm 1999) follows a different approach to evaluate the mutual sheltering effects. Duijm includes these effects in the drag coefficient and he introduces an

effective frontal area of the obstacles. The author also maintains the z_d definition and, with the aim to extend the values range of λF for which the model can be applied, he includes the efforts of shear stresses related to the substrate and to the top of the obstacles. Moreover the model does not depend on wind direction and on obstacles arrays and it even faces the possible presence of not squared form or rectangular form obstacles (for example l forms or squared forms partly wide). The aim of the model is to be applied to random situations. The concept is to create a regular array of obstacles equivalent to the real one. The model would require more data for the comparison when $\lambda F > 0.5$ or $\lambda F < 0.01$ and, besides that, it has never been applied to urban areas.

Raupach's model

Raupach's model (Raupach 1994), developed for random building arrangements, employs a range of statistical consideration in order to evaluate the effect of a mutual sheltering situation. This method ties the aerodynamic parameters to the middle height of the buildings and to the frontal area index.

Raupach's model can be used for frontal area densities lower than approximately 0.1–0.2 because the model can not describe overlapping of sheltering in dense arrays. Increasing the involved frontal area, the effect of mutual sheltering becomes more meaningful and the evaluation of z0 can be overestimated.

Bottema's model

The aims of Bottema's model (Bottema 1996 1997) are the following:

- grouping experimental data (particularly wind tunnel) obtained from the relation between the buildings lay-out and the aerodynamic roughness parameters.
- creation of a model able to analytically evaluate the roughness parameters in function of buildings characteristics and their geometric arrangement.

Bottema's model will be further analyzed in chapter number two.

Bottema-Mestayer's application

This application (Bottema and Mestayer 1998) calculates the roughness length and the displacement height from the Strasburg cadastral database. The roughness basic unit is a 2-D grid cell and the Bottema's model is used for the calculation of the roughness length. Due to the complexity of z_d calculation in case of building random placement, the authors propose a simplified formulation connected to the height and to the planar area density of the buildings.

The "Mutual Sheltering" problem has been approached by all models in different ways. The mutual sheltering is a relative decrement of the wind velocity caused by an obstacle towards another. The so called height buildings model and the Lettau's one are not expected to reproduce the effect of mutual sheltering for higher obstacles densities. In Macdonald's model and Duijm's model the effect of sheltering is represented by the drag coefficient of the obstacles through the introduction of an effective frontal area density. Raupach's model introduces a shelter coefficient derived from the w/h ratio and Bottema's model studies the problem using z_d as a parameter of mutual sheltering, founding itself on the calculation of distances among obstacles.

1.3 Proceedings

The objective of this work is to determine the urban roughness parameters starting from a real urban environment. These input data contain information concerning: the length of the roads arcs, the area and perimeter of the buildings and the rooftop height of the different building units which compose a building block. In this work the buildings geometry has not been modified even for concave buildings. Starting from this type of database, the most important parameters are deduced from geometrical and topological evaluations by ARC Info programming. The first step of the work has the aim to elaborate the initial database to make simpler the calculation of geometric and topological parameters. In this context the orientation of the arcs, necessary to make the system able to calculate the most important quantities for any wind direction, are calculated. Bottema's model (Bottema 1996 1997) is taken as reference and it has been adapted to the analysed urban environment. The parameters describing the buildings distribution on territory, are computed. All these parameters are calculated for each buildings side according to the wind direction choice. We supposed that the analysed sides belong to a regular building which is part of a normal or staggered regular array or with overlapping. All the calculations are referred to a single block side and the needed parameters are estimated by considering the specific typology of the distribution (kind of array) containing the block. The wind direction choice is the program first step and it is arbitrary. Subsequently the blocks sides, involved in the wind direction choice, are selected and only for them the model parameters are computed. After that step, necessary for the model application, a 2-D grid cell is superimposed to the buildings cover and then z_d and z_o are estimated for each cell whose dimension is (200 x 200) m. Afterwards, the Raupach's model and the Bottema-Mestayer formula for the calculation of z_d are applied. Finally a comparison between the obtained results is carried out.

The developed procedure concerns the following items:

1. Creation of a reference database;
2. Calculation of z_d and z_o according to Bottema's canonical formulation, by estimating the most important geometrical parameters for the evaluation of z_d and z_o;
3. Calculation of z_d and z_o according to Bottema-Mestayer's formula and Raupahc's method;
4. Comparison between three methods.

2 Developed Work

2.1 Input Data

The input data are represented by the cadastral databases of a portion of Rome relative to buildings and road network (Figure 1).

These data include the information concerning the roads arcs length, the buildings area and perimeter and the rooftop height of the different building units which

Fig. 1. Cadastral database

compose a building block. In this work the buildings geometry, including those having a concave shape, has not been changed. Starting from this type of data, the most important parameters are deduced from geometrical evaluations by ARCInfo programming.

2.2 Preliminary Processing

The present work first step aims at carrying out, from the input database, the data necessary for the model parameters subsequent extraction. The most important data characterizations concern:

- the identification of the unitary building block, starting from the building units;
- the identification of the linear building block sides;
- the orientation, as of the north, of each side; this information is necessary to evaluate which sides have to be considered relevant for a chosen wind direction.

These characterizations are carried out by implementing an AML code which operates according to the following steps:

- it carries out the intersection between building units and creates a polygonal cover in which we find blocks (Figure 2A).
- it rebuilds the linear topology of blocks (Figure 2B) and splits the perimeter in the block vertexes (Figure 2C). This procedure has the aim to obtain, for each block, a number of arcs which is equivalent to the number of the sides. The output of the procedure is a linear coverage composed of coded lines; each of them has two new attributes describing: a) the block code, b) the block areal dimension and c) the belonging side which is recorded by the program in an clockwise ordered way.
- it calculates the nodes coordinates for the linear coverage.

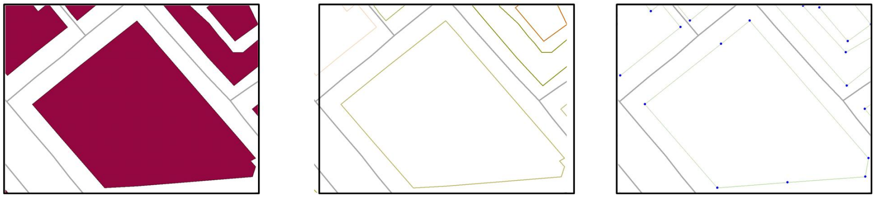

Fig. 2. Step A, B and C. The procedure creates a polygonal cover, rebuilds a linear topology and splits the perimeter in the block vertex.

- for each arc, it calculates the orientation as to the north; in this way we can: a) associate each arc the belonging side and b) we consider connected arcs having similar orientation (or a slight angular difference or a slight length) as an unique arc belonging to the same side of the block (Figure 2C). This operation is performed to further reduce the number of elements to be managed and to split the polygonal representing the block in a number of arcs equivalent to the number of the sides. Furthermore, we aim at creating a procedure that, using the arcs orientation, can calculate the meaningful parameters for any chosen wind direction and for each arc. In order to compute the arcs orientation, the program carries out the following steps:

a) It considers, for each arc, the length L and the coordinates of both the final [P2 = (X2 , Y2)] and the initial node [P1 = (X1 , Y1)];
b) It calculates the distances B and A and the alfa angle = arcsin (B/L);
c) It establishes the arc orientation through the value of the alfa angle in accordance with the values of the arc initial and final node coordinates which is done considering eight possible cases (Figure 3).

- By considering a block at a time, the program associates to each arc the belonging side in relation to both the orientation and the length of the arc itself, always considering the building area. The considered arc is compared to the previous connected one in the chain of sides; if the angle between the two arcs is less than 45° or if (even with a wider angle) the arc length is less than an established value, then both arcs will have the same identification number as for the side; alternatively the considered arc will have a value equivalent to the one of the previous arc side plus 1. Moreover the possibility that the first, the last and the second last arcs in the chain belong to the same side is considered: they are compared one another and if the condition is met, then their identification number is changed. Considering the established value to which the length of the arc has to be compared, the following L values are considered :

1. for buildings with an area lower than 150 m2 L = 0
2. for buildings with an area lower than 500 m2 L = 5 m
3. for buildings with an area higher than 500 m2 L = 7.5 m

The above values are chosen in relation to the analysis of the considered zone.

- Finally the program creates a new cover by unsplitting the arcs having the same block identification and side number and coding these new elements by using all the necessary information derived from the previous cover. This new cover represents the database to which we will refer for the calculation of the parameters $z_{d,pl}$ and z_o.

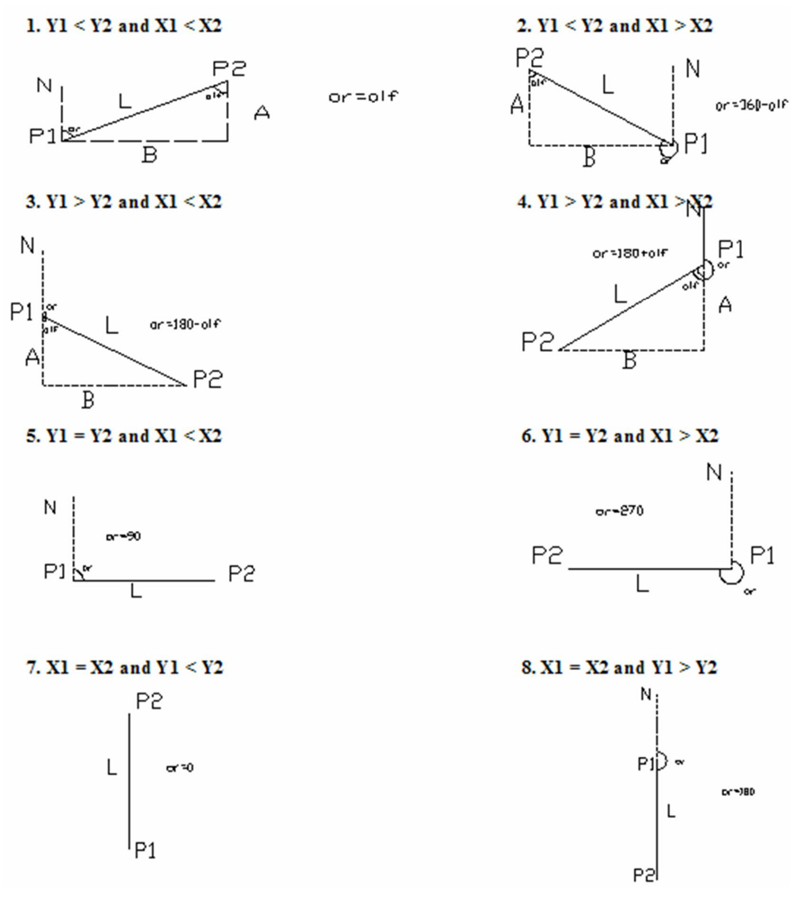

Fig. 3. Arcs orientation evaluation, considering eight possible cases. Each case is characterized by the value of : L, [P2 = (X2 , Y2)] and [P1 = (X1 , Y1)], B, A and alfa.

2.3 Analytical Determination of the Required Parameters to the Application of Bottema's Model

The aim of this work is to calculate the parameters necessary for the evaluation of $z_{d,pl}$ and z_o in relation to Bottema's model. Referring to this model, the equations which give us the quantities $z_{d,pl}$ and z_o are the following:

$$z_0 = (h - z_{d,pl})\exp\left(-\frac{k}{\sqrt{0.5\lambda_F C_{dh}}}\right) \tag{1}$$

where C_{dh} is a drag coefficient which depends only on the obstacle shape.
A formula for the evaluation of C_{dh} is:

$$C_{dh} = 1.2\max(1 - 0.15 l_x / h, 0.82)\min(0.65 + 0.06 w / h, 1.0) \tag{2}$$

where $\lambda_f = wh/d_x d_y$ is the frontal area density.

1. For a regular normal array of obstacles (Figure 4a) we have:
   for low densities if $S_x > 4Lg$:

$$\frac{z_{d,pl}}{h} = \frac{l_x + \frac{4Lg}{3}}{d_x} \tag{3}$$

   for high densities if $S_x \leq 4Lg$:

$$\frac{z_{d,pl}}{h} = \frac{l_x + \left(2 - \frac{S_x}{4Lg}\right)\frac{S_x}{3}}{d_x} \tag{4}$$

2. For a staggered array of obstacles as in Figure 4b, the minimum value of d_x and d_y is respectively $2l_x$ and $0.5w$:
   for low densities if $S_x - d_x/2 > 4Lg$:

$$\frac{z_{d,pl}}{h} = \frac{l_x + \frac{4Lg}{3}}{\frac{d_x}{2}} \tag{5}$$

   for high densities if $S_x - d_x/2 \leq 4Lg$:

$$\frac{z_{d,pl}}{h} = \frac{l_x + \left(2 - \frac{S_x - \frac{d_x}{2}}{4Lg}\right)\left(\frac{S_x - \frac{d_x}{2}}{3}\right)}{\frac{d_x}{2}} \tag{6}$$

3. For a regular array in case of overlap: if $d_y/w < 1$ then we have overlap S_y becomes negative and z_d is now made up of two parts. The first one represents a normal regular array of buildings as to the zone covered by the upstream row, the second one represents a staggered array as to the remaining zone.

$$z_d = z_{d,pl} = \left(\frac{2d}{w} - 1\right) z_{d,pl(staggered)} + \left(2 - \frac{2d}{w}\right) z_{d,pl(normal)} \tag{7}$$

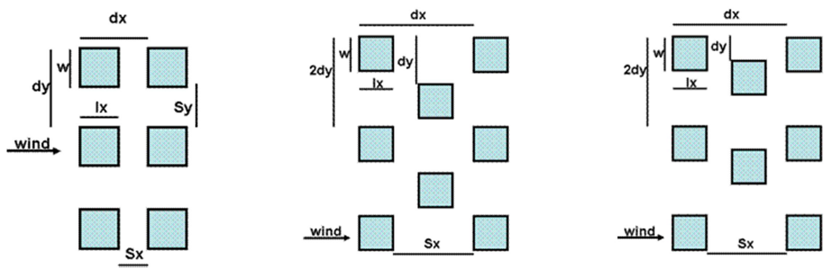

Fig. 4. Different kind of obstacles array: a ,b, c

The necessary parameters for the evaluation of z_o and $z_{d,pl}$ are: h, 4Lg, l_x, d_x, S_x, d_y, S_y, w. All those parameters are calculated for each arc, established a wind direction and supposing each arc is part of a regular obstacle in a regular array. Before starting the computation phase, the program allows to choose a whatever wind direction. For example a wind direction equal to 340°, with respect to the straight line representing the North direction, is chosen. The arcs involved by the chosen wind direction are selected and only these arcs are considered. In the proposed case study selected arcs are 694 among 1431 possible ones.

- h

  Data at our disposal give the height of the different parts which form a building. The height of the arcs belonging to a building is thus established through an average weighted on the area of the building itself:

$$h_{arc} = \frac{\sum_{i=1}^{n} h_i A_i}{A_{totbuilding}} \tag{8}$$

where n is the number of the parts which form a building.

- 4Lg

$$4Lg = LR + LF \tag{9}$$

  – LR and LF derive from experimental results and represent the lengths of the recirculation zones respectively calculated from the windward side and the upstream side.
  – Lg is the geometrical influence scale of an obstacle: Lg = (2wh)/(2h+w).

  Just for this parameter the real length of the arc (w), independently from the wind direction, is used.

- d_x, S_x, l_x

The length d_x represents the distance between two different buildings sides orthogonal to the wind direction and is made up of the lengths l_x and S_x (Figure 5). The first one is the length of the arc which is linked to the considered arc and is parallel to the wind direction, while the second one represents the width of the road which divides the two buildings. The adopted database does not reveal the position of a building in relation to the others, so it's necessary to know, for each side, the opposite building position in order to establish the distance between them. The program carries out the following operations:

1. It calculates the average point of each arc taking into account the nodes coordinates;
2. It draws the parallel straight line to the wind direction which passes through the arc average point and goes towards the interior of the building, always on the right of the arc direction. An established value is given to the length of the straight line; it depends on the value of the area of the building to which the arc belongs. In the examined urban area we found that, for small buildings, this value is lesser because they are nearer. When the length is known, if we think about the similitude between the two right-angle triangles, one having as its hypotenuse the arc and the second having as its hypotenuse the straight line, we can establish the straight line final point. Then the straight line is drawn in relation to the coordinates of its initial and final points, considering the eight cases formerly examined for the determination of the orientation.

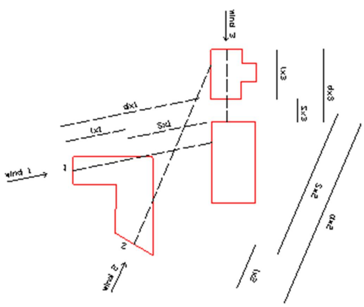

Fig. 5. Examples of d_x, S_x and l_x evaluation

3. It carries out the intersection of the straight line and the buildings cover, finding the building opposite the in wind direction one. After the intersection, the straight line is split into various stretches having the identification numbers of the building to which the arc belongs, of the opposite building and of the road. Ordering the stretches according to their identification number, we can calculate the lengths d_x, l_x and S_x. Since the buildings have no regular shape, are made up of various arcs and the wind direction can be any, we can assume that the length l_x is the same of the straight line stretch having, as identification number, the same of the building to which the considered arc belongs.

- d_y, S_y, w
  The length d_y represents the distance between two building sides parallel to the wind direction and it derives from the lengths w and S_y (Figure 6). In case of normal regular distribution the first one is the length of the considered arc, and the second the width of the road which separates the two buildings. In case of a staggered array and of overlapping, the lengths d_y and S_y remain the same while w changes. Precisely w is the length of the side orthogonal to the wind direction

and windward of the building which is opposite the considered arc. So, if there is overlapping d_y has an inferior value than w and, consequently, $S_y = d_y - w$ becomes negative. In this way the length d_y represents an indicator of overlapping. According to the values of the parameters above described, we use the various solutions offered by Bottema's model.

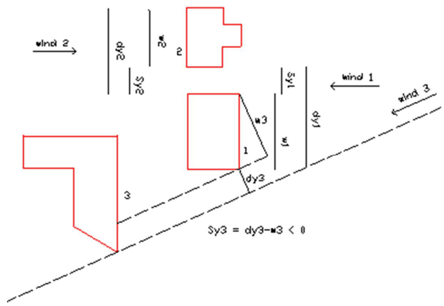

Fig. 6. Description of the parameters d_y, S_y, w

In order to calculate the parameters d_y, S_y and w, the program carries out the following operations:

1. It recognises the buildings which are opposite to the considered arc. This is possible by creating the straight lines parallel to the wind direction and by using, as starting point, respectively the initial, the middle and the final point of the considered arc. This procedure could be improved if we increase the number of straight line: this in order to consider the possibility that an arc may have some buildings opposite it. As for d_x parameter, the straight line is established in relation to the area of the building to which the arc belongs. The straight lines are created following the same procedure previously used for the evaluation of d_x. Then the program carries out the intersection between the straight lines and the buildings cover. The intersection divides the straight line into some stretches: each of them has the identification number of the involved road or of the involved building. This procedure allows to recognise the building which is opposite the arc and, if the straight line intersects more than one building, it allows to choose the building nearer to the arc. Each of the three straight lines is cyclically checked, so that we can get the identification number of the involved buildings.

Some particular cases can be singled out:

- If more than one straight line intersects the same building, only one of the straight lines is considered;
- If one or two of the three straight lines does not intersect anything, they are not considered;
- If all the three straight line does not intersect anything (which is typical for boundary conditions; case B Figure 7), we give d_y the value d_yB and w the value wB.

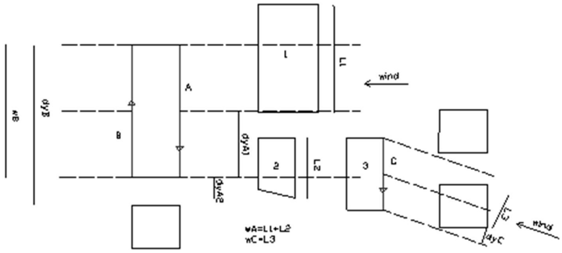

Fig. 7. Examples of d_y, S_y and w evaluation

In the other cases, once the frontal buildings was determined, the length d_y is calculated for each arc. The length d_y is analytically evaluated according to the geometry of the involved buildings (Figure 8). The idea is to calculate the distance between the final node (TN) of the considered arc and a meaningful point of the opposite building. This distance can be thought as the hypotenuse of a right-angle triangle in which a cathetus is the straight line having the same direction of the wind and passing through the final point of the arc, and the other cathetus is d_y. The meaningful point, which enables to find the hypotenuse of the triangle, is found considering the direction and the orientation of the arc. This point of the building, frontally located, is chosen according to these two parameters; the point of the building with a higher or a lower coordinate X or Y is selected.

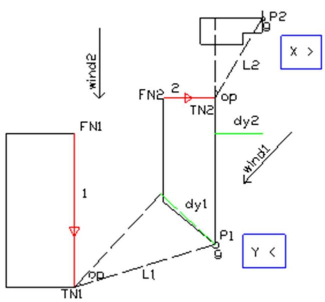

Fig. 8. Length d_y evaluation

To obtain the length d_y it is necessary to calculate the angle op included between the straight line Dw and the hypotenuse L (Figure 9).

To calculate op the orientation of the hypotenuse L has to be firstly considered. It is quantified by the angle (g), which is included between the hypotenuse and the straight line that indicates the north and passes through the point P. In the examination of the angles, which quantify the orientation of the straight lines, the above described eight cases are considered and for each of them the angle to be found is obtained by comparing the angles g and Aw. For example, in a case similar to the Figure 10, the angle op = g – Aw. Considering the orientations, the program takes into account also the particular situations in which a building partly surrounds another (Figure 10). In these situations the way to calculate the angles, which determine the orientations, depends on the geometry of each case.

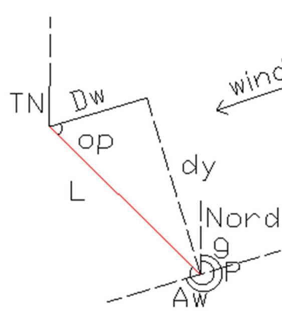

Fig. 9. Assessment of the straight line orientation

This case is presented in Figure 10:

X1 = X2 and Y1 < Y2 with X1, X2, Y1 and Y2 indicating the coordinates of the initial and final arc point. This is the case in which the orientation of the straight line L (g) exceeds the arc one plus 180°. With the same approach the other seven possible cases are faced.

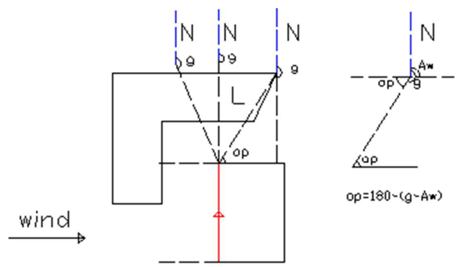

Fig. 10. Particular situations in which a building partly surrounds another

Another possible situation is the one of half-closed buildings in which the straight lines, drawn from considered arc, can intersect the building to which the arc belongs. For these kind of buildings dy value is given equal to zero and w is the length of the arc. Finally, other particular situations are faced: in these cases the arc belongs to an imposing building deeply irregular as to the shape and containing a lot of arcs (Figure 11). In this case, since dy would be considered in relation to the building to which the arc itself belongs, we assign dy a value equal to zero and w the length of the arc. Considering the two possible preceding situations, we found 70 cases among the 694 possible ones.

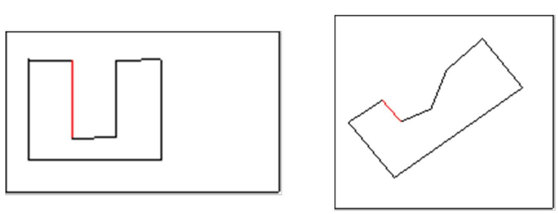

Fig. 11. Examples of two particular situations

2. The program considers the length w. In the boundary cases, where the arc has no buildings opposite to it, w has the same length of the arc itself. When there is overlapping, to determine w, we select the involved buildings and among the arcs which constitute them, we choose those ones having an orientation included in a range which goes from the orientation of the considered arc to, more or less, 20°. We are obliged to apply this procedure, which gives a not always precise value of w, as, when the buildings opposite the arc are find out, they are represented through a polygonal and not through a linear topology, so we are not able to identify the arcs we are searching for. The w values, calculated for each building, are summed up and the final w value is obtained. Furthermore it is also possible the case in which the selected buildings have no arcs with the searched orientation: 59 cases among the 694 possible ones were found out. In these situations we take into account the inferior meaningful point and the superior one of the selected buildings and we calculate their distance giving this value to the w parameter (Figure 12). Once established w value, the length w (wind), which is actually struck by the wind, is determined by calculating the projection of w along the orthogonal to the wind direction.

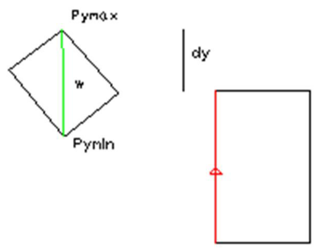

Fig. 12. Length w evaluation

3. In all cases the procedure finds more than one building opposite the considered arc and then different values of dy are present; a unique value of dy is considered and computed as follows:

$$d_y = \frac{\sum d_{yi} w_i}{w} \tag{10}$$

where d_{yi} and w_i are respectively the d_y and w values calculated for the different buildings opposite the arc.

4. Finally the program calculates the value of S_y as the difference of d_y and w: $S_y = d_y - w$.

If there is overlapping S_y becomes negative and it can be used as an indicator for the overlapping.

2.4 Evaluation of $z_{d,pl}$ and z_0

Once the different arc parameters are determined, we proceed with the calculation of $z_{d,pl}$ and z_o. The main unit for the calculation of $z_{d,pl}$ and z_o is a 2-D grid cell that can be orientated in any direction. The dimension of the grid cell may change. We choose a dimension of 200 m x 200 m as we want to obtain a unique value of $z_{d,pl}$ and z_o for each 200 m resolution cell. For each cell the frontal area density (λ_f) , the planar area density (λ_p) and the average (weighted on the area) of the buildings height have also been calculated. In order to recognize the arcs contained in each cell, an intersection between the definitive cover and the grid cell is made. Afterwards, following the formulations of Bottema's model, both $z_{d,pl}$ and z_o are calculated for each cell. In order to carry out the calculation, if the d_y value of the arc is lower than 5 m (in this case we consider that as a normal array), we suppose that the building to which the considered arc belongs is part of a normal regular array in the chosen wind direction. If d_y has a bigger dimension, we consider the formula relative to the regular array in which we find overlapping. To obtain a unique value of $z_{d,pl}$ and z_o, concerning each cell, the arcs contained in each of them are selected and a length weighted average is made:

$$Z_{d,pl} = \frac{\sum_{i=1}^{n} Z_{d,pl(i)} \bullet L_i}{\sum_{i=1}^{n} L_i} \tag{11}$$

where n and L are respectively the number of arcs and the length of the arc i.

3 Conclusion

The figures below show the results relating to z_d and z_0 for a 100 m x 100 m grid cell.

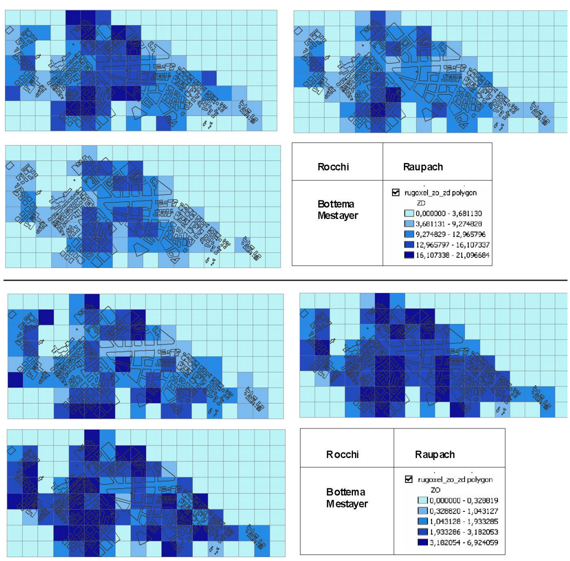

Fig. 13. Comparison between the results of this work and the results of the application of Bottema-Mestayer and Roupach models

Figure 13 shows how the difference between the values obtained through the three methods decreases when the planar area density increases (chromatic similitude). Consequently, when the difference between the cell area and the buildings block total area (included in it) is low, it is clear that the values obtained are similar. The value of z_d calculated through the Bottema-Mestayer method does not vary according to wind direction, as the experimental relationship, which determines the parameter, is based on the planar area density that does not change with the wind. For cells with a planar area density different to 0, it is possible to have a frontal area density equal to 0, as the buildings sides (present in the cell) are not involved in wind direction. This happens when cells contain some isolated buildings. Even in these cases, using the experimental procedure here presented, z_d and z_0 will always be different to 0. The Bottema-Mestayer method differs from the others which employ mathematical relationships based on frontal area density.

The previous analysis was repeated taking into consideration only the inner cells. Avoiding boundary effects, the difference in roughness values is reduced.

The graph (Figure 14) shows that the difference of the z_d and z_0 values, obtained through the three models, increase for the low frontal area density values (0 – 0.2). Modifying the wind direction, the calculation procedure was implemented again (Figure 15). This allows to underline the addiction of the main parameters to wind

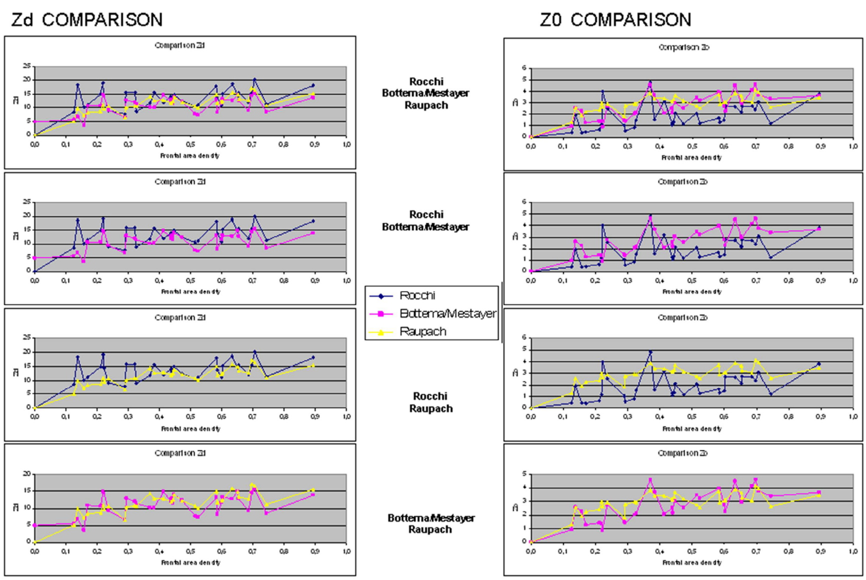

Fig. 14. Z_d and Z_0 as a function of frontal area density after the exclusion of "border effects"

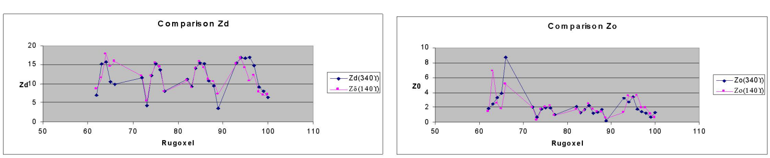

Fig. 15. Analysis of the results obtained modifying the wind direction

direction. In the second implementation a wind direction of 140°, in comparison to the North-South straight line, was selected and 740 arcs among the total amount of 1431 were identified.

By comparing the results, we can observe that the trend of the three curves is quite similar while a more sensible difference is detected in relation to both z_0 and z_d values. Moreover, the difference increases with lower values of frontal and planar density.

This trend can be explained by analyzing the different approaches adopted in the previous three models. The Bottema-Mestayer model is empirical and adopts, as principal parameters, the buildings height and their planar density; so it does not consider the mutual distance between the buildings blocks. Moreover, from many applications, it seems that the model tends to return overestimated values with frontal density values greater than 0.2. The developed new procedure, on the contrary, is founded on the analytical evaluation of the mutual distance between buildings, which influence the results due to the weight they have in the model formulation. The analytical adopted approach allows to apply the model in every urban context and for any wind direction. Very few studies are now available, concerning the application in existing urban contexts of theoretical models of urban roughness parameters estimation, so it is quite difficult to fully appreciate the goodness of the obtained results. At this time we are looking for the validation of the experimented procedures by employing the devised model in urban areas already tested with other methods.

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Appendix

In this section the most important equations related to the methods mentioned before are reported.

- Height buildings method

$$Z_0 = f_0 \overline{Z}_H \qquad Z_d = f_d \overline{Z}_H \tag{12}$$

where f_0 and f_d are the empirical coefficient.

- Lettau's model

$$\frac{Z_0}{h} = 0.5 l_F \tag{13}$$

- MacDonald's model

$$\frac{Z_d}{Z_H} = 1 + a^{-l_P}(l_P - 1) \tag{14}$$

$$\frac{Z_0}{Z_H} = \left(1 - \frac{Z_d}{Z_H}\right) \exp\left[-\left\{0.5 b \frac{C_{dH}}{K^2}\left(1 - \frac{Z_d}{Z_H}\right) l_f\right\}^{-0.5}\right] \tag{15}$$

$$C'_D = C_D\, k_S k_i k_l k_\theta k_\gamma \tag{16}$$

MacDonald suggests some values for α (empirical coefficient): it is equal to 1 if $z_d/H=\lambda_P$, is equal to 4.43 for staggered arrays and to 3.59 for regular arrays. β parameter, the correction factor of the aerodinamic resistance, is equal to 1.

- Duijm's model

$$l_{F,eff} = l_F\left[1 - S\frac{Z_{d,pl}}{h}\right] \tag{17}$$

$$\frac{Z_0}{\overline{h}} = \left(\frac{h - Z_d}{\overline{h}}\right) \exp\left[-\frac{k}{\sqrt{\dfrac{t_{drag} + t_{substrato} + t_{top}}{rU^2(h)}}}\right] \tag{18}$$

- Raupach's model

$$1 - \frac{z_d}{h} = \frac{1 - exp(-\sqrt{2c_l \lambda_f})}{\sqrt{2c_l \lambda_f}} \tag{19}$$

$$z_0 = (h - z_d)\, exp(-\psi_k)\, exp\left(-k\frac{U_h}{u_*}\right) \tag{20}$$

where :

$$\frac{U_k}{u_*} = \frac{exp\left(c\lambda_F \frac{U_k}{2u_*}\right)}{\sqrt{C_S + \frac{1}{2}C_{dh}\lambda_F}} \tag{21}$$

- Bottema's model

$$U(z) = \frac{u_*}{k} ln\left(\frac{z - z_d}{z_0}\right) \tag{22}$$

U(z) is the wind mean speed at z height on the surface.
The basic model equation is :

$$z_0 = (z_{ref} - z_d) exp\left(-\frac{k}{\sqrt{0.5\lambda_F C_D(z_{ref}, \lambda_F, w/h, ...)}}\right) \tag{23}$$

Z_{ref} is within the logarithmic height range, C_D is the drag coefficient and λ_F is the frontal area density.

- Bottema-Mestayer's application

$$z_d = h\left((\lambda_P)^{0.6}\right) \tag{24}$$

where λ_P is the planar area density of the basic cell.

An Object-Oriented Model for the Sustainable Management of Evolving Spatio-temporal Information

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Abstract. The sustainable management of geographic information through time is fundamental in the field of spatial planning, because handling of long-term statistical indicators is useful for setting up prospective scenarios. Sustainability means the control of complex information which is often incomplete: data come from multiple scales and heterogeneous grids, from various suppliers, at many dates, with a semantic which keeps evolving. Under these conditions, a framework for data quality assessment and estimation of missing values is necessary. This paper draws out a proposition for a system based on an object oriented spatio-temporal data model fit to figure out some relationships of interest when managing missing values, and providing a support for storage and exploitation of metadata through the usage of thematic and geographic ontologies.

Keywords: Spatio-temporal model, statistical indicator, geographical unit, mesh, ontology, missing value, estimation.

1 Introduction

Recent developments in a continuously changing and globalizing world require a more and more thorough planning at national and international levels, in order to ensure a better adaptation in a rapidly evolving world. Yet, this planning should use a knowledge of territories based on the management of sound and detailed data, spanning over a long period of time, allowing experts to identify and understand trends, to find possible problems and answers, to elaborate and test policy scenarios. Some efforts have been done to obtain a complete database at the European level containing a comprehensive set of socio-demographic indicators recorded since the conception of the European Union. However, some obstacles persist concerning the heterogeneity of data recorded in the past, and the necessity of assuring upward compatibility with future data.

Heterogeneity of data is mainly due to the process of data collection. Indeed, the reality of data production is far from ideal: there are many data suppliers, who collect their data on different spatial supports at various frequencies, and who do not use the same methodology for measuring. Nowadays, via the control and the help of European organizations, such as the European Environment Agency (EEA), EUROSTAT, etc., suppliers try to produce environmental, social or economical data with an

B. Murgante, G. Borruso, A. Lapucci (Eds.): Geocomputation & Urban Planning, SCI 176, pp. 167–186.
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enhanced degree of consistency. This is the purpose of European directives like *INfrastructure for SPatial InfoRmation in Europe* (INSPIRE).[1]

Moreover, territorial organization of units evolves over time. Therefore, it is hard dealing with retrospective data series, in order to recollect them with harmonized methodologies, and one must deal with territories redistributed between units, at all scales, as it has occurred in the past and it may well happen in the future. This is a challenge for storing a comprehensive set of long-term socio-demographic indicators. Our objective is to take into account three dimensions (spatial, temporal and thematic) and the evolving nature of the information, in order to provide a reliable source of information about a given territory. Dealing with this evolving, spatio-temporal, thematic information poses a set of conceptual problems, some of them known and studied for some time, like the split tract problem (Howenstein 1993), the Modifiable Area Unit Problem (Holt et al., 1996), the change and dynamics of territorial units (Kavouras 2001; Norman et al. 2003), and the representation of space and time in conceptual models for GIS (Peuquet 2002; Albrecht 2007). These researches provide fragments of solution for the harmonization of heterogeneous data, but there is still a need for a system unifying them into a complete framework.

To meet this goal, we intend to build an environment fit to manage statistical indicators relating to the study of a given territory. This paper gives an overview of problems occurring when managing socio-economics indicators, and then draws out a proposition for a system based on an object oriented spatio-temporal data model, including an appropriate handling of operational ontologies and metadata.

This paper is organized as follows. Section 2 details the requirements of a system for socio-economic indicators management. Section 3 presents a spatio-temporal object-oriented data model, based on a qualitative approach, and expressing the spatio-temporal relationships of interest. Section 4 explains that this model is at the core of a framework suited to the estimation of missing values, exploiting metadata through the use of thematic and geographic ontologies. The conclusion gives an outline and some directions for future work.

2 Requirements for Handling Long-Term Statistical Indicators

2.1 Definition of a Statistical Indicator

Statistical information is defined in the United Nations thesaurus2 as: “an information gathered by statistical observation or produced by survey data processing. Statistical information describes, expresses in figures, characteristics of a community (population).” Within this thesaurus, a statistical indicator is “a data element that represents statistical data for a specified time, place, and other characteristics”. Therefore, statistical information is anchored in time and space. Another definition3 can be found: “an indicator is a variable having for object to measure or to appreciate a state or an evolution. An indicator has to be a simple information (easily understandable) which may be quantified in a clear, reproducible and fast way and has to synthesize complex

[1] http://www.ec-gis.org.inspire/
[2] http://www.unece.org/stats/publications/53metadaterminology.pdf
[3] http://www.geotraceagri.net/en/tools/indicators_gt.php

phenomena with various scales (plots of land, farm, region, etc.)". This means that statistical information should help in the understanding and in the anticipation of the evolution of a phenomenon. As it is said, statistical information can be collected at various geographic scales. In general, observation level of the territory is the State. National Statistical Institutes are the official suppliers of data. Periodically (but periods can vary from 5 to 10 years for the same institute), these institutes collect data about the population structure (total population, and its distribution by age, sex, social category). They also collect economic information: household revenue and indebtedness, Gross Domestic Product (GDP), number of employed, unemployed, and so on.

2.2 Spatial Organization of Data and Related Issues

Statistical indicators result from counting variables of interest (inhabitants, plants, etc.) over territorial divisions. Areas of accounting (also called Geographical Units, GU) have a space spatial footprint which can be represented by a geo-referenced shape (a geometry like a polygon). The set of polygons form a space partition which we call zoning or *mesh*. A mesh is a division of territory into a set of GU, which can be of various natures: administrative, economic, hydrologic, etc. Producers try to collect data at various spatial scales, defining spatial observation scales, using existing hierarchies of mesh. Indeed, meshes can be organized in hierarchies, where a mesh of level *n* includes (or nests) a mesh of lower level *n+1*, dividing the tessellation into sub-GU. By convention, mesh of level 0 is the most general partition of the space, and is at the top of the hierarchy. On the contrary, mesh of rank *n* is the most refined grained division of the space. The hierarchy constitutes a tree of depth *n*, where GU of mesh of rank *n* are leaves, and root GU is the whole study area. This is the case for the hierarchy *Nomenclature of Territorial Units for Statistics* (NUTS), an institutional division of European space, based on the population size of units. At rank 0, GU are the Member States; at level 1, great regions are populated by 3-7 millions of inhabitants; at level 2, European regions have between 800,000 and 3 millions of inhabitants; at level 3, GU includes between 150,000 and 800,000 inhabitants. At more detailed levels, there are districts (level 4), and municipalities (level 5), also named Local Administrative Units (LAU). This mechanism allows observing a territory at multiple scales from LAU to State levels.

Geographical units of meshes and/or their hierarchical organization evolve over time as shown on the example of Figure 1. It displays trees of meshes at two periods of time t_1 and t_2.

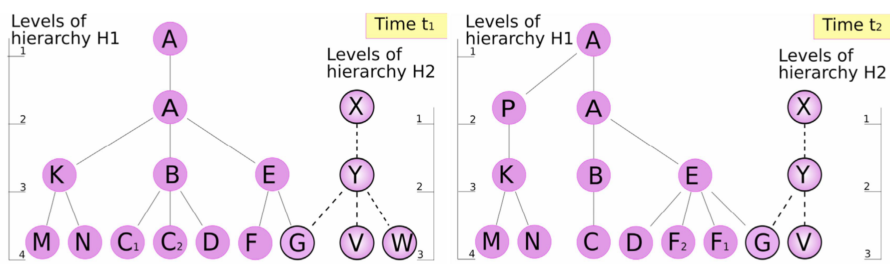

Fig. 1. Hierarchic organization of meshes and their evolutions from time t_1 to time t_2

For spatial analysis purposes, one may be interested in the comparison of various indicators collected at different epochs on different meshes. The main problem comes from the fact that there are many kinds of hierarchies to manage. Environmental or economic indicators are not necessarily measured on the same territorial partition. If sometimes those various hierarchies share a common mesh (see *G* on figure 1, which belongs to level 4 of h_1, and level 3 of h_2), the most often, the spatial footprints of the corresponding partitions (administrative units, economic basins, watershed activities, functional areas) do not match. Consequently, data are not directly transferable from one grid to another.

Even by limiting the study to only one partition, we face the problem of mesh evolution over time. First, boundaries of GU can change over time. For instance, river catchments of Loire basin may have evolved slightly since the last version of river catchment's mesh. In addition, organization of GU into hierarchy evolves through time. Some GU may appear, disappear, or be modified. As a result, mesh and hierarchy of GU change. Figure 1 illustrates this evolution by depicting two hierarchies h1 and h2 at the instants t_1 and t_2. For example, Germany is the result of the 1990 reunification of East Germany and West Germany (C_1 and C_2 have been merged to create *C)*, Czechoslovakia has split into Czech Republic and Slovakia in 1992 (scission of *F* into F_1 and F_2); the French department of Isère lost in 1967 some of its *communes* in favor of the neighboring department of Rhône (change of superior unit for *D* from *B* to *E*).

Another difficulty comes from the designation of geographic entities which can also evolve through time, and/or differ from one database source to another: even if boundaries do not change, area names and reference codes often vary with different versions, as well as spelling used across years and between different data suppliers and agencies.

Thus, the main difficulty when studying census data arises from the heterogeneity of spatial supports, and the evolution of meshes through time. When analyzing two time-series of demographic data (as an example) coming from a mesh which has changed, it cannot be known whether changes in the relationships between variables collected for areas are real or if they are an artifact of the boundary system in which they were collected (Norman et al. 2003). (Gotway and Young 2002; Openshaw and Taylor 1979) have made a broad survey of solutions to the well-known problem of Modifiable Area Unit Problem (MAUP) and Change Of Support (COSP).

However, these statistical methods do not fully use available knowledge on hierarchical spatial organization of units. As a matter of facts, this spatial organization is interesting for checking data, and providing estimations and projections. We may use data collected at various levels to check their consistency. For instance, aggregated values of GU at a certain level should match the one measured at the upper level of the tree. Then, a very simple use case for estimation could be to sum values of GU of a sub-mesh to calculate the likely value of a GU of upper level. More generally, estimation will proceed by using spatial relationships of hierarchy and/or proximity. Indeed, many families of methods for estimating missing values make assumptions about the similarity of nearby geographic units, following the first Tobler's law of geography: "Everything is related to everything else, but near things are more related than distant things".

In conclusion, our goal is to model the various meshes and their evolution inside a hierarchical spatial organization, enabling an extended usage of the model for estimation purposes.

2.3 Overview on Thematic Data and Related Issues

Still, knowledge of spatial organization of unit is insufficient to build a harmonized temporal series of statistical indicators. Indeed, one must deal with the heterogeneity and evolution of indicators, through space and time. Indicators do not always have the same name and meaning all over the world (excluding the effects of multi-language translations), and through time. Thus, categories and classification of data differ from one country to another, from one period of time to another. For instance, socio-professional categories in France are established to classify employed people according to their professional status (employee, employer, self-employed), size of their company, their sector of activity (industry, services, agriculture), study level (diploma) required for their profession, etc. Yet this nomenclature is not valid or used in the rest of Europe (Kieffer et al., 2002). Then, each country has built its own categories, based on specific theories and its history. Similarly, using the same designation, the definition (meaning) of an indicator may be different in two states, and/or between two suppliers. This is well illustrated by the two definitions for "unemployment" chosen by *French National Social and Economical Institute* (INSEE) and EUROSTAT institutes. At the European level (EUROSTAT), as in France, a person is considered as "without work" if he has had no activity for at least one hour during a week of reference, and if he can prove his "job search". The registration or renewal of his registration at the *National Agency For Employment* (*ANPE*) is one proof for job searching according to the INSEE, but not as interpreted by EUROSTAT. As a consequence, the unemployment rate in France in February 2007 is valued differently according to the provider (8.4% for INSEE or 8.8% for EUROSTAT). Therefore, there is a need for an extensive model of indicators semantic allowing for the automatic discovery of equivalencies between various definitions of indicators (what ever the translation). In that sense, metadata about indicators, which are provided by producers, should help building such a model (Haas et al. 2003; Pattuelli et al. 2003).

Furthermore, there is a multiplication of data sources due to multiple productions of data series over the same time period, and the existence of numerous data producers. Indeed, if, in general, States take charge of their own production of data, lots of data are provided by suppliers collecting primary data at the state level (i.e. EUROSTAT, the *World Bank*, etc.), or organisms such as the *Organization for Economic Cooperation and Development* (OECD) which do not hesitate to modify data coming from primary sources in order to enhance the consistency level of data, or to adapt figures to a certain political vision. Sometimes, organisms like the *European Environment Agency* (EEA) or EUROSTAT make some independent data surveys, such as the "Labour Force Survey", which provide data about the number of unemployed, employed people, etc. at regional level, which are not necessarily equivalent to national data. Moreover, data are often published after some adjustments or estimation processes which can introduce inconsistencies. Producers being aware of this problem, publish updated versions of the same dataset in various files or databases (the so-called sources).

In order to control the quality of data, and as recommended by the ESPON Handbook for data collection, data collection should be limited to raw (that is to say primary) data, and the lineage of data has to be well documented. The storage of lineage information requires documenting the various statistical series with the name of producer, production date, etc. This information represent statistical metadata, which are as important as data themselves. Furthermore, metadata also provide the various confidence levels on data source, estimation errors, weighting expressions, statistical summaries, etc., which should help to assess the quality level of a statistical series. The effective handling of metadata on statistical indicators has already been argued argued (McCarthy 1982; Kent and Schuerhoff 1997). The problem is to build a model for metadata which is generic enough, and allowing their exploitation for quality assessment and estimation of missing data (Kent and Schuerhoff 1997; Haas et al. 2003; Hert et al. 2007). The main difficulty is due to the evolution of metadata structures through time, and a lack of metadata standards between various producers. Producers of data are rather conscious of the importance of building a metadata standard, and many projects concerned about this problem have emerged[4,5,6]. Therefore, there is the need for ontologies of concepts involved in statistical metadata, like "GovStat" ontology (Pattuelli et al. 2003), and for languages dedicated to modeling and exchange of statistical metadata, like SMDX[7].

3 ESTI: A Framework for Evolutive Spatio-temporal Information

The purpose of our work is to provide a model for storage of statistical information collected at multiple geographical scales, by various producers at different dates. This model should help the estimate and harmonization tasks on stored datasets. To achieve such tasks, the analyst is concerned by the position of one territory compared to another and by the relations that this territory holds with the rest of the world, rather than with viewing a geographical continuum. For this reason, a conception based on a qualitative approach as proposed by (Lardon et al. 1999) has been favored.

3.1 A Qualitative Approach

This approach focuses primarily on structures of order between studied spaces: an event occurs before, after or simultaneously over another, a place is located inside or next to another, etc.. Any information becomes relative to another phenomenon, and knowledge is organized according to the relations between objects in both the spatial (Egenhofer and Franzosa 1991) and temporal dimensions (Allen 1983). The qualitative approach is based on the characterization of specific objects (called *geographical entity)* in space and time. It deals with *thematic data* (population, level of wealth, pollution, etc.) describing categories of spatial objects (cities, regions, rivers, etc.). These objects are associated with a *spatial extension*, which provides information about their shape and location. The spatial extension is described by a two or three-dimensional Euclidean geometry, more precisely one of the three basic geometry types: point, line and shape. These objects have an intrinsic *identity*, described through attributes such as name or code in a given nomenclature.

4 COSSI http://www.tilastokeskus.fi/org/tut/dthemes/drafts/cossi_en.html
5 CODACMOS http://www.codacmos.eu.org/
6 METANET http://www.epros.ed.ac.uk/metanet/
7 SDMX http://www.sdmx.org/

The integration of temporal dimension into data modeling has been the subject of research efforts for over a decade (Albrecht 2007). Considering the simplified model previously presented, each specific aspect (spatial extension, identity, thematic data) of a geographic entity can evolve independently over time. First, the spatial extension presents a *movement* in space: its location, its path, or its shape can change over time. Second, the thematic characteristics have a limited existence (a *'life'*), i.e. the values of data associated with the geographical entity change (population increases, flow of river changes, etc.). Third, identity attributes of the geographical entity can also change: a city may change its name (as Saint-Petersbourg which was named Petrograd from 1914 to 1924, then Leningrad from 1924 to 1991), or two municipalities can merge to create a new municipality (as the merging of French *communes* Bourgoin and Jallieu to form Bourgoin-Jallieu in 1967). The process of monitoring the identity of geographical entities over time is known as *genealogy*. Figure 2 represents an extension of the static representation of a geographical entity, including the dynamic and evolving temporal dimension.

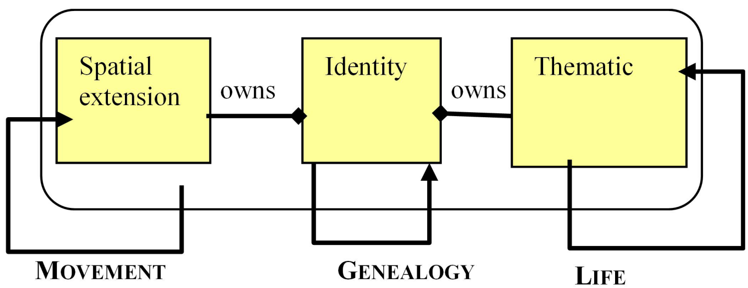

Fig. 2. Dynamics of a geographical unit

3.2 An Evolutive Spatio-temporal Object-Oriented Model

Object-oriented (OO) models have been extensively explained (Gordillo et al. 1999) since the fundamental proposition of Worboys (Worboys 1998), which defined a spatio-temporal object model with attributes evolving independently. In this approach, the geographic area is composed of a set of objects (geographical units), each object being attached to a set of atoms (spatial, semantic and thematic attributes). Each atom has a lifespan interval of validity, corresponding to the period during which the considered attribute remains unchanged. The object oriented paradigm allows us to model our observations of the world, not just as collections of data, but as complex entities, with an identity, an internal structure and a behavior, and having relations with other entities. Moreover, as argued by (Rigaux and Scholl 1995), an object representation is better suited for handling multi-scale partitions, and allows taking advantage of the hierarchic partitions of space, using geometric operations on tree structured entities.

However, the notion of identity of a spatial object is not clear in previous research works: is it defined by its name, its spatial encroachment, its genealogy, or a combination of the three variables? In that sense, work done in geospatial ontology has brought some answers. Indeed, as argued in (Worboys 2005; Franck 2003) the process of change, that is to say the events occurring over time, affects entities identity, and ontologies of change can be used to determine under which conditions objects acquire or lose their identity, how their properties change over time, and how they can be divided into other objects. Then, the conceptual work of Hornsby (Hornsby and Egenhofer 1998) about changes in geographical entities, based on the identification of entities and their components, serves as a basis for a later work (Lohfink et al. 2007) in the field of OO modeling about the representation of processes of merging, scission, or territorial redistribution which can occur between the various entities of a mesh.

Thus, based on a qualitative approach, our proposal is an object-oriented (OO) model, modeling the spatial organization of primary data, and some basic information about data lineage. Precisely, primary data are data provided like inputs to our system, delivered by the producers of statistical indicators. Producers may have built those data using various estimation and sub-sampling methods, but from our point of view, they are still primary data, and all we know for sure is the data source (the provider name), which constitutes the basic lineage information.

We have chosen the Unified Modeling Language (UML) for its expressiveness for representing complex relationships between entities, and its extensibility. For instance, spatio-temporal constraints can be formulated using UML extensions like the Object Constraints Language (OCL) (Warmer and Kleppe 1999). At present, to improve the readability of the model, the OCL statements are not included within the model, and we express them like algebraic expressions in the text. Moreover, since its break-through during 1990's, UML has kept spreading throughout the world and has become a reference (Rumbaugh et al. 1999), it can even be easily understood by non-specialists.

In addition to UML, some other innovative tools for spatio-temporal modeling have emerged, such as MADS (Parent et al. 2006) or Perceptory (Bédard et al. 2004). Those powerful solutions make possible for the designer to keep far from the implementation model, since they offer some abstract types specific to the spatio-temporal domain. For instance, MADS comes with a set of graphic symbols (*pictograms*) expressing various temporal constraints concerning entities validity and their relations, and then an automatic mapping toward any relational schema is provided.

Yet, our model needs to express more than topological constraints about spatial inclusion of entities, and some specific constraints about thematic values cannot be represented using these frameworks. For instance, the constraint "the sum of population indicator measured on GU of one mesh should be equal to the population accounted on their super-GU" cannot be expressed in MADS and Perceptory. Moreover, using these frameworks, the lineage of indicator values cannot be fully handled. For instance, State GDP can be measured on one period differently according to various data providers. Then, a possible solution could be the use of a mechanism to manage their various points of view, as explained in (Vangenot 1998). Yet, this point of view is subjected to temporal variations, due to new data sources or methodologies for indicator measurements, and this cannot be expressed with these solutions.

To conclude, our model focuses on the Geographical Units (GU) and their multiple representations, in regard to the characteristics of GU (name, spatial representation, and so on), and from the point of view of their relationships with other GUs (relationship of hierarchy, genealogy, proximity) (see Figure 3), as detailed in the next sections.

The management of this evolving character, observed on several dimensions and expressed in an independent manner on the considered dimensions, leads us to propose a view of the GU (the class `GeographicUnit`) split into several entities, as shown in UML class diagram of figure 3. This overview of the model presents all entities of the model, and it highlights the fact that the GU is at the center of the model. A GU is linked to 3 parts, one for the thematic information, one for the spatial information, and the last for the identity of the GU. Each part will be described in details, as well as the relations Hierarchy and Proximity in the following sections. Previously, some fundamental information must be detailed about the formalisms adopted for representing the time and the space.

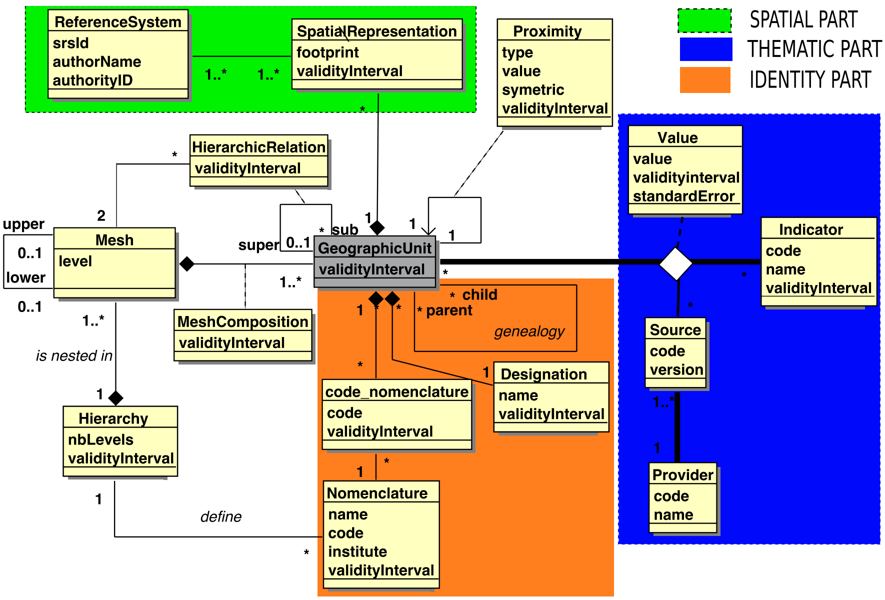

Fig. 3. The OO model overview, centered on the GU

3.2.1 About Time Representation

Linear time formalization as, for instance, the one proposed by (Allen 1983), seems the better suited for a discrete and qualitative approach. Allen adopts a linear time, structured in a series of intervals I_i. An interval I_i is an ordered pair of points (*instants* (Jensen et al. 1998)). This time space is associated with a set of relationships (*before, meets, equal, overlaps, during, starts, finishes*) which can answer queries about temporal proximity of two phenomena. It is important that end-user is responsible for the choice of time granularity of the interval - *chronon* - because he knows his data, and their level of accuracy (day, month, year, …). Thus, the various entities of our model have a time interval of validity, defined by the attribute `validityInterval`, which is of type `DateTimeInterval`, as defined in the OWL-Time (Pan and Hobbs 2004) model (which is based on the Allen time formalization). Through the class `TemporalUnit`, the user can choose granularity of time.

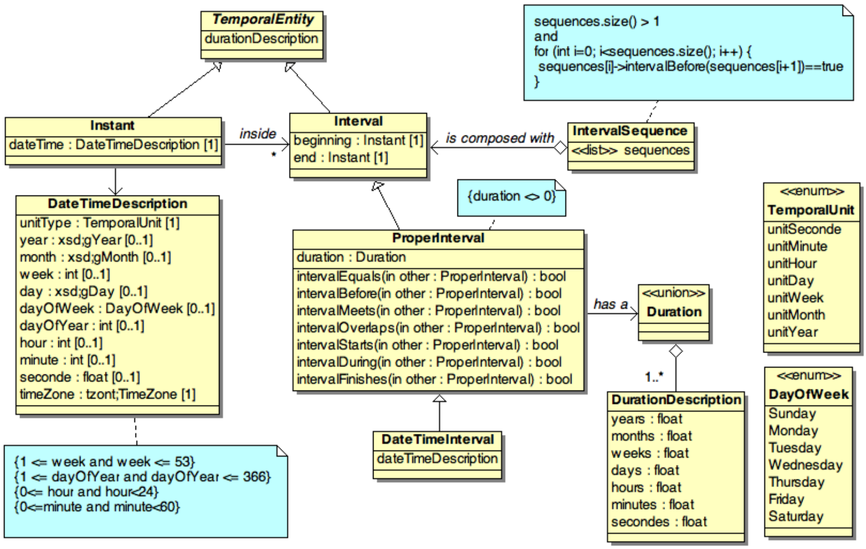

Fig. 4. The OWL-Time model expressed with UML

Figure 4 gives a full overview of classes which can be used according to the OWL-Time model, and that we re-use for the ESTI framework.

In summary, each interval is defined by dates of beginning and end: $I = [t_i, t_f[$. For each geographical entity A, if we refer to the ontology of Hornsby (Hornsby and Egenhofer 1998), which clarifies the condition of 'creation', 'continuation', and 'suppression' of a geographical entity, $A.t_i$ corresponds to the creation time of an entity, e.g. the transition from non existing state without history (like USA before the declaration of independence in 1776) to existing state with history (like USA in 2008), and $A.t_f$ corresponds to its suppression time, e.g. transition from existing state to non-existing state with history (like USSR since 1991).

3.2.2 About Space Representation

Each GU has its own spatial footprint (class SpatialRepresentation), (see figure 3), a geometry which can be of various natures, that is to say that abstract class SpatialRepresentation must be realized into concrete classes extending it, like a Point, a Line, a Polygon, or a composition of Shapes; these geometries are related to a particular reference system (ReferenceSystem), defining the scale of the representation, and the projection system in use. This abstraction level allows the user for a multiple representation of the same geographic feature, following the data source or the point of view he wishes to offer. This spatial representation can evolve independently of identity and thematic part of a GU. When a set of GU forms a mesh, its geometries (known through their SpatialRepresentation) compose a tessellation of space, which can evolve and be modeled independently of any identity or thematic changes. In order to simplify the expression of constraints involving spatial representation, we note $GU.g$ the footprint of any GU.

The temporal grammar of Allen (Allen 1983) presents interesting similarities with the one proposed by Egenhofer (Egenhofer and Franzosa 1991) for spatial relationships that have been simplified (Cheylan and Lardon 1993) into (*disconnection, external connection, intersection, inner connection, inclusion, equality*). This applies, for example, to the geometric shapes of geographical entities of a mesh, and can help to deduce relations of proximity, inclusion, etc., occurring between these units.

3.2.3 About Identity

When entities have names, those names are given in the reference language of the system. Additional translations for supporting a multi-lingual system will be stored into an external module. For instance, a GU has a unique Designation with a name for each period of validity, even though the entity may have several names for use at the same time with different translations. The model is plugged with an additional dictionary or a geographic ontology, providing synonyms for this unique key. Furthermore, in order to update information into the system, although each GU has a unique system identifier, it is necessary to register the code of the unit used in external systems (code_nomenclature), which generally endorsed a classification (Nomenclature), defining a hierarchy. This code is likely to evolve in different nomenclature versions (for the same hierarchy of meshes), which justify that it has an interval of time validity.

As in (Lardon et al. 1999, Ning 2006), changes of identity of a geographic entity, i.e. all the genealogical information describing territorial redistribution process (fusions, scissions, etc.) are represented in these models by a reflexive relationship of genealogy, called genealogy, annotated with the roles "parent" and "child" at each end, and whose multiplicity is free. An entity GU_k created after the merge of n GU_{ki} has n parents whose end of validity intervals meet the beginning of the validity interval of the new entity (C1). Moreover, two spatial constraints can be formulated: (C2) is about the inclusion of parent GU into child GU, and (C3) is about the fact that the new GU footprint is the result of the union of parent footprints:

$$\forall GU_{ki},\ _{i=1..n},\ GU_{ki}.t_f = GU_k.t_i \qquad \text{(C1)}$$

$$\forall GU_{ki},\ _{i=1..n},\ GU_{ki}.g \subseteq GU_k.g \qquad \text{(C2)}$$

$$\forall GU_{ki},\ _{i=1..n},\ \cup GU_{ki}.g = GU_k.g \qquad \text{(C3)}$$

Similarly, the split of a GU_k creating n new GU_{ki} implies that a GU can have many children (whose validity interval begin with the end of the parent validity interval), and we have the same spatial constraints (C1) and (C2), with the following temporal constraints (C4):

$$\forall GU_{ki},\ _{i=1..n},\ GU_k.t_f = GU_{ki}.t_i \qquad \text{(C4)}$$

More generally, at the very moment of redistribution of territories between a set of units, all units play both the roles of parent and child. We could also note the reflexive association genealogy like Child <GU_1, GU_2>, where GU_2 is a child of GU_1. Then, the reunification of East Germany and West Germany in 1990 figured in figure 1 can be expressed like: Child <C_1, C> and Child <C_2, C> with following constraints:

$$C_1.t_f = C.t_i,\ C_2.t_f = C.t_i,\ C_1.g \subseteq C.g,\ C_2.g \subseteq C.g,$$
$$(C_1.g \cup C_2.g) = C.g$$

Similarly, the split of Czechoslovakia into Czech Republic and Slovakia in 1992 can be expressed like (using the notation of figure 1): Child <F, F_1 > and Child <F, F_2> with following constraints:

$$F_1.t_i = F.t_f,\ F_2.t_i = F.t_f,\ F_1.g \subseteq F.g,\ F_2.g \subseteq F.g,$$
$$(F_1.g \cup F_2.g) = F.g$$

3.2.4 About Hierarchy

`Hierarchy` represents a hierarchy of meshes: each level of the hierarchy is a mesh (`Mesh`) which is composed of GUs (at least one GU). A `Hierarchy` is defined by a `Nomenclature`, which may have many versions. The hierarchy remains valid until no level of mesh is introduced nor removed, that is to say that the temporal validity of a hierarchy is linked to the number of meshes it nests. Inside this hierarchy, we can distinguish two types of relations that GUs entertain between themselves: `MeshComposition` and `HierarchicRelation`. A `HierarchicRelation` puts into relation two GUs belonging to two different meshes: the sub-unit of mesh of level *n* belongs to one super-unit of mesh of level *m*, with $m<n$. `MeshComposition` indicates that a GU belongs to the same mesh of level *n*. The two associations have different `validityInterval`, since a mesh composition can evolve independently from the vertical hierarchical relations between GUs. That is to say that one mesh can keep the same composition of GUs, while one of its GU changes to another superior GU. It is the case considered in figure 1 when the entity *K* changed of super-GU from *A* to *P*, while the number of units in the mesh of level 3 in h_1 is unchanged. For instance, the sub-division of USA in counties can remain unchanged, while a county change of State occurs.

It is important to notice that a GU like *A* in figure 1 can belong to two different meshes inside the same hierarchy, and it can be its own super-GU, and can have finally a different super-GU in the higher level during the same period. For example, 'Île-de-France' including Paris and its suburb area belongs to NUTS-2 and NUTS-1, and when considering the mesh formed by units of NUTS-2, the super-GU of 'Île-de-France' is itself, whereas at the NUTS-1 level, the super-GU of 'Île-de-France' is the state France of NUTS-0 level. This is often the case with capitals or big metropolis, like San Francisco which is both a municipality and a county in USA. Using another formalism, one can also note the `HierarchicRelation` with *Sup<A, m, B, n, h, I>*, expressing that *A* is the super-GU of *B* in the hierarchy *h*, during the time covered by interval *I*, and *B* belongs to mesh of level *n* in this hierarchy, *A* to mesh of level *m* in the same hierarchy, and $m<n$. Whenever a set of GU forms a mesh whihc is not nested inside a hierarchy of meshes, we consider that it forms a hierarchy by itself, with a unique level. Then, no `HierarchyRelation` between GUs should exist; only the `MeshComposition` is instantiated, indicating the period of membership of each GU to the mesh. The `HierarchyRelation` *Sup<A, m, B, n, h, I>* between GUs implies the spatio-temporal constraints (C5) and (C6) between a super-GU *A* and a sub-GU *B*:

$$I \subseteq (B.I_b \cap A.I_a) \quad \text{(C5)}$$
$$B.g \subseteq A.g \quad \text{(C6)}$$

Using this hierarchical relation in conjunction with the genealogy relation, it becomes possible to restitute the evolution processes occurring between two successive periods I_1 and I_2, as exposed in figure 1.

- Membership of *A* to two meshes of different levels (levels 1 and 2) during I_1 : *Sup<A, 1, A, 2,* h_1*,* I_1*>*.
- Merging of C_1 and C_2 to create *C* is expressed like : Child<C_1, C>, Child<C_2, C>, et *Sup<B, 3,* C_1*, 4,* h_1*,* I_1*>*, *Sup<B, 3,* C_2*, 4,* h_1*,* I_1*>*, *Sup<B, 3, C, 4,* h_1*,* I_2*>*.
- Split of *F* into F_1 et F_2 is expressed with : Child<F, F_1>, Child<F, F_2>, et *Sup<E, 3, F, 4,* h_1*,* I_1*>, Sup<E, 3,* F_1*, 4,* h_1*,* I_2*>, Sup<E, 3,* F_2*, 4,* h_1*,* I_2*>*.
- Change of superior unit for *D*, from *B* to *E*, is expressed like: *Sup<B, 3, D, 4,* h_1*,* I_1*>, Sup<E, 3, D, 4,* h_1*,* I_2*>*.
- Membership of G to two different hierarchies h_1 et h_2 is expressed like: *Sup<E, 3, G, 4,* h_1*,* I_1*>, Sup<Y, 2, G, 3,* h_2*,* I_2*>*.

3.2.5 About Proximity

The representation of information about proximity relations seems crucial for using estimation methods, due to first Tobler's law. Proximity is a neighborhood relationship existing between two units, qualified by a certain distance. This notion of separation is broader and fuzzier than the strict definition of a mathematical distance and it is not necessarily linked to the topological relations between GUs that can be deducted through their `SpatialRepresentation`. In particular, proximity relation between geographical units is not necessarily symmetrical and, for example, the time taken to reach Grenoble from Genoa by road is not the same as the return duration. This is because the geographic area is not isotropic. Contiguity is a special case of proximity: between two units *A* and *B*, the distance measure is 0 if they touch, 1 otherwise. Accordingly, we introduce a relation expressing an oriented relationship of proximity between two GUs *A* and *B,* and realized by an association class `Proximity` having four attributes:

- `type`, a string defining the type of used distance (contiguity, distance metric distance schedule, etc.):
- `value`, a float storing the numerical value associated with the distance between the two units;
- `symmetric`, a boolean to avoid any duplication, if the distance value is identical whatever the direction;
- `validityInterval`, a time interval to express the temporal validity of the relation.

For example, the proximity relationship of the previous example can be noted as *Proximity <Grenoble, Genoa, road, 4, false>*. It means that the distance time to reach Genoa from Grenoble by road is 4 hours. *Proximity <Paris, London, railway, 3, true>* means that the distance in time to reach London from Paris by train is 3 hours, and is identical to the time to make the return journey from London to Paris by train.

The temporal validity of the Proximity relation is always included within the intersection of the validityInterval of two entities A and B involved in the relation: *Proximity.I* $\subseteq (B.I_b \cap A.I_a)$.

The various types of proximity are not enumerated in the model: indeed, there is an infinite number of distances (train, road, Euclidean, orthodromic distances, etc.). This could lead to the registration of redundant keys (Proximity.type): for example, "contiguity" and "adjacency" which bear the same meaning. Then, loading data process needs to be supervised by an expert, a human or a software, able to verify these facts. To facilitate search and retrieval of information, a thesaurus (or an ontology) of proximity relations will be established in an external module interacting with the database, linking key recorded in the model with all similar notions.

3.2.6 About Thematic

The thematic dimension here considered takes into account all statistical indicators with their respective values and their sources. Indeed, information concerning the source of data is a minimum for determining the lineage. The value of an indicator is symbolized in the form of a class of association (`Value`), involving a geographical unit (`GeographicUnit`), which symbolizes the territorial unit, an indicator (*Indicator*), and the data source (`Source`). The source is the physical storage of information: it is a publication, a record or a database. It is published at a time, date of publication of data (`version`), which is not related to the period of validity of the specified

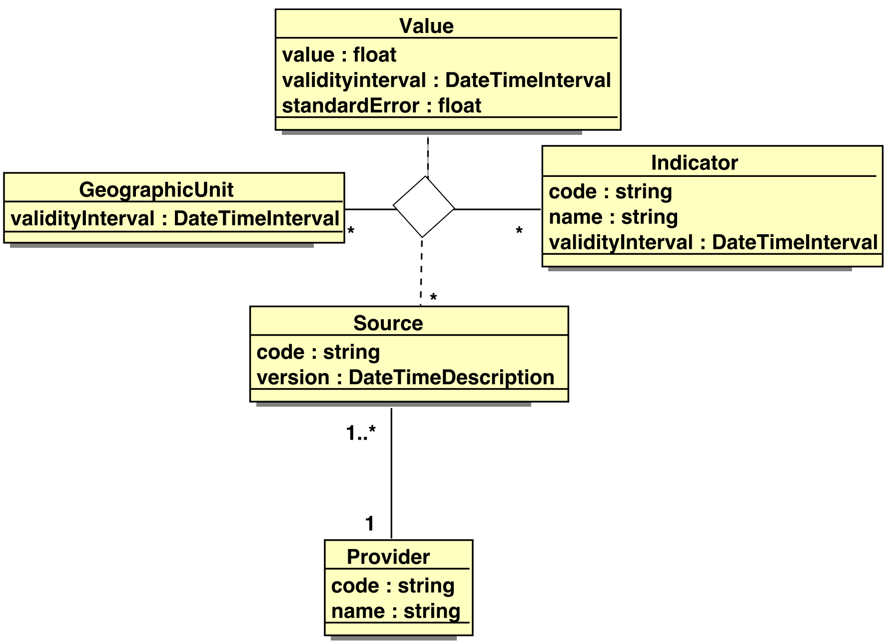

Fig. 5. The thematic part of the geographic information

value (validityInterval). Indeed, the producer of data (represented by Provider) - a statistical institute in general - may publish several times a series of data on a certain indicator within many years of interval. The producer of data is known by its name (name) and its acronym (code). The indicator has a name and a code (which is stored for updating purposes). Figure 5 gives the corresponding UML class diagram.

When information is available, standard error (StandardError) is associated with measure. Indeed, whenever the measure is the result of an estimation, produced from a sample (which is often the case in census surveys), then standard error measures the variability of this estimate, and knowing confidence level and error dispersion law, Margin Of Error (MOE) can be deduced. For example, with a Gaussian law, MOE is then 1.645 * standard error: this means that the measure belongs to the range [estimate-MOE, estimate+MOE] with a 90% confidence level.

3.3 Estimation of Missing Values

The methodology to enhance dataset quality consists in providing estimation strategies for missing indicator values. Those strategies can also be used for simulation purposes, estimating past and future hypothetical situations. Our model can be easily manipulated to provide such estimation. For example, we know that the sum of values measured on GU of a lower mesh is equal to the sum of values measured on GU of the upper mesh. This knowledge can be re-used as explained bellow.

Let us show an example of a one-dimension estimation method. If we consider that Tobler's law is right, data evolution of one unit may be strongly correlated to the values of its neighbors (neighborhood being accepted in its largest meaning). In this example, we simply exploit spatial relations, in order to infer some data. Let us suppose that we have a series of values for population indicator (I), for each year (T), at state level in France (E), by one source (EUROSTAT). We also have the same indicator collected by region in France by the INSEE, but only at two dates: 1989 and 1999. We would like to estimate the population of 'Ile de France' in 1995.

Table 1. Available data of the French population (in thousands), at country and region scales

Dates	1989	1995	1999
France	56,615	57,844	58,519
Ile de France	11,323	?	12,874

Using the model, one can see that 'Ile de France' is spatially included within the France unit because `Sup <France, 1, 'Ile de France', 2, NUTS, [1989, 1999]>` relation is stored in the system. One can think that the evolution of 'Ile de France' population is correlated to the French one, and compute the part of population that 'Ile de France' represents for the French population, at the dates 1989 and 1999: 20% and 22% respectively. Making the assumption that this proportion has evolved in a linear way, one can estimate that the population proportion of 'Ile de France' is of 21% of France in 1995. Then, by applying this rating to compute 'Ile de France' population for 1995 based on French total population in 1995, one finds 57,844 * 21%, or 12,147 inhabitants.

To illustrate how the same datum could be estimated in a different way, let us make the following assumptions: the datum is known on ‘Ile de France’ for 1989 and 1999, but in this case, France total population data are unknown for this period. But yearly population data are available for some of the units included within ‘Ile de France’ (French departments Essonne, ‘Seine-et-Marne’ and ‘Hauts-de-Seine’), and the system has stored this information:

```
Sup <‘Ile de France’, 2, Essonne, 3, NUTS, [1989, 1999]>
Sup <‘Ile de France’, 2, ‘Seine-et-Marne’, 3, NUTS, [1989, 1999]>
Sup <‘Ile de France’, 2, ‘Hauts-de-Seine’, 3, NUTS, [1989, 1999]>
```

Based on the hypothesis that the population of ‘Ile de France’ unit evolves according to the same trend as its components, the datum of ‘Ile de France’ can be inferred.

This illustrates that for one query, there might be many strategies (and *in fine* methods) for its estimation. Each strategy is adapted to a particular case (or missing value configuration), according to data characteristics.

4 Extending the ESTI Model with Metadata

The proposed OO model does not handle well the description and the semantics associated with data. Imagine you need to find the numbers concerning unemployment in 2008 in France. Your request may return various statistical sets provided either by EUROSTAT, or by INSEE. Nothing indicates the differences existing between the methodologies leading to such different values. This small example shows a problem which has been well detailed in a previous study concerning the integration of semantically heterogeneous databases (Partridge 2002): it is argued that ontologies may allow understanding, classifying, and organizing information at a meta level. As shown in (Franck 2003), we need to map the socio-economic reality (known through vague terms such as “unemployment”) to a statistical data model, fully described by a set of metadata linked to data themselves. The requirement is similar, when considering spatial information. For example, the user knows that France, as a country, has Germany, Italy and Spain as neighbors. He cannot give the code used in the system or the exact boundaries of the space he has in mind to retrieve the neighbors. Neighbors must be inferred by the system by means of the key word “France” which should be mapped with the data model and its various translations over time, using a geographic ontology.

Therefore, a system built on the three following layers of knowledge appears to be efficient: the first level will deal with raw data, as expressed in our spatio-temporal model, a second layer will provide metadata, and a third level will allow an efficient usage of metadata through ontologies.

Indicators are fully described by metadata expressed in SMDX format, while those metadata are organized via ontologies like GovStat, which represent terms specific to statistical metadata domains and their relationships. For the spatial part, one can refer to INSPIRE directives and to metadata model provided by the OGC. Similarly, taxonomy of geographic relationships powered by ontologies must be provided. For example, a subsumption relation “*is_a”* could be specified between contiguity and adjacency (contiguity is_a adjacency), indicating that both terms designate the same type of proximity in the system.

By consequence, we propose an application management module**,** providing an interface between users and the application, and based on the architecture detailed in figure 6. This module performs maintenance, update, importation and exportation tasks. Its main purposes are to simplify the interaction with the users (finding the right data in such a large database can be quite difficult without assistance) and to maintain the internal coherence of data on updates (assisting update operations in order to input complete and error-free data in the database as much as possible). The module has two components:

- the **geographic ontology,** which contains a corpus of geographic entities (name, validity interval) together with some semantic relations between these entities (inclusion, proximity, genealogy, etc.);
- the **thematic ontology**, which contains a hierarchical description of the indicator set, comprised by the database. The indicators are either *basic* or *synthetic* (elaborated from other indicators) and, in the latter case, the ontology also refers to the operational method required for computing the synthetic indicator.

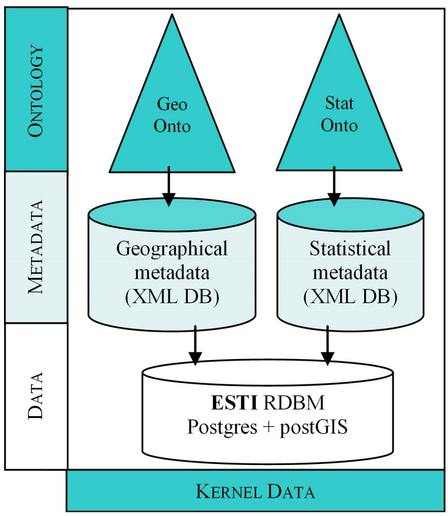

Fig. 6. The application management module

Some few plans about implementation choices can be drawn. As an example, these ontologies could be expressed with the OWL language to index the corresponding metadata repositories (XML databases). Metadata could be mapped onto the ESTI relational database, implemented with Postgres and its spatial extension PostGIS. Indeed, the PostGIS implementation of geographic types honors the "Simple Features for SQL" specification edited by Open Geospatial Consortium (OGC8), and this favors the system interoperability and the conformance to INSPIRE directives for data dissemination. It also offers a set of simple tests of topological relations, like

[8] http://www.opengeospatial.org/standards/go

contiguity or spatial inclusion, which may be very useful when inferring previously described relationships between GUs. In addition, spatial indexes (*Quadtree, R-tree*) could be used to speed up the research of GUs based on spatial criteria. One can see that nowadays, all necessary tools for building such an ambitious information system are available.

5 Conclusion and Future Work

This chapter describes a framework (ESTI) for the long-term management of statistical indicators of various natures, referenced in space and time: socio-economic (such as population or GDP), environmental (such as a forest area or the rate of nitrates), etc. This management is a critical issue for the establishment of future scenarios in the field of spatial planning. We show that this information is difficult to handle, due to its heterogeneity through space and over time: the spatial support of data is very unstable and insufficiently defined, but also semantics of indicators needs to be clarified through ontology descriptions. Thus, based on a qualitative approach, we propose a conceptual spatio-temporal model for evolving data, integrating the various components of information. We use it to describe the life cycle of a geographical unit, through the combined development of its thematic variables, spatial representations, and the description of its genealogy. Great attention is given to the description of indicators and of their source. In addition, our contribution takes into account the spatial organization of geographic units, and of spatial relation (proximity for instance) between them. These relationships and knowledge of the indicators are of great importance to the main objective of our work: to create an expert system, triggering estimation methods, in order to complete the missing information. This model is the core of a framework called ESTI, which should ease the processing of queries guided by geographic and thematic ontologies. The system is designed to allow the estimation of missing values through the implementation of estimation methods. ESTI is based on many modules and incorporates various structures and representations of data (ontologies, databases, knowledge bases). The architecture is being developed in the draft Long Term DataBase (LTDB) initiated within the framework of the European ESPON 3.2: 'Spatial Scenarios and Policy in Relation to the European Spatial Development Perspective and Cohesion' [9]. The goal of the project is to handle the most useful indicators and criteria in drawing up scenarios and European policies (population, labor force and indicators of wealth for the most part).

Our future work concerns the development of a first prototype of the ESTI architecture and its validation on a set of indicators coming from various sources (EUROSTAT, INSEE, etc.). At the moment, our proposal gives only an overview of the primary data model and its integration into a global framework for sustainable management of statistical indicators: a next step would be to describe update mechanisms, and the automatic discovery of relations (hierarchic, genealogy, proximity) between geographical entities. In addition, modules dedicated to the management of ontologies (geographic or thematic), require a thorough study. Then, an estimation

[9] www.espon.eu/mmp/online/website/content/projects/260/716/file_2647/fr-3.2-DN2_Final_Jan 2007.pdf

module cooperating with the application management in order to determine the value of a given indicator for a geographical unit at a given time, will be designed to trigger, when appropriate, some methods of estimation for missing data. Eventually, we envision a distributed version or n-tier architecture of ESTI, allowing exchanges between different distributed ontologies and data sources.

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GIS and LIDAR Data Analysis for the Integration of Multidimensional Indicators on Urban Morphogenesis Multi-agent Vector Based Geosimulation

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Abstract. In this paper we present an application of GIS and Airborne Light Detection and Ranging (LIDAR) data analysis for computation of buildings visibility, solar exposition and extraction of morphological indicators in the context of urban group analysis and morphogenesis geosimulation. The interdisciplinary project between geomaticians and architects aims to provide a simulation model based upon dynamic computation of building agents' satisfaction degree, incorporating analysis results using a hybrid approach derived from GIS and raw LIDAR data.

Keywords: GIS, LIDAR data, visibility analysis, sunshine analysis, building morphology, multi-agent system, geosimulation, urban groups.

1 Introduction

The context of this study is concerned with the dynamics of mega cities, understood as complex auto-organized urban systems (Berger and Nouhaud 2004). Our project aims at developing a software simulation platform to provide an efficient decision support, and thus allowing to assess scenarios of dynamics impacts induced by new planned architectural programs. The approach is based upon multi-agent vector based methodology considering 3D vector buildings (meaning 2D geometry plus height attribute) as cognitive agents having different behaviors according to programmatic use and their physical environment (roads, railway, rivers, green areas, etc.). Among morphogenetic laws which are considered, visibility analysis and morphological indicators are involved in the perception computation of an agent building, moreover with high priority degree, in particular cases such as in southern West Switzerland where a house building agent will be better satisfied if it has a wide view of Lake Geneva.

Thus, using the capability of LIDAR data in order to construct an accurate 2.5D urban surface model, visibility and sunshine analysis at different heights (for existing

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buildings facades and from ground surface) is implemented and integrated in a multi-agent vector urban morphogenesis modeling for urban and landscape-planning process. As presented by Osaragi and Otani (2007), all visibility analysis in urban areas based on 2.5D urban surface models must take into consideration the geographical relief of the terrain. Research work has been undertaken in order to apply GIS and LIDAR data to extract 3D morphological indicators (properties) of buildings, such as 3D complexity, 3D total volume and roof type. These indicators can be also used as input on the analysis of urban groups here presented.

2 Interpolation and Construction of 2.5D Urban Surface Model

2.1 Background

Previous literature on interpolation of LIDAR point clouds is vast. The advantages and disadvantages of several interpolation methods, such as triangle-based linear interpolation, nearest neighbor interpolation and kriging interpolation were presented by (Zinger et al. 2002). The most accurate surfaces are created using a grid with a sampling size that relates as close as possible to the LIDAR point density during the acquisition phase (Behan 2000). For applications where high level of accuracy is demanded, control techniques that analyze the quality of digital terrain models can be carried out (Menezes et al. 2005).

A method to construct a 2.5D urban surface model (incorporating the geographical relief), based on LIDAR and GIS buildings data, has been proposed by Osaragi nd Otani (2007).

2.2 2.5D Urban Surface Model

Airborne Laser Scanning is an emergent technology that integrates sensors in order to obtain very accurate 3D coordinates (x, y, z) of points located on surface of the earth, such as ground points, buildings and trees. In order to establish the position of the sensor each time a point is measured, the Global Positioning System (GPS) is used. For finding out the attitude of the sensor, an Inertial Navigation System (INS) is adopted by using a narrow laser beam to determine the range between the sensor and the target points.

The use of LIDAR data with fine density of points (at least 4 to 6 points per square meter) jointly with 2D vector digital maps of buildings footprints, both originally on the same geodetic reference system and, later on, converted to the same projected coordinate system, allows the construction of a 2.5D urban surface model - due to its highest level of accuracy, the use of detailed vector buildings footprints in order to classify LIDAR points contained within buildings is crucial for the improvement of the final result of the 2.5D urban surface model constructed.

First, we interpolate a digital terrain model (DTM) by classifying the LIDAR points according to the following sequential operations:

1. Using a GIS software, LIDAR points contained within building polygons and in the 2 meters buffer generated from building polygons are eliminated;
2. Using the classification tools provided by TerraScan software, LIDAR points whose elevation value vary significantly from surrounding points are considered to be points indicating features such as aerial points (i.e., if the laser beam touches a bird), trees and vehicles, and thus are removed.

After eliminating the points indicating all these features, a DTM can be interpolated only from ground points – with good density of LIDAR points (such as in our testing areas, located in Lausanne and Geneva cities, where LIDAR points were acquired with a density of 4 to 6 points per square meter) there is no great difference among some of the existing gridding interpolation methods that can be employed, such as the nearest neighbor binning, inverse distance weighting, triangulation with linear interpolation, minimum curvature, kriging and radial basis functions (Gonçalves 2006). All these interpolation methods are available in common GIS software available on the market.

For its generalized use by the scientific community for DTM interpolation, the triangular interpolation was chosen. The used algorithm, originally written by Rudolph Franklin in 1973, creates a triangulated irregular network (TIN) structure from the

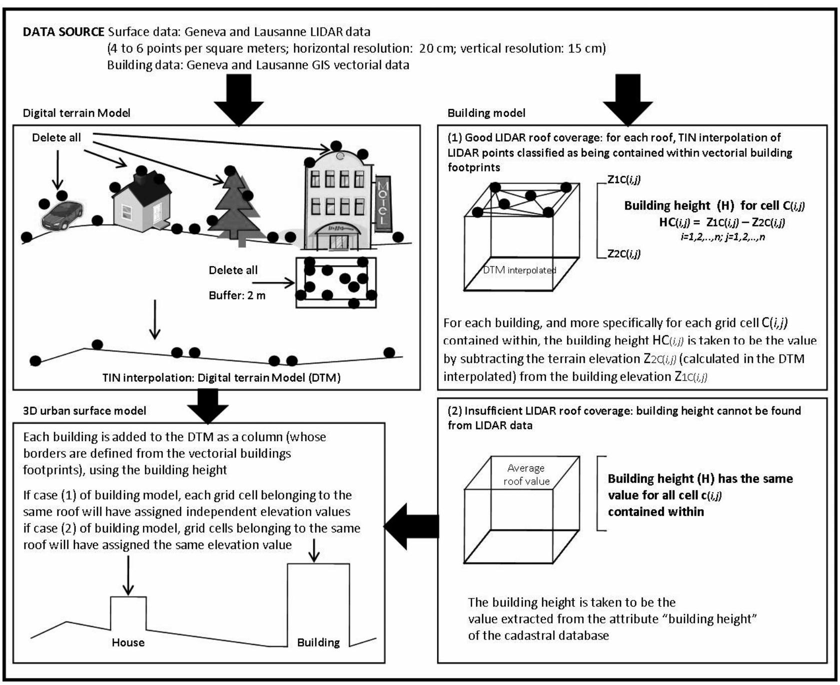


Fig. 1. Construction of 2.5D urban surface model

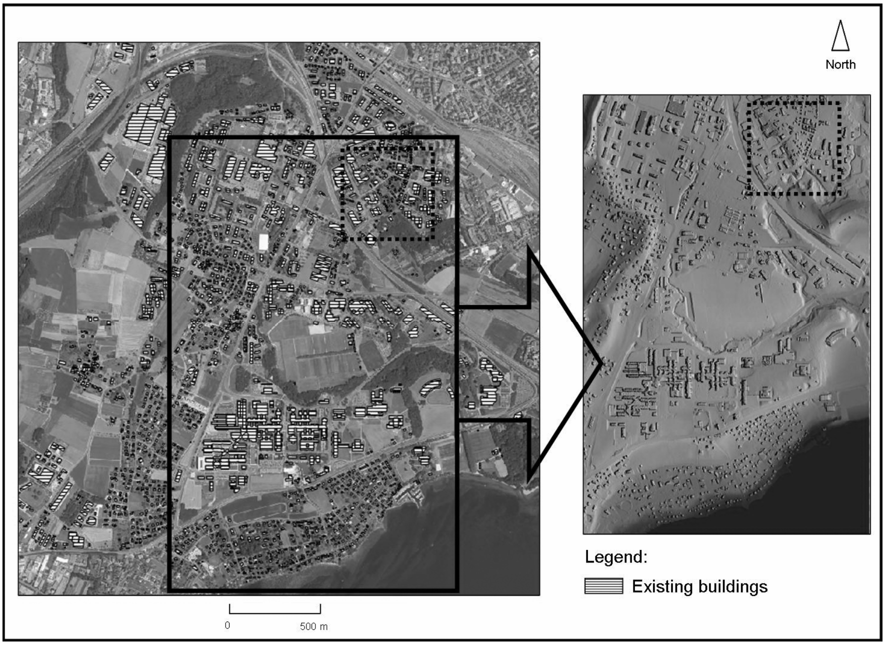


Fig. 2. Left picture: GIS building footprints and aerial pictures of the district of Chavannes, city of Lausanne; right picture: 2.5D urban surface model of the district of Chavannes, city of Lausanne; dashed rectangle: case study (pilot zone), within an area of 500 × 500 meters

LIDAR points using a Delaunay Triangulation[1] routine. The original points are connected in such a way that no triangle edges are intersected by other triangles. A sequential search, allows the set up of a triangle in which each grid node is enclosed. The gradients of the picked triangle enable the interpolation of a value for the grid node.

Secondly, we interpolate (using only the LIDAR points classified as being contained within vector building footprints) a value for each grid cell corresponding to a roof value, for all the existing buildings on the areas of study. Thus, a triangulation with linear interpolation is also applied to each one of the roofs of the buildings. For each building, and more specifically for each grid cell contained within, the building height is taken to be the value of subtraction of the terrain elevation (calculated in the DTM interpolated) from the building elevation. Due to the presence of obstacles, such as trees, in the few cases where a lack of LIDAR points exists in buildings roofs, the grid cells corresponding to each of these roofs have assigned an average building height value extracted from the attribute "building height" of the cadastral database.

Lastly, each building is added to the DTM as a column (whose borders are defined from the vectorial buildings footprints), using the building height found previously for each cell contained within, as described in last paragraph. The final result allows the construction of a 2.5D urban surface model, which is composed of only terrain and buildings heights information.

[1] Delaunay triangulation maximizes the minimum angle of all the angles of the triangles in the triangulation undertaken.

Data source and parameters needed for generating 2.5D urban surface model are shown in Figure 1 and an example of 2.5D urban surface model, for Chavannes district, at the city of Lausanne, is shown in Figure 2. In this same figure, the dashed rectangle represents our case study (pilot zone).

3 Urban Analysis System

3.1 Background

Visibility analysis can be sub-divided into two important vectors: related to morphological properties of the built environment, and the importance of objects positioned within that space respectively (Rees 2000). The most important progress in mathematical algorithms and techniques related to visibility analysis were evaluated by (Ervin and Steinitz 2003).

Concerning landscape analysis, *viewshed* is an area of land, water, and other environmental elements that is visible from a fixed point. From the viewer's position, the viewshed is the set of all ground points that the viewer can visualize. The correct definition of viewsheds promptly became a key-element for decision support related to landscape and urban-planning. Viewshed analysis is supported in a regular square grid (RSG) of elevations and the basic algorithm is based on lines radiation from angles being analyzed (also called target point in classical GIS products) at a fixed angular growth (Bishop 2003).

Due to the fast development of modern cities around the world and the huge concentrations of buildings and people, sunshine analysis is already an important issue for urban planning, especially for quality of life evaluation. Traditional solar laws are based on trivial angular criteria, such as obstruction angles rules (Knowles 1974).

3.2 Visibility Analysis System

In our visibility analysis system, that takes into consideration certain criteria related to the multi-agent vectorial urban morphogenesis modeling, an evaluation of all target points being visible from a view point location is implemented – taking as example the case study (city of Lausanne), an analysis of the percentage of area of Lake Geneva visible from land view point location is undertaken and will be introduced as an input parameter of the multi-agent vectorial urban morphogenesis modeling.

Therefore, the viewpoint location is designated by a point *V*, the surface is represented with a 1 meter by 1 meter (1×1) grid and the centre points of each node (cell) of the grid under analysis are considered to be the target points *T*. For the case in study, the visibility analysis system evaluates which points *T* belonging to the Lake Geneva are visible from a land viewpoint location *V* - in fact, a point *T* is always invisible if the vector from the point *V* to *T* is obstructed and, inversely, is always visible if the vector from the point *V* to *T* is not obstructed.

For each viewpoint location *V,* the visibility analysis is made in two different perspectives:

1. Directly using the 2.5D urban surface model:
   – Terrain viewpoint location;
   – Roof of building viewpoint location (Figure3)
2. Slicing the buildings facades (faces) at different levels, in a vertical direction (elevation values), on a floor-by-floor basis:
   – Direction *Top-Bottom*: For an existing building facade, every 3 meters (assuming that this value corresponds to the average height of a building/house floor) from the top of a building until the ground (bottom);
   – Direction *Bottom-Top*: For ground areas under analysis (where buildings still do not exist) also every 3 meters, from one ground point (bottom) until a specific height (top), representing the elevation value of a virtual new building façade.

It is important to note that different viewpoints on the same building facade level (especially if the buildings are particularly wide) might have different visibility. For the case in study here shown (please consult section 4) only the central points (x and y axis) of each building facade level (z axis) were taken into analysis (Figure 3).

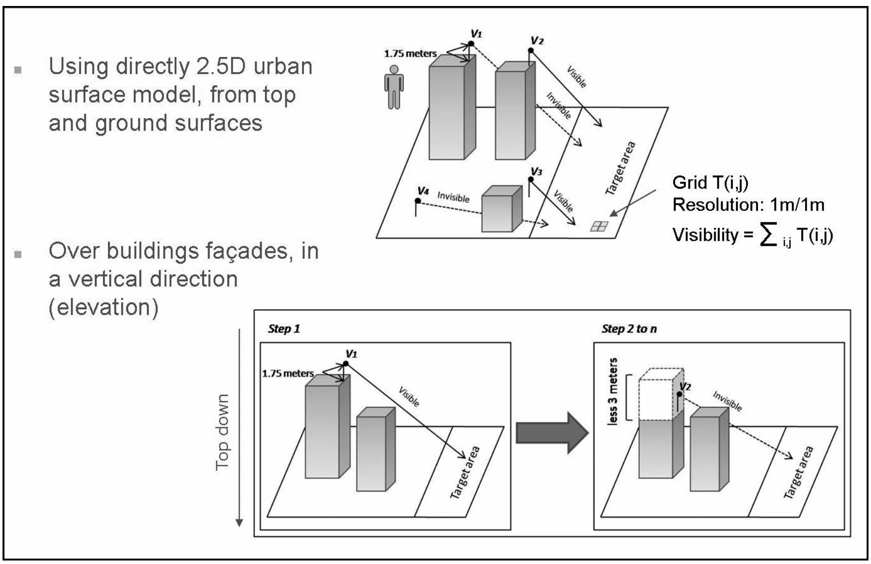


Fig. 3. Method of extracting visible domain of target area using directly the 2.5D urban surface model, from top and ground surfaces and over building facades, in a vertical direction

Hence, another great advantage of using this system is that a sunshine analysis can also be undertaken if the sun is regarded as a viewpoint location *V*, as presented in section 3.3.

An example of visibility analysis from the top of one building facade in the city of Lausanne to the Lake Geneva is shown in Figure 4.

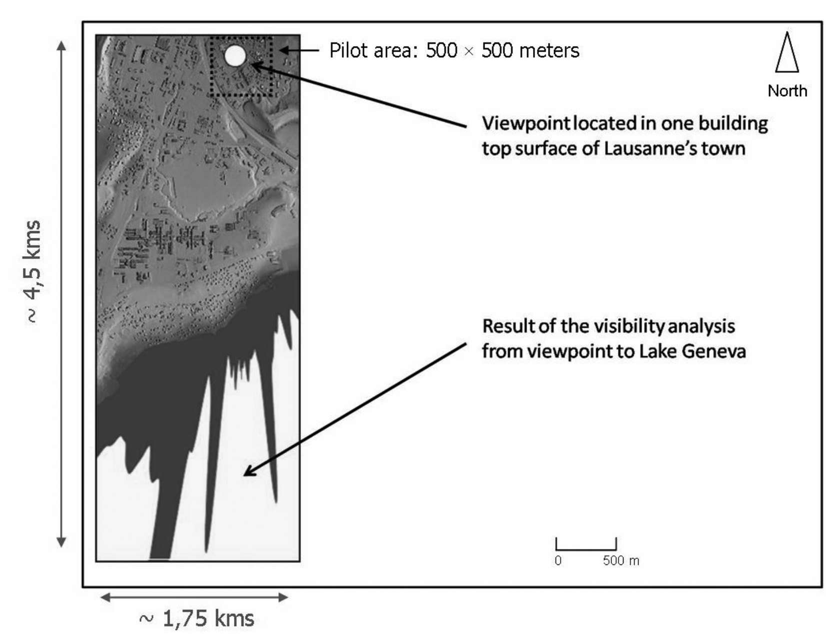


Fig. 4. Example of visibility analysis from a viewpoint located in one building top surface of the city of Lausanne to the Lake Geneva

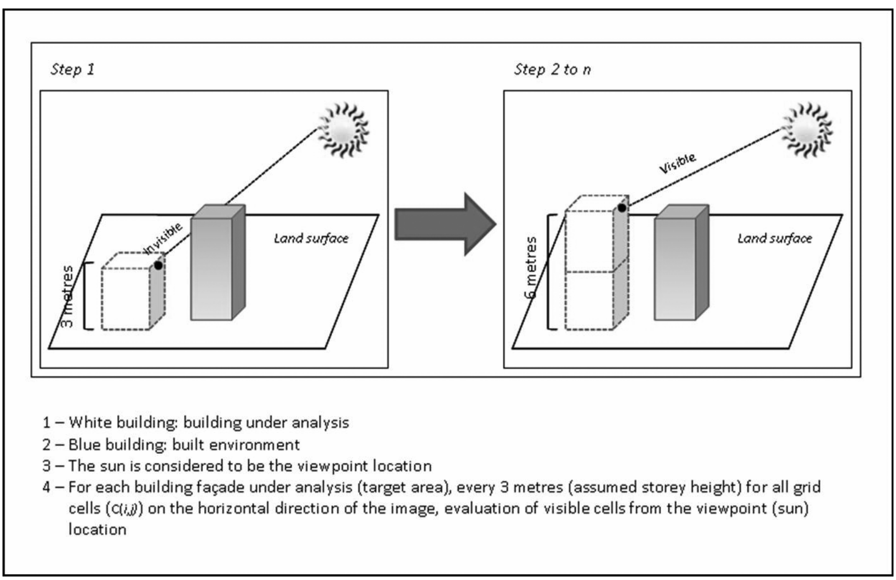


Fig. 5. Sunshine analysis over building facades, in a vertical direction

3.3 Sunshine Analysis

Access to sunshine analysis, here defined as the number of hours/day (discrete number of hours of sun) of solar radiation received by a building or set of buildings, has always been one of the main issues of urban form. This has been acknowledged by traditional bylaws, such as those implemented in the planning of New York and some other cities around the world (Ratti and Morello, 2005).

The sunshine analysis system developed here is very similar to the visibility analysis system presented in the previous section (3.2) of this paper - in fact, it is undertaken by considering the sun as the viewpoint location and all surface cells as the target area (Figure 5). Thus, the sun (viewpoint location) for a certain time of the year, also called "sun track", is calculated based on the latitude of the study area. Hence, the output surface will have assigned a discrete number, matching the number of hours of direct solar radiation.

4 Multi-agent Vector Simulation Modeling

4.1 Background

There is extensive research on the subject of urban geosimulation, mainly dealing with cellular agents (Arentze et al. 2006), (Batty, 2005), (Benenson and Thorrens 2004), (Caneparo et al., 2006), (Couclelis 1997), (Hammam et al. 2007), (Portugali 2000) and (Waddell et al. 2003). Limits of cellular agents which are same as for cellular automata (CA) were explained by (Hammam et al. 2007). Moreover, to our knowledge, no simulation of the urban morphogenesis used vector agents modeling. Thus our approach is quite innovative as it is based upon multi-scale vector multi-agent modeling of buildings - their physical neighborhood, their spatial and topological relationships and their states and behaviors according to modeled dynamic laws of urban morphogenesis from micro level (surfaces in buildings, buildings and programs) to macro level (metropolis). The laws used in our model refer to general architecture knowledge on city morphogenesis, mainly formulated by Alexander (2005).

4.2 Simulation Model

In a first approach one considers only interactions between buildings in order to explain urban morphogenesis. Later, one will introduce geology of the urban basement and socio-economic aspects as well as transport and demography.

The localization and programming of buildings obeys not only to the laws of architecture and urban planning, but also to the laws related to their programmatic use as we further call *function* (house, school, shop, office, factory, etc.) as well as relationships with the natural (topography, lakes, rivers, etc.) and built environment (neighbor programs, identity and morphology of the district, road infrastructures, etc).

In our first multi agent prototype, 6 kinds of laws are considered in the system:

- Growing;
- Stability;
- Influence;

- Visibility;
- Morphology;
- Physical constraints.

We will further develop hereafter only functional influence, visibility and sunshine laws that closely concern the purpose of this paper. For more information on the project approach, please refer to Plazanet and Silva (2007).

4.3 Satisfaction Degree

Each agent has its own desires and computes its satisfaction degree according to its desires, thus translating answers to questions such as: Am I happy with the proximity with services which it needs or unsatisfied because of injures in my neighborhood? The computation principle is somewhat close to the Newtonian model of gravity. Many authors have already integrated this criterion in their model, notably Arentze et al. (2006), Benenson and Thorrens (2004) and Couclelis (1997). The closer the building is to a service (taking into account minimum distance threshold of buildings one to each other), the higher its satisfaction degree. On the contrary, the closer the building is to a critical zone, the least satisfaction.

For example, we define the *satisfaction degree* called DS (expressed as a percentage) of a building agent, according to functional influence and neighborhood, as follows (please consult Figure 6):

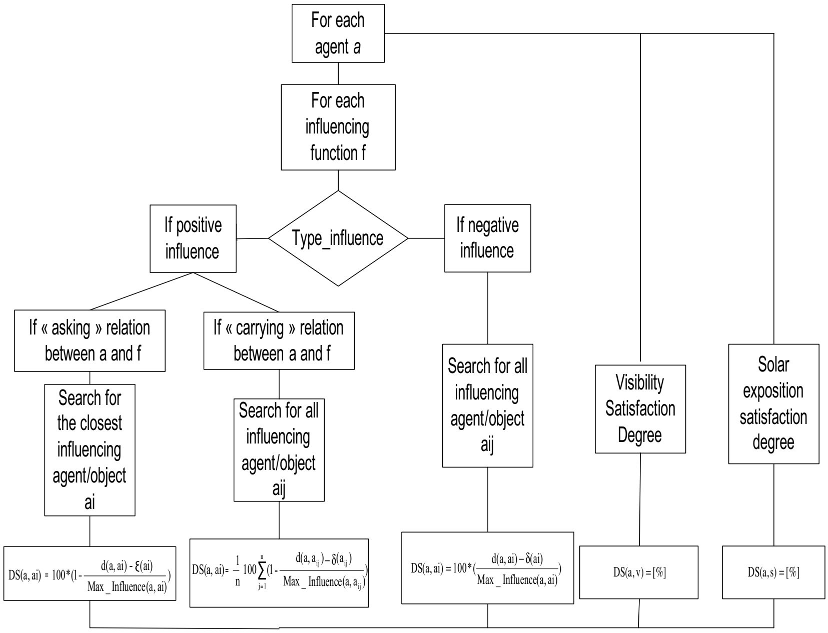
- an agent ***ai***, one of the *n* agents influencing an agent ***a***;
- **Type_influence (ai,a)**: kind of influence of the *ai* agent on *a* with **S** as service and **N** as Noise (injury);
- **Coef_influence (ai,a)**: importance value of influence of *ai* on *a* (from 0 to 10);
- **Max_influence (ai,a)**: maximum influence radius in metres of *ai* on *a*;
- **δ(ai)**, minimum separation threshold between *ai* and any agent (corresponding to the height(*ai*) according to architectural law);
- **DS(a,ai),** satisfaction degree of *a* according to *a*;

We have chosen an aggregation function in order to model behavior of agents which reflects their overall desires for this first prototype. We will further investigate methods for the assessment of agent's satisfaction.

4.4 Integration of Visibility and Sunshine Analysis

We introduce in the computation of DS the following parameters derived from visibility and sunshine analysis (Figure 6):

- **DS(a,v),** visibility: percentage of visibility over the lake. It is a DS like of a building according to the visibility. We consider it as a positive influence;
- **DS(a,s),** solar exposition: the number of hours of solar exposition normalized and expressed as a percentage.



$$DS(a) = \frac{\sum_{i=1}^{n} DS(a, a_i) * Coef\_influence(a, a_i) + DS(a, v) * Coef\_vis + DS(a, s) * Coef\_sol}{\sum_{i=1}^{n} Coef\_influence(a, a_i) + Coef\_vis + Coef\_sol}$$

Fig. 6. Computation of Satisfaction Degree of a building agent

4.5 Analysis of Urban Groups[2]

One important assumption is that the complexity of human activities is based on natural or social geometry (the anthropological form) that creates such urban forms.

Besides, cities can be naturally developed by symmetric principles based on anthropological forms as a result of an economy of space, energy and matter. If a form appears and proves to be optimal, there is a high probability that it may reappear elsewhere with another resolution adjusted to the new context. This is considered to be a “natural” optimization process.

[2] Implementation choices: We are currently developing on the open source GeOxygene Java platform (http://oxygene-project.sourceforge.net/) from the COGIT laboratory of French Mapping Agency (IGN-France). GeOxygene provides main GIS functionalities and ensures the mapping between DBMS tables (Postgres with Postgis extension) and Java classes. We actually have 2D simulation results as shown hereafter. Next step in applying 3D data will investigate their use for dynamic 3D visualization of morphogenesis geosimulation results. A PhD thesis is currently carried out in or-der to implement agents’ behavior and to experiment different levels of interaction.

4.6 Definition of Housing Groups

Although people consider that contemporary cities are chaotic even at an intermediate level (which corresponds to the district level), in reality we can notice regular and symmetric structures in the habitat that reflect a spatial organization based on some simple geometric forms. This phenomenon enables us to highlight that the habitat is reorganizing itself in groups of buildings.

Hence, it is then possible to consider the city as a totality of individuals (buildings) that are naturally grouping themselves with criteria of proximity and accessibility to services (shopping, schools, offices, etc.).

In this context, we define a group as a set of building constructions that have the following common characteristics: same program, proximity between buildings and similar geometrical form. Particularly, as a first step, we focus on the housing groups that define mainly individual and collective cities form.

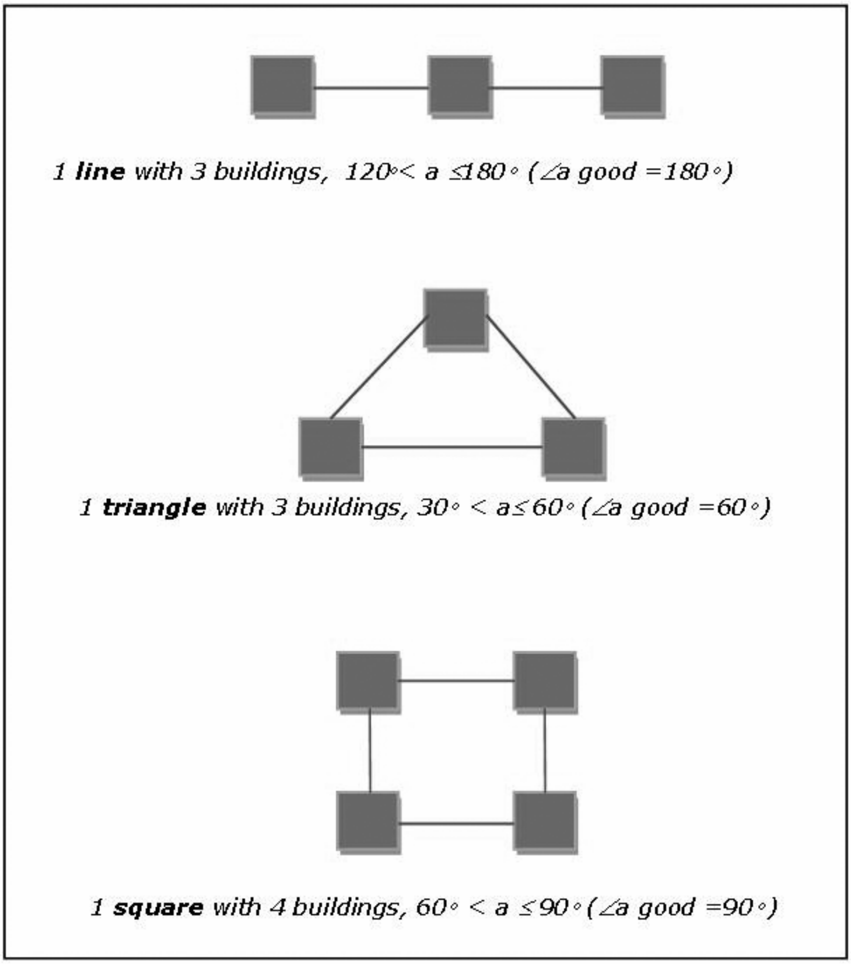


Fig. 7. Three elementary organization forms

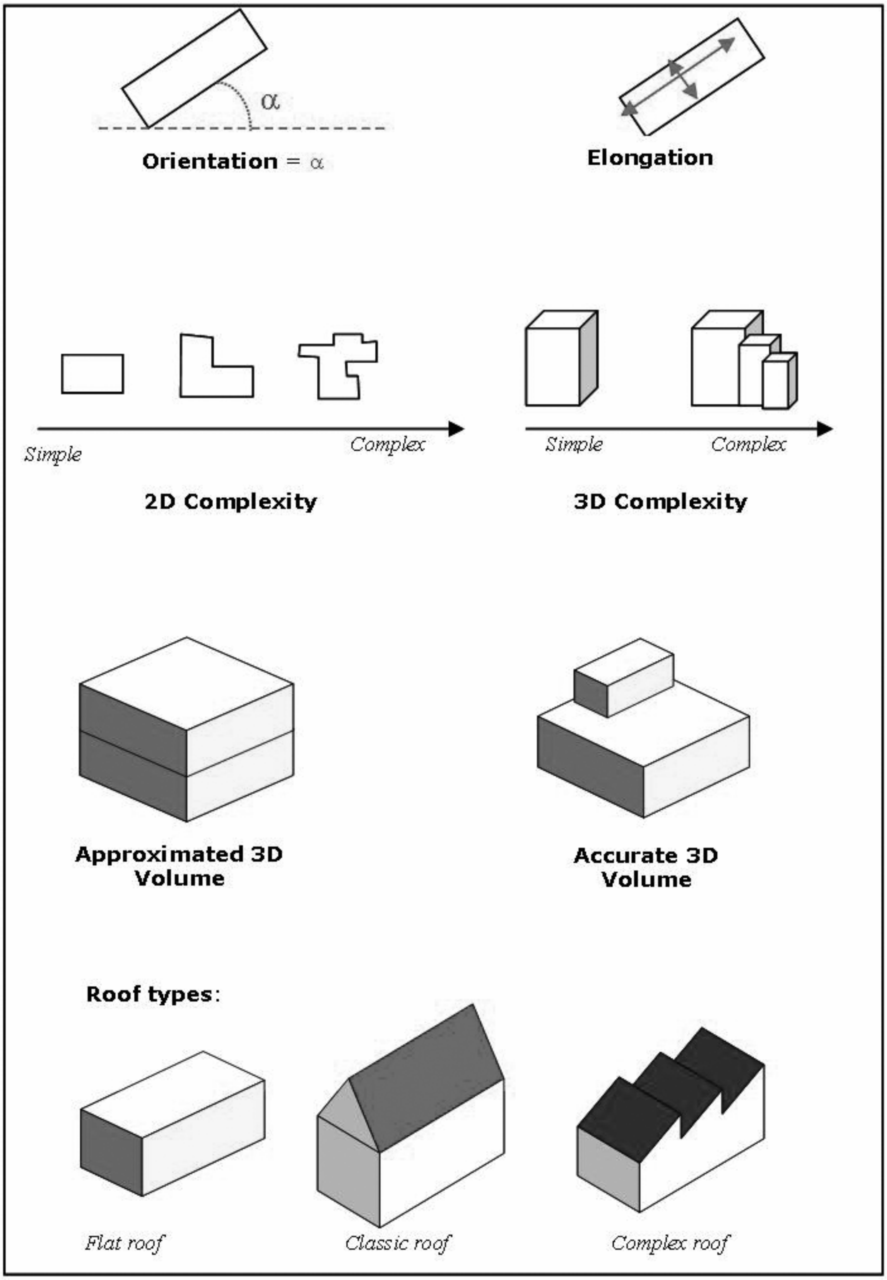


Fig. 8. Morphological indicators of buildings

We can define "housing groups" as follows: HG={$H_{n>=3}$}, with H: housing building, n: number of elements of the group.

By observing these groups in different metropolitan areas, we notice that generally, they can be unfolded into simple elementary figures which are the following basic geometric shapes: line, triangle or square. Thus, we consider the hypothesis that these groups of habitation can be described by an invariable of shape defined by 2, 3 or 4 individuals: « —, △, □».

Hence, by repetition of the simple figures corresponding to the group invariant it is possible to construct other complex ones by a symmetric operation: translation, rotation, etc.

The three elementary organization figures based on the concepts defined above are shown in figure 7.

4.7 Morphological Indicators of Buildings

Each building has its own morphological characteristics. Thus, in order to detect the housing groups we also consider the following characteristics:

- Orientation;
- Elongation = length / width; value between 0 and 1 (1: square, 0<rectangle<=1);
- Surface (m^2);
- 2D complexity = number of points composing the shape of each surface;
- 3D complexity = number of plane surfaces composing the volume; derived from the analysis of LIDAR data;
- Approximated 3D volume (m^3) = surface × height; surface is derived from the simulation results and height is taken from the number of storey of each building multiplied by 3 (considered to be the average height, in meters, of each building storey);
- Accurate 3D volume (m^3): derived from an hybrid approach using GIS and LIDAR data (as shown in section 4.10);
- Roof type: result from the analysis of LIDAR data (as shown in section 4.9);
- Mean slope of the roof (degrees): outcome from the analysis of LIDAR data (as shown in section 4.9)

The morphological characteristics which enable us to detect the buildings groups are shown in Figure 8.

4.8 Detection of Housing Groups Using a Database with Geomatic Algorithms

In order to improve our database a Java algorithm library was developed in order to detect the housing groups. The detection method is based on the neighborhood and angle indicators. Below, it is presented how groups are introduced in the agent simulation as dynamic agents.

Thus, in order to detect these groups we added a *link* class to the conceptual data model, which enable us to determine the group classes (as shown in Figure 9).

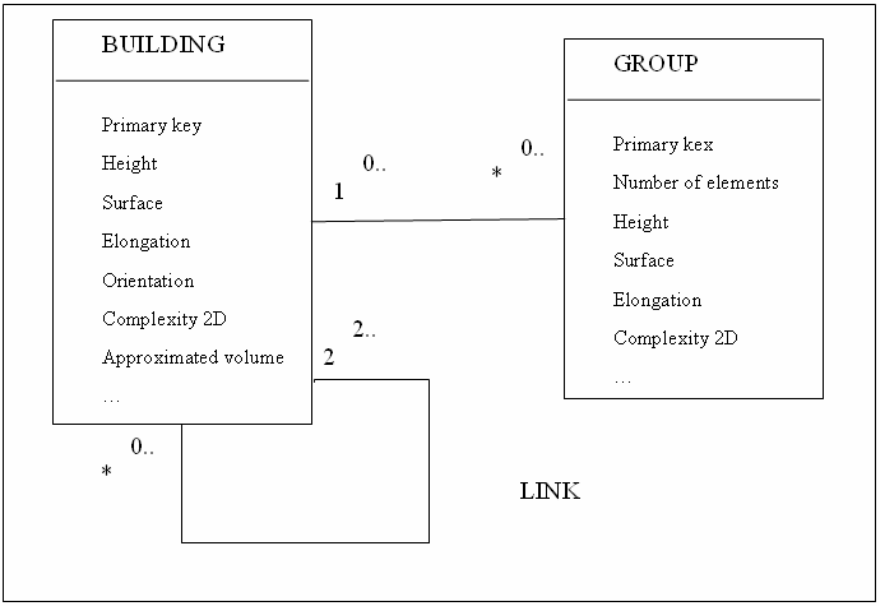


Fig. 9. UML model with the group class and the link association class

The *Housing Group* detection method established here is performed following three criteria: programming, neighborhood and building's shape. This is a four-staged method:

1. Calculation of shape descriptors for each building;
2. Detection of links between building and neighbors. As presented in section 4.7 descriptors for each building are calculated, notably:
   - 2D complexity;
   - Surface;
   - Orientation;
   - Elongation;
   - Approximated 3D Volume;
3. Creation of the groups following the detected links;
4. Spatial regrouping following angles between the links

4.9 Calculation of Morphological Indicators of Buildings Using GIS and LIDAR Data

Research work was undertaken in order to apply GIS and LIDAR data to calculate 3D morphological indicators of buildings, such as 3D volume, 3D complexity, roof type and mean slope of the roof. In fact, our current prototype implements a 3D modeling methodology in which the volume is calculated by multiplying the surface of each building (derived from the simulation results) by its height (taken from the number of storey of each building multiplied by 3, considered to be the average height, in meters, of each building storey).

Thus, using different techniques derived from GIS and LIDAR data enable us to interpolate the 3D shape (evaluating its complexity), calculate the volume, define the roof type or determine the mean slope of the roof of each building more accurately (Zwolak 2008). In this case, buildings are modeled in three different ways:

- **volume calculation:** using a 2.5D urban surface model constructed by means of a hybrid approach with GIS and LIDAR data, as presented in Fig. 1. The volume built on each cell of the grid is an elementary prism whose base is a unit square and whose height is its value on the 2.5D urban surface model. The total built volume of each building comes straightforwardly by summing the elementary volumes on each pixel that belong to one same building;
- **3D complexity:** using a Hough transform based approach for extraction of buildings by means of raw LIDAR points that are classified into independent parts (with different geometries) of each building envelope, which allow us to analyze and classify its complexity (Lohani and Singh 2007);
- **roof type and mean slope of the roof:** using a Hough transform based approach for extraction of buildings by means of raw LIDAR points that are classified into independent parts of each roof (with different geometries), which allow us to analyze and classify the roof type and to calculate its mean slope (Lohani and Singh 2007).

4.10 Integration of an Agent Group in the Simulation Model

A new element is introduced at the meso level: the housing group. That group can be defined as a set of buildings with the same type, with homogenous distribution, with similar shape (2D), complexity, elongation, etc., and that have a strong identity.

The group class has the following attributes:

- primary key;
- 2D geometry corresponding to the convex envelope of aggregated buildings.
- type (residential, industrial, etc.) that may be not the same as that in the register;
- number of components;
- shape descriptor for each building composing the group (as shown in section 4.8):
  - Orientation;
  - Elongation;
  - 2D Complexity;
  - Surface;
  - Approximated 3D volume;
  - 3D complexity;
  - Accurate 3D volume;
  - Mean slope of the roof.

5 Analysis of Results

5.1 Visibility and Sunshine Analysis

In our research the hypothesis that we intend to prove is that a city is a self-organized system. Presently, our first results seem to indicate accordingly, however simulations have to be improved.

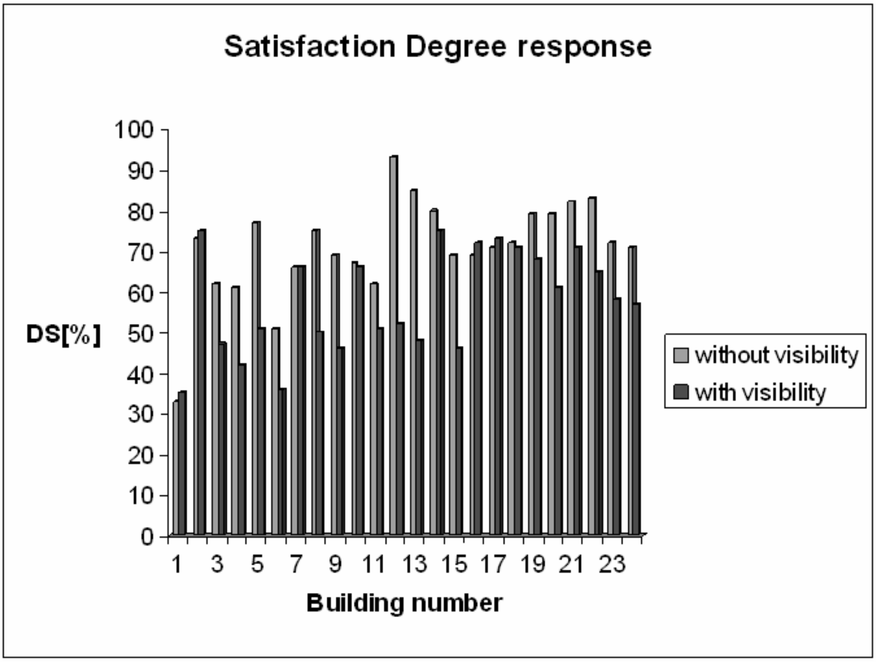


Fig. 10. Impact of visibility parameter on DS of existing buildings

Our model was run (with and without the visibility parameter) on the pilot zone[3] of the city of Lausanne, as shown in Figure 2. The impact on the degree of satisfaction (DS) is illustrated in Figure 10. Hence, we can confirm the major importance between these two simulations because we have chosen a high coefficient for the visibility factor. It is a modeling choice that reflects the characteristic of the site chosen for the study: zone along a lake. It is quite known that along Leman region (large area along Geneva lake), the view on the lake is a major factor for satisfaction of people, and consequently of residential buildings. A well-considered analysis allows us to conclude that a building can have a DS lower than another (buildings 1 and 14) if the visibility parameter is not considered or, inversely, a higher DS if the latter is considered. Thus, these results may suggest the possibility of another city self-organization which may better reflect reality (compared to the zone of selected study).

Furthermore, in order to create new buildings, two simulations (with and without the visibility parameter) were also performed for the same pilot zone of Chavannes district, at the city of Lausanne. Hence, simulated buildings were only created for demonstration purposes. For some points distributed on our pilot zone, visibility parameters were calculated, and values of visibility for missing points were extrapolated. The results are shown in Figure 11.

[3] Within an area of 500 × 500 meters (Chavannes district, city of Lausanne).

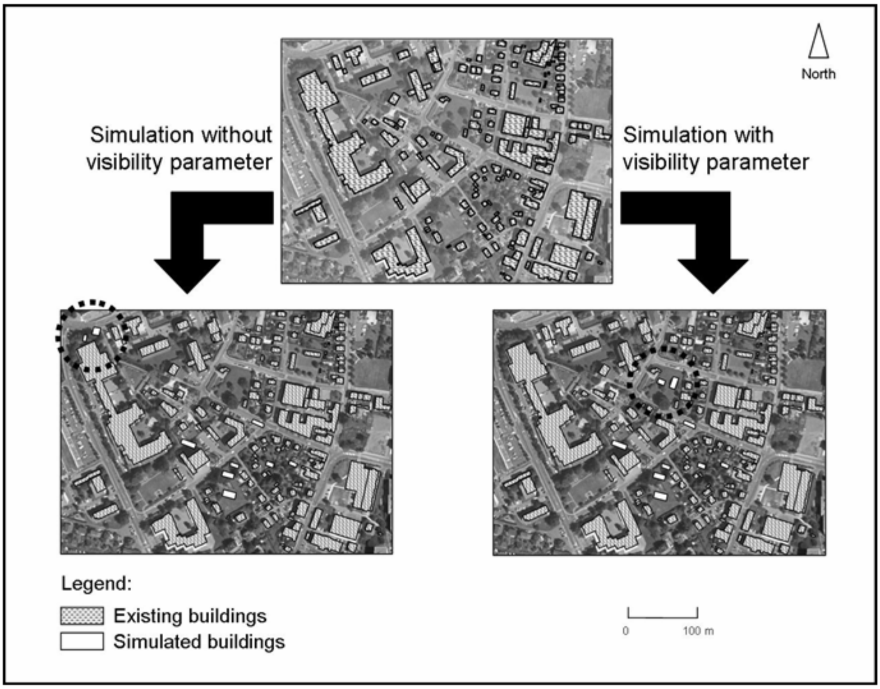


Fig. 11. Simulation without visibility parameter (left); Simulation with visibility parameter (right)

From the analysis of Figure 11 we can verify that impact of visibility on results is important. Moreover, these results implicitly depend on the degree of importance given to visibility factor.

At present, our multi-agent system is under improvement by integrating the sunshine parameter. This enhancement is an important issue for urban planning, especially for environmental reasons, security and quality of life evaluation.

5.2 Analysis of Urban Groups

We tested the group detection method (without application of GIS and LIDAR data analysis) in our study zone. Figure 12 displays the location of our four studied zones, at Chavannes district, city of Lausanne.

Figure 13 shows the new representation of the city at the mesoscale level, based on the housing groups linked to the existing equipments and public spaces of the pilot zone studied.

Figure 14 show the housing groups detected in our study zone. It is concluded that, although meaningful results may be achieved using this method, there is nevertheless room for improvement based on the following reasons:

- In example 1 we can see a line with 5 buildings correctly detected. Although links are created regarding its form similarity, the result presents an inhomogeneous group following 2D complexity form. Indeed, the building at the top of the figure has a complexity of 10 points despite the fact that other buildings have a complexity of 4 or 6 points.
- The example 2 shows a building group with the same homogeneous complexity. However, it is difficult to determine whether its form is a triangle or a line.
- The example 3 shows double links due to the existence of contiguous buildings. Thus, considering further developments, we either have to add this type of buildings to links' detection or to consider it as a type of building with a particular form.
- In example 4 we can identify a square grouping. However, we notice that some links (the diagonal blue links) are not relevant. In fact, they not only distort the calculation of the group angle, but they also disturb the representation of the city at a mesoscale level.

According to the results shown above, some important inaccuracies are generated by the method of detection here presented. It is thus necessary to adjust the method of detection by improving both the algorithmic part and the accuracy inherent to the input data used. The latter may be improved using the LIDAR data available, which

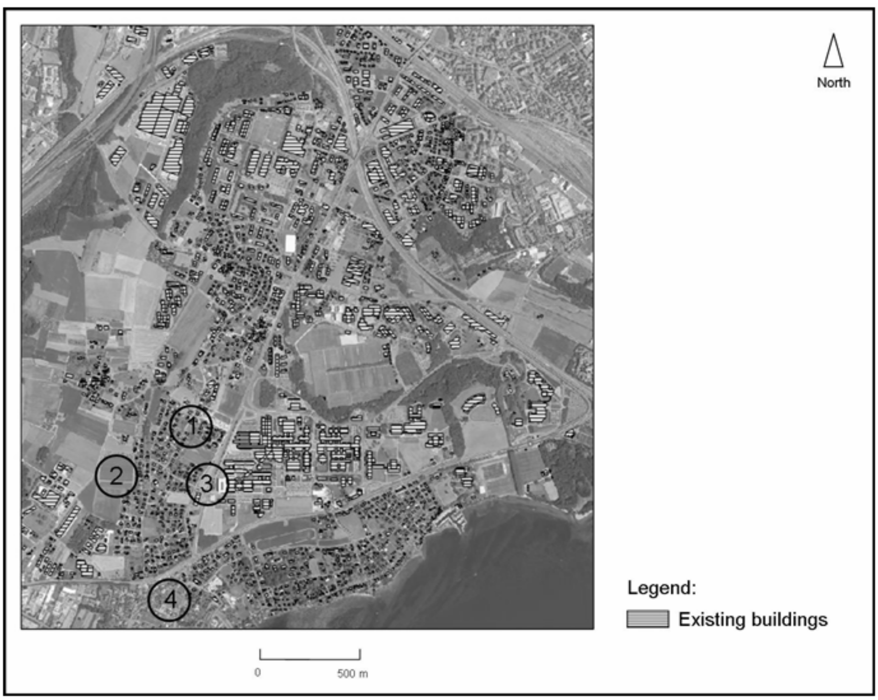


Fig. 12. Four studied zones, at Chavannes district, city of Lausanne, with approximated position of the extracted groups

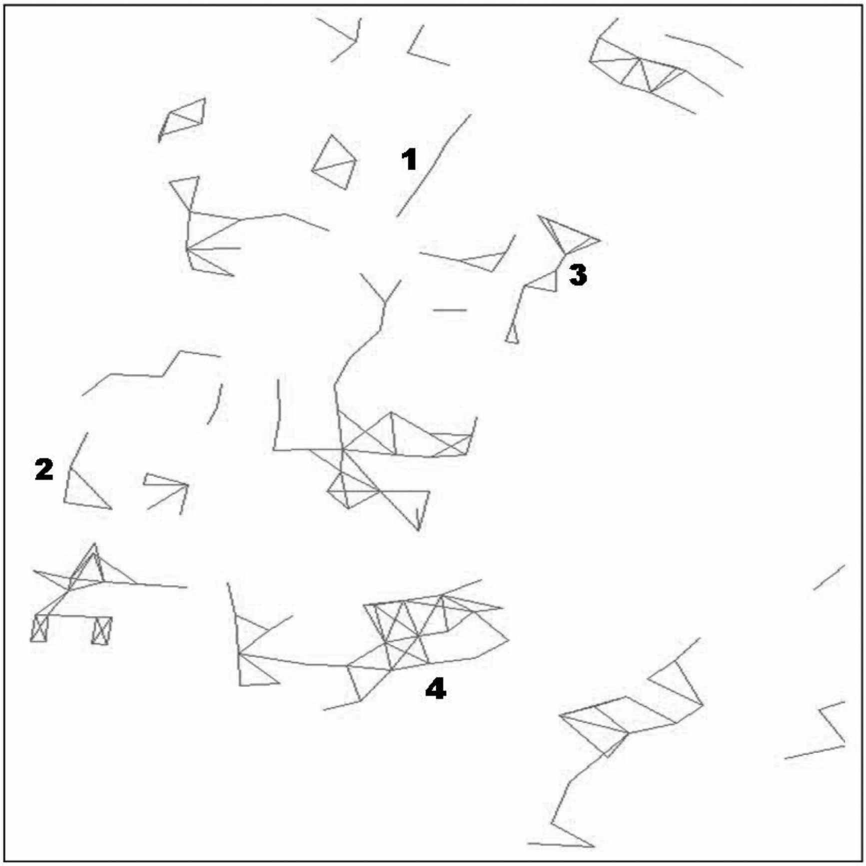


Fig. 13. Part of the studied zone with approximated position of the extracted groups

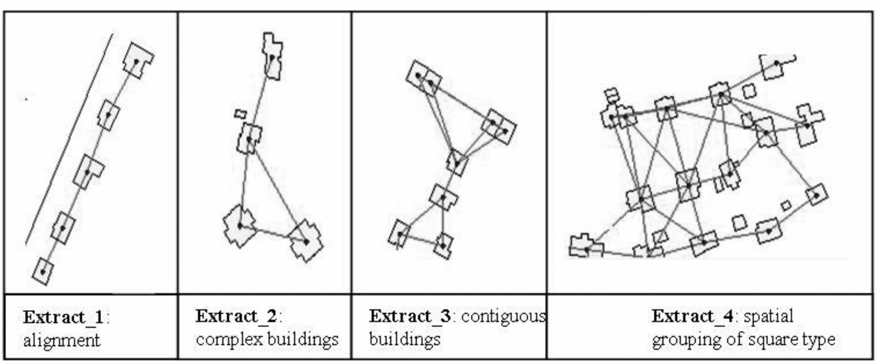


Fig. 14. Zoom on each the detected four groups

allows us to extract relevant indicators, such as the volume and type of roof of each building, in order to detect the housing groups. Hence, it is expected that simulations performed subsequently will enable us to compare new results with the results presented above and, thus, getting more precise our model.

6 Conclusions and Perspectives

Using a hybrid approach derived from GIS and raw LIDAR data allows the analysis of fast and accurate urban indicators - visibility and sunshine studies and extraction of morphological properties of buildings, such as 3D complexity, 3D volume and roof type, were undertaken and can be used for many applications and purposes. Thus, as explained above, the use of this type of data in urban simulation can be a very useful tool that rapidly provides simulation and analysis about the form of a city to users of fields beyond geomatics.

With regards to future work, improvements on the simulations results would allow a better interpretation of the degree of importance of the use of raw LIDAR data, more specifically its derived 3D urban indicators, in our model. The implementation of other urban indicators is a possible improvement that should be carefully analyzed.

Finally, we expect to improve the visual results by using a realistic 3D urban model of the pilot zone here presented: Chavannes district, city of Lausanne. Thus, for integration and spatial location of new buildings, this 3D urban model will have in consideration the 2D output of our multi-agent vector based geosimulation.

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Urban Pattern Morphology Time Variation in Southern Italy by Using Landsat Imagery

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Abstract. This paper analyses the spatial characterization of urban expansion by using spatial fractal analysis applied to multidate Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) satellite imagery. The investigation was focused on four small towns in southern Italy, for which the border was extracted from NASA Landsat images acquired in 1976 (MSS), in 1991 (TM) and 1999 (ETM). The border was analyzed using the box counting method, which is a well-know technique to estimate the spatial fractal dimension, that quantifies the shape irregularity of an object. The obtained results show that the fractal dimension of the border of the investigated towns is a good indicator of the dynamics of the regular/irregular urban expansion.

Keywords: box counting method, fractal dimension, satellite, time series.

1 Introduction

The size distribution and the dynamic expansion of urban areas is a key issue for the management of city growth and mitigation of negative impacts on environment and ecosystems. Even if urban growth is perceived as necessary for a sustainable economy, uncontrolled or sprawling urban growth can cause various problems such as loss of open space, landscape alteration, environmental pollution, traffic congestion, infrastructure pressure, and other social and economical issues. To face these drawbacks, a continuous monitoring of the urban growth evolution in terms of type and extent of changes over time is essential for supporting planners and decision makers in future urban planning. The analysis of the city size distribution deals with different disciplines such as geography, economy, demography, ecology, physics, statistics because the evolution of a city is a dynamic process involving a number of different factors. The main issue of great importance in modelling urban growth includes spatial and temporal dynamics, scale dynamics, man-induced land use change.

The understanding and the monitoring of urban expansion processes are a challenging issue concerning the availability of both (i) time-series data set and (ii) updated information relating to current urban spatial structure and city edges in order to define and locate the evolution trends. In such a context, an effective contribution can be offered by satellite remote sensing technologies, which are able to provide both historical data archive and up-to-date imagery. Satellite technologies represent a

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cost-effective mean for obtaining useful data that can be easily and systematically updated for the whole globe. The use of satellite imagery along with spatial analysis techniques can be used for monitoring and planning purposes as these enable the reporting of ongoing trends of urban growth at a detailed level.

Nevertheless, the exploitation of satellite Earth Observation in the field of urban growth monitoring is a relatively new tool, although during the last three decades great efforts have been addressed to the application of remote sensing to detecting land use and land cover change.

Over the years, satellite time series such as Landsat TM, MSS images were used to assess urban growth, mainly for several cities (Masek et al. 2000; Yang and Lo 2002; Yuan et al. 2005). A number of studies have been performed relating to the assessment of urban morphology changes, using satellite remote sensing data in the analysis of urban change. Such studies were mainly focused on the evaluation of temporal dynamics of urban growth analysing the urban sprawl phenomenon and the loss of agricultural land. Nevertheless, the analysis of temporal patterns of change, resulting from the modification of urban morphology received a modest attention within the remote sensing area.

Many researches have recently explored the way of measuring the dynamics of urban morphology. Shen (Shen 2002), for example, compared the morphology of 20 urban areas in USA obtaining a wide range of results due to the different size and character of each case study. Frankhauser (Frankhauser 1998) has also used the fractal dimension in the examination of outskirt areas in European cities trying to obtain a typology of urban agglomerations. Finally Benguigui (Benguigui et al. 2000) by examining the built-up settlement of Tel Aviv concludes that the fractal dimension tends to increase through time.

Fig. 1. Location of the Andria, Bitonto, Palo del Colle and Canosa towns

This paper is focused on the fractal analysis of the border of four small towns in southern Italy (Andria, Bitonto, Canosa and Palo del Colle), using multidate NASA Landsat images acquired in 1976, 1991 and 1999 (Figure 1). These towns were involved in a continuous urban expansion connected with the economic and demographic increase. The urban expansion was characterized by a change in the border, which was featured by a more or less regular shape modification. The analysis of the dynamics of such urban expansion can, therefore, adequately carried out by the investigation of the spatial properties of the border through time. The regularity/irregularity of the border of a town can be appropriately investigated by using fractal tools. The fractal method used in the present study was the box counting, well suited to analyze the spatial properties of fractal objects.

2 Data Set

Since 1972, the Landsat satellites have provided repetitive, synoptic, global coverage of high-resolution multispectral imagery. The characteristics of the MSS and TM bands were selected to maximize each band's capabilities for detecting and monitoring different types of land surface cover characteristics. In the present study, the spatial resolution of MSS is 57 m, while that of TM is 30m. The data were downloaded freely from NASA satellite archive (www.landsat.org).

Table 1 and Table 2 show the spectral characteristics of MSS and ETM images. The TM spectral characteristics are identical to those of ETM, except for the panchromatic scene, indicated in Table 1 and in Table 2 as Band Number 8.

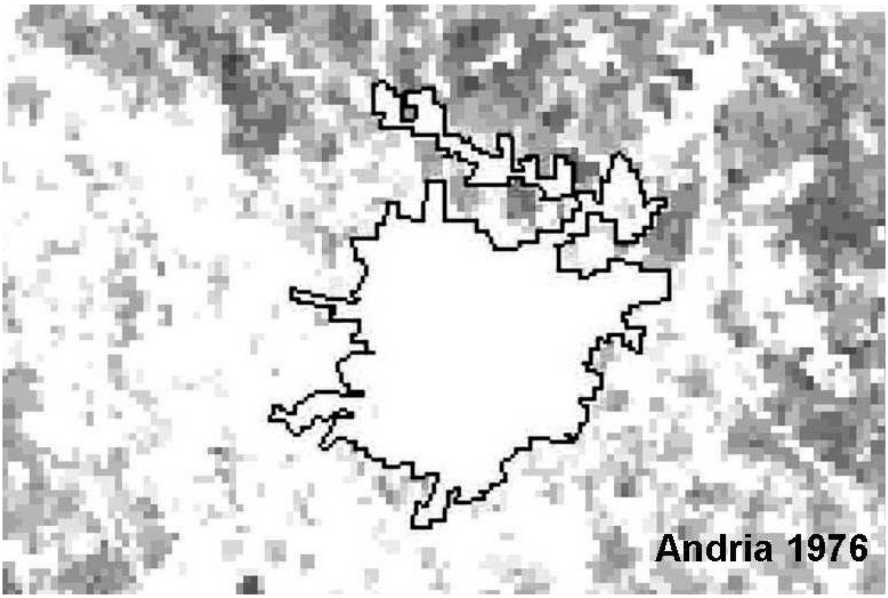
Table 1. MSS spectral characteristics

Band Number	μm	Resolution
4	0.5-0.6	68 m X 83 m
5	0.6-0.7	68 m X 83 m
6	0.7-0.8	68 m X 83 m
8	10.41-12.6	68 m X 83 m

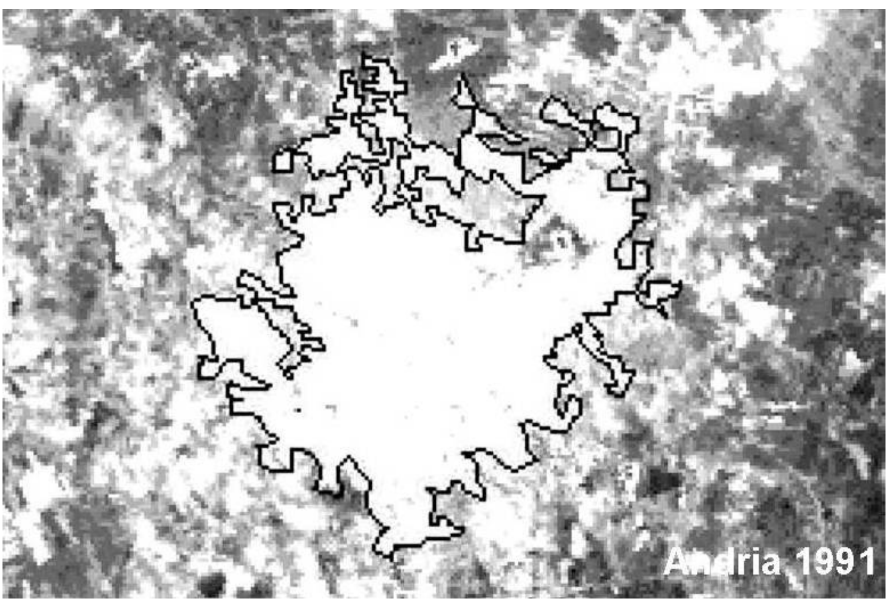
Table 2. ETM spectral characteristics

Band Number	μm	Resolution
1	0.45-0.52	30 m
2	0.52-0.60	30 m
3	0.63-0.69	30 m
4	0.76-0.90	30 m
5	1.55-1.75	30 m
6	10.4-12.5	120 m
7	2.08-2.35	30 m
8	0.52-0.9	15 m

The investigation was performed by using MSS images acquired in 1976 and TM images acquired in 1991 and 1999. The MSS images were re-sampled at the same spatial resolution as TM data. Four small towns in southern Italy (Andria, Bitonto, Canosa and Palo del Colle) were analyzed (Figure 1).

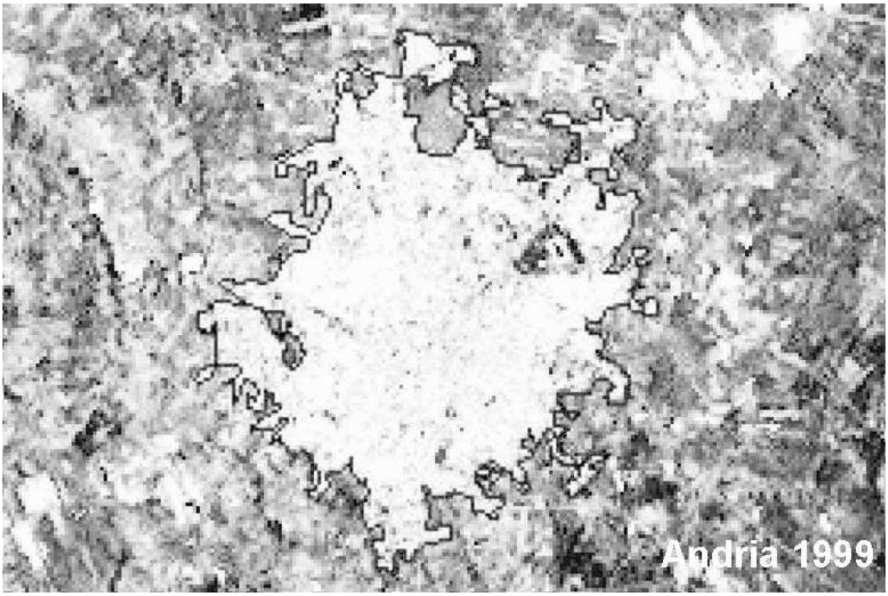


a)



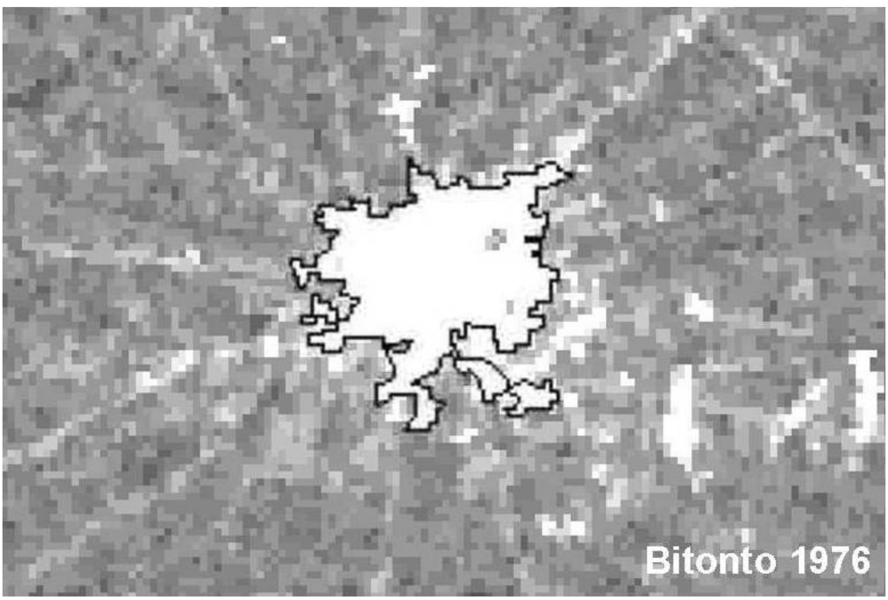
b)

Fig. 2. Border of Andria town in (a) 1976, (b) 1991 and (c) 1999



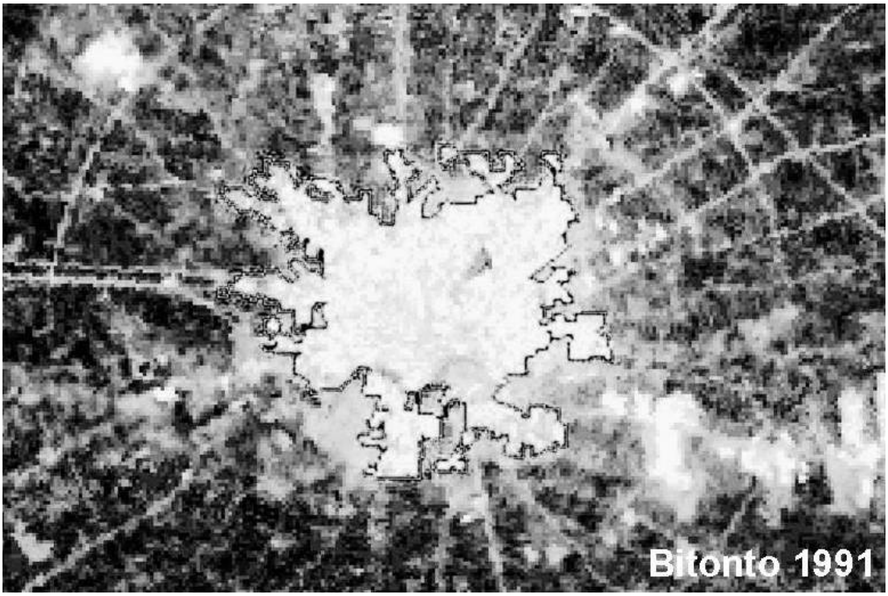
c)

Fig. 2. (*continued*)



a)

Fig. 3. Border of Bitonto town in (a) 1976, (b) 1991 and (c) 1999



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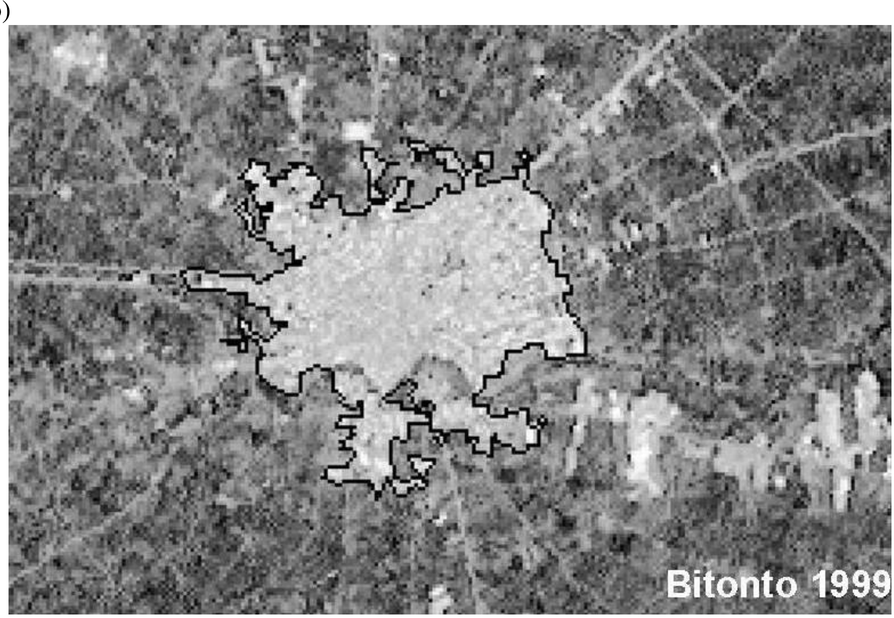
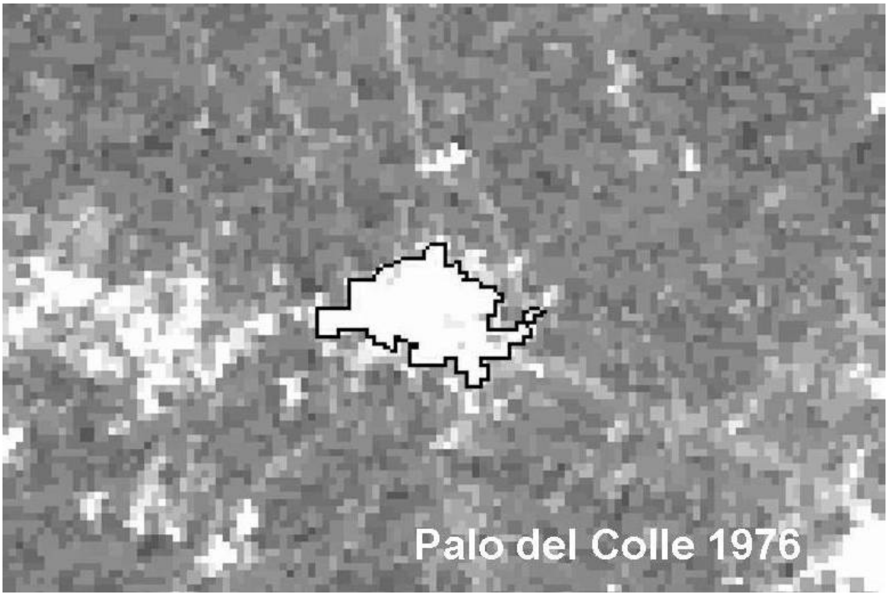


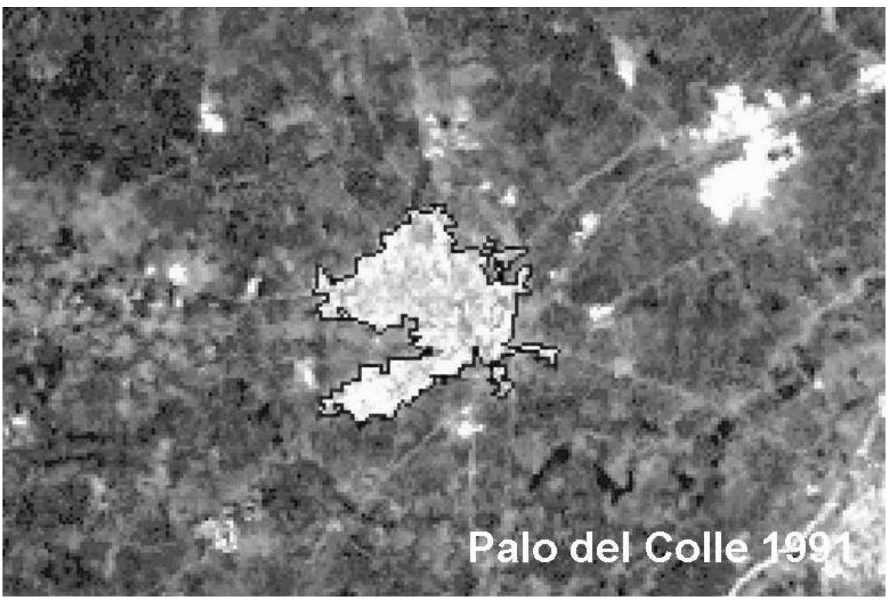
c)

Fig. 3. (*continued*)

The border of the towns was recognized by a visual inspection. The variation of the urban area observed from 1976 to 1999 was connected with economic and demographic factors (Figures 2, 3, 4, 5). All the four investigated towns are located in the Apulia Region that is characterized by an active and dynamic local economy mainly based on small and medium enterprises operative in the commerce, industry and services.

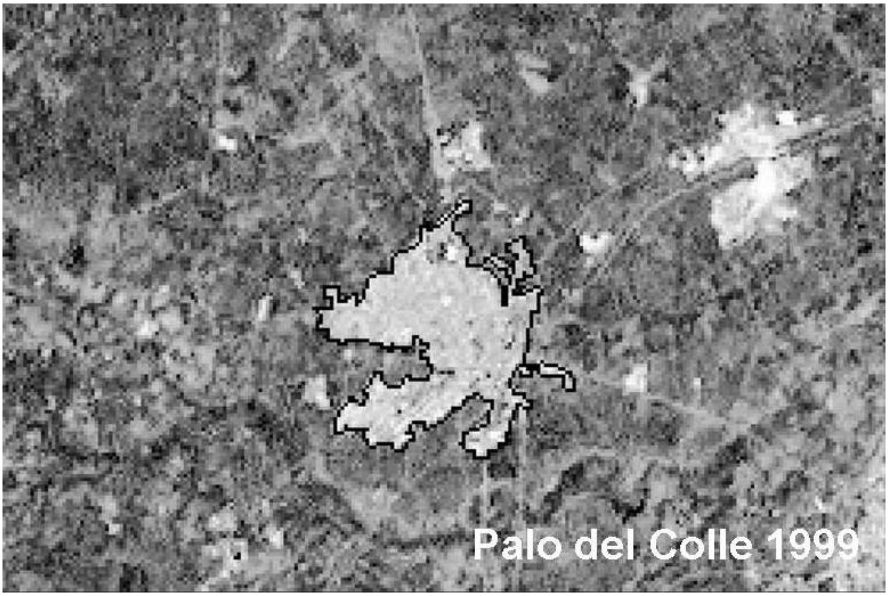


a)



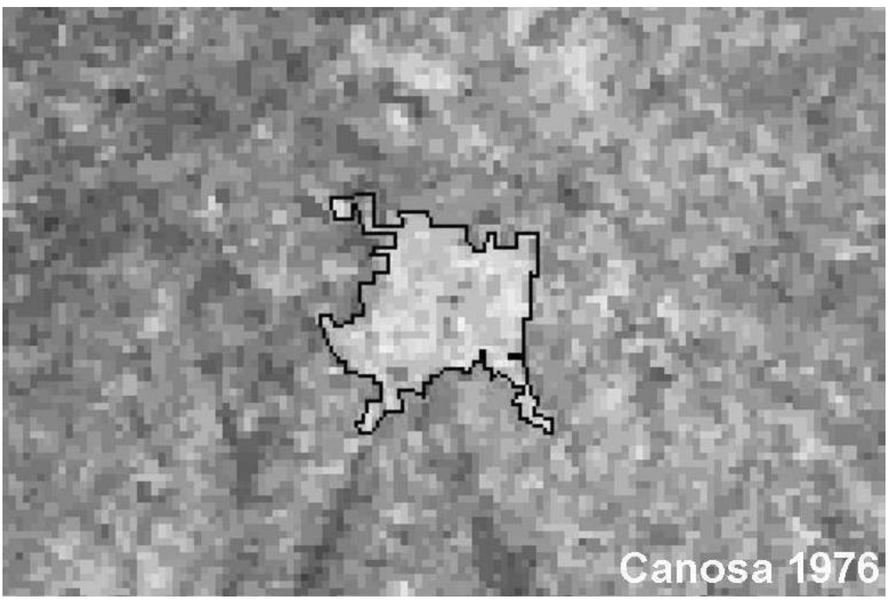
b)

Fig. 4. Border of Palo del Colle town in (a) 1976, (b) 1991 and (c) 1999



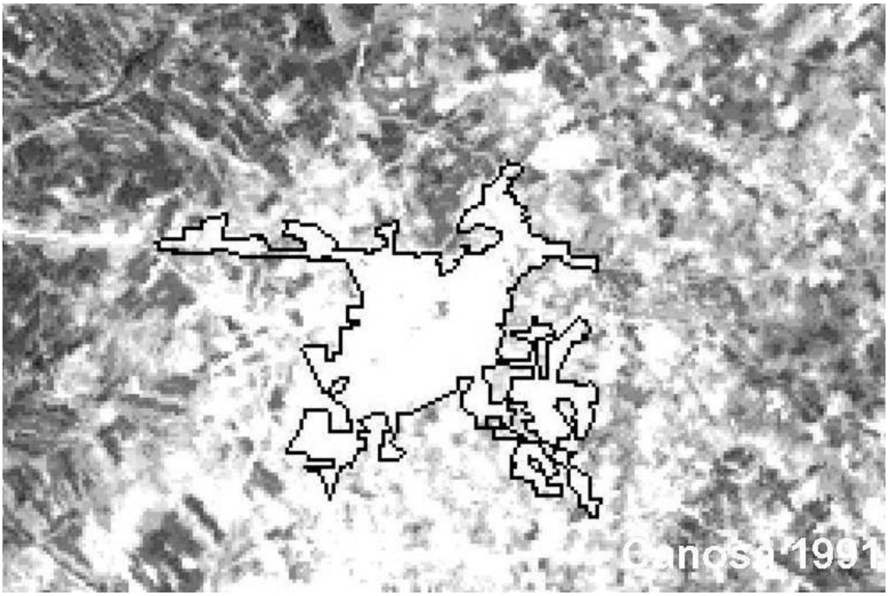
c)

Fig. 4. (*continued*)



a)

Fig. 5. Border of Canosa town in (a) 1976, (b) 1991 and (c) 1999



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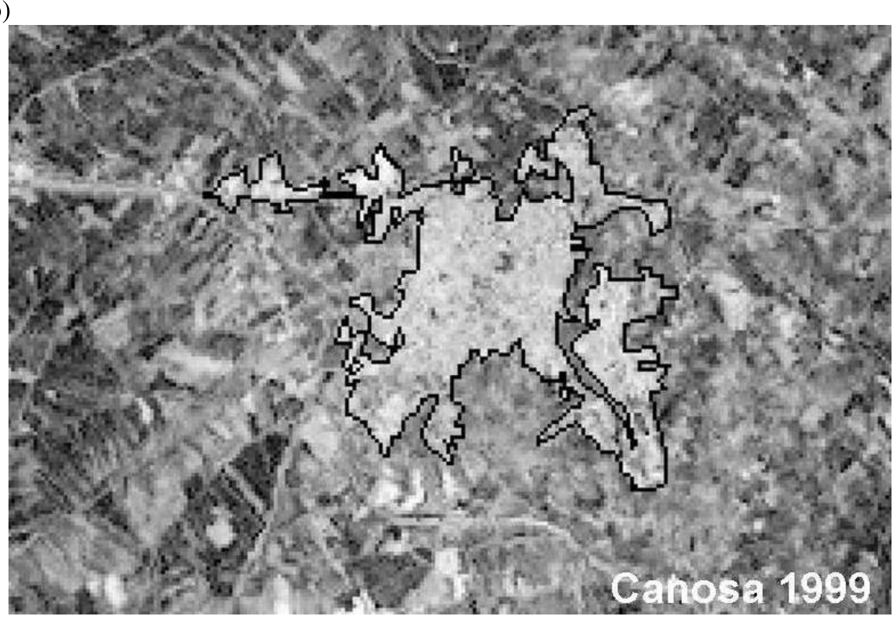

c)

Fig. 5. (*continued*)

3 Method

The use of fractal dimension as a measure of shape irregularity is well known.

A fractal is defined as a set for which the Hausdorff-Besicovitch dimension strictly exceeds the topological dimension (Mandelbrot 1983). The Hausdorff-Besicovitch dimension is simply known as fractal dimension. In the particular case of curves in a plane, while a topological line is one-dimensional, a fractal curve has a fractal dimension D that is in the range 1 < D < 2. The theoretical basis of the concepts of fractals and fractal dimension can be found in Maldelbrot (1983), Feder (1988) and Peitgen et al. (1992), while the use of fractals in Geophysics is widely described in Turcotte (1997) and Korvin (1992).

Fractal curves may be classified into self-similar or self-affine curves. Let suppose that the curve is plotted as a profile, which represents a function y(x). If it has the same magnitude and units on the x and y axes and there is a power relationship between the step used to calculate the length of the curve and the actual length, then the curve is defined to be self-similar (Wilson 2000). On the other hand, if the plot has different magnitudes or units on its axes, the curve is assumed to be self-affine. Examples of self-affine curves are functions of time or space, such as time series. Carr and Benzer (1991) showed that the fractal dimension of self-affine curves describes the stochastic nature of the y versus x plot.

In this paper, the fractal dimension is computed with the box-counting method. The box-counting method computes the degree of irregularity of borders; therefore the higher the fractal dimension, the more irregular the border. The image of the town under study is divided in nonoverlapping cells of size L. Then the number of cells occupied by at least one point belonging to the border is computed. The procedure is iterated for different sizes L and the number of cells as a function of the size L behaves as a power-law for fractal borders:

$$N(L) \approx L^{-df_{BOX}} \tag{1}$$

where df_{BOX} is the estimation of the fractal dimension D by means of the box-counting method:

$$df_{box} = \lim_{L \to 0} \frac{\ln(N(L))}{\ln(1/L)} \tag{2}$$

The estimate of the fractal dimension is performed calculating the slope of the line fitting the equation 1 in its linear part.

Longley and Batty (1989) note that the box-counting method may be less suited to the task of hugging the more intricate details of the base curve but, because of its low computer processing requirements, it is recommended as a method suitable for yielding a good approximation to the fractal dimension.

4 Results and Discussion

The border of the investigate towns was analyzed by comparing the patterns of development of the years 1976, 1991 and 1999. The borders of the towns in the three years of reference are shown in Figure 2 (a, b, c for Andria), Figure 3 (a, b, c, for Bitonto), Figure 4 (a, b, c for Palo del Colle) and Figure 5 (a, b, c for Canosa). The spatial scales used for the estimation of the fractal dimension range between approximately: i) 0.08 km and 3.3km for Andria town; ii) 0.08 km and 1.58 km for Bitonto town; iii) 0.08 km and 0.88 km for Palo del colle town and iv) 0.08 km and 1.30 km for Canosa town. The curves N(L)~1/L for the images acquired in 1976, 1991 and 1999 for each town are shown in Figure 6 (Andria), Figure 7 (Bitonto), Figure 8 (Palo del Colle) and Figure 9 (Canosa). The lower bound of that range is related to the positional accuracy, and the upper bound to the influence of the finite size of the area. Figure 10 summarizes the results of the box-counting method applied to the satellite images.

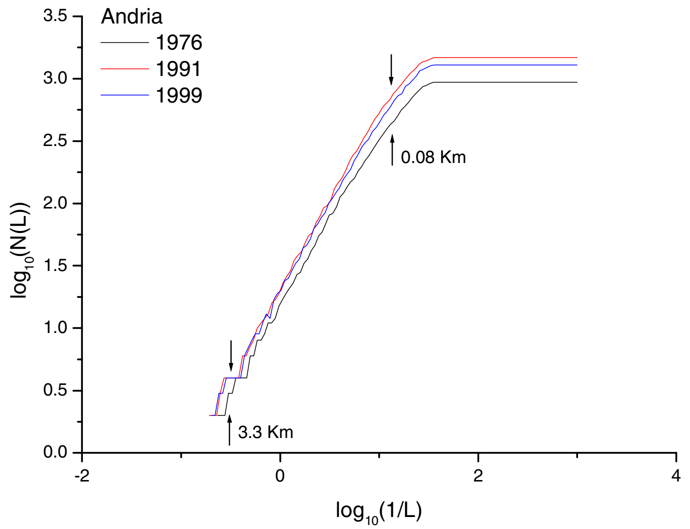

Fig. 6. Box counting analysis for Andria town

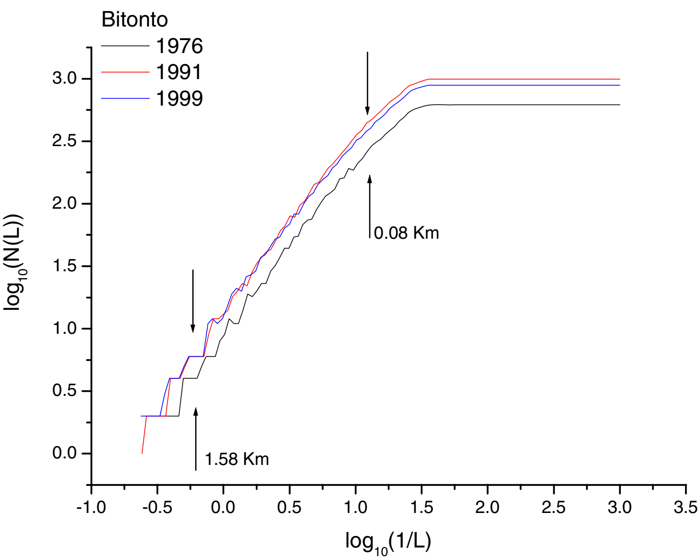

Fig. 7. Box counting analysis for Bitonto town

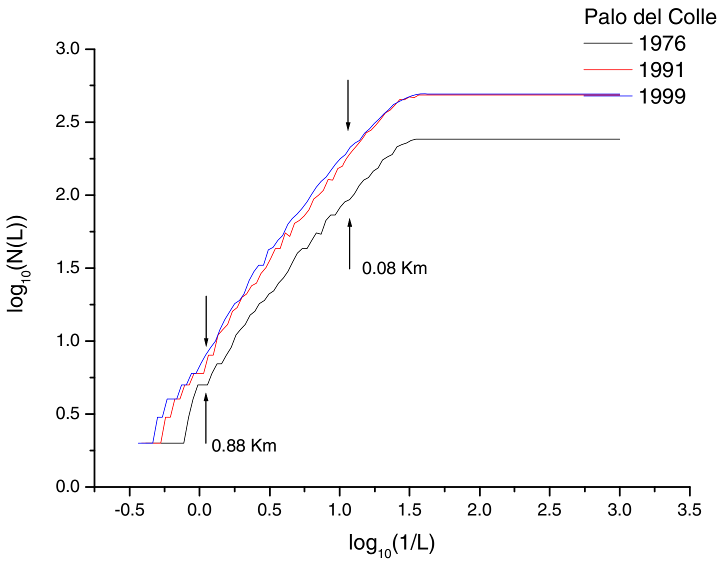

Fig. 8. Box counting analysis for Palo del Colle town

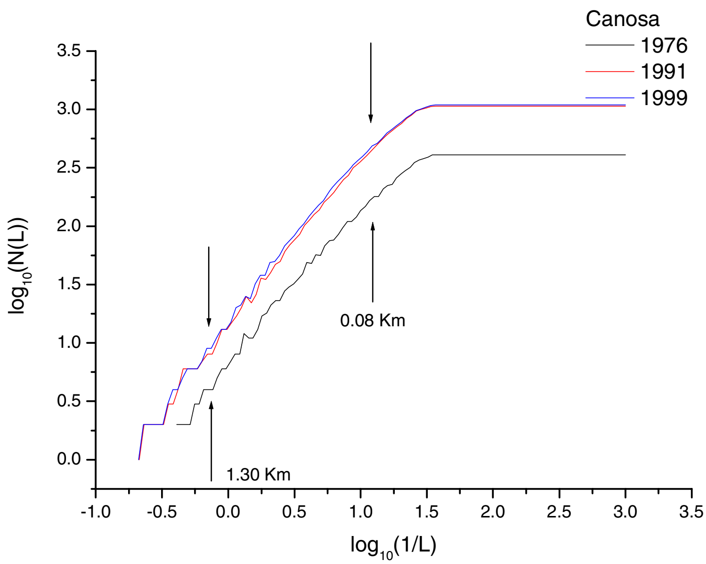

Fig. 9. Box counting analysis for Canosa town

It must be noted that the reliability of the calculated df_{Box} value is examined by the correlation coefficient r, which in our case ranges around 0.99. The value of the coefficient can be considered good if we take into account the suggestions of Batty (2005) and Benguigui et al. (2000). It can be therefore stated that the urban pattern under investigation displays clearly a fractal structure. It is visible an increase of the fractal dimension for Palo del Colle from 1.25 in 1976 to 1.37 in 1999, indicating a tendency of the urban expansion to a more irregular shape.

Quite different is the behavior of the fractal dimension for the other three towns, which all show a maximum in 1991 with df_{Box} ~1.45 for Bitonto, 1.43 for Andria and 1.42 for Canosa. Taking into account the obtained results of fractal analysis, we can observe that the distribution of the built-up area was more homogeneous and less fragmented in the year 1976, without the presence of different urban nuclei. During the period up to 1999 changes led to a remarkable increase of density on every scale leading into an increase in the value of df_{Box} for Palo del Colle town. For the other three towns, the maximum degree of heterogeneity was in 1991, after that the shape started to be more regular.

Of course, the analysis of just three epochs is still preliminary, but suggests that the fractal dimension approach is a good indicator of temporal change in urban morphology.

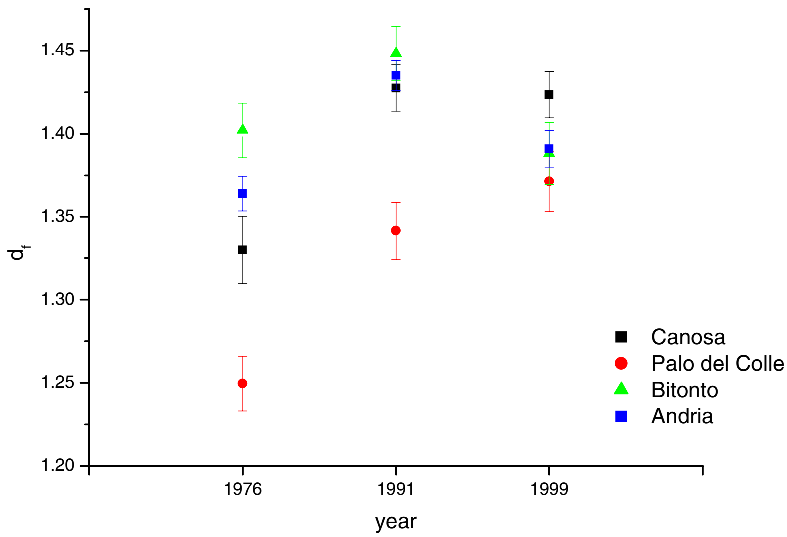

Fig. 10. Fractal dimensions for the four towns

5 Conclusions

In the present paper, fractal analysis was considered as a method of examining the transformations taking place in four urbanized areas located in southern Italy. The built-up pattern of the towns was examined and the main objective was the determination of whether their structure can be described as more or less regular. Analyzing and comparing three different years, the process of urban morphology variation was observed, and the value of the fractal dimension of the urbanized area was calculated. This analysis shows the geometrical features of the transformation that took place in the towns under investigation. Furthermore the box-counting analysis showed the spatial fractal character of the urban pattern where similar structures are observed at many scales, according with results obtained in other researches (Frankhauser 1998; Benguigui et al. 2000; Batty and Longley 1994). The relevance of the technique used here is that it provides a reliable way of quantifying the urban structure and its transformation through time. However this study is preliminary and quite suggestive and its main objective was to present a way of applying the fractal analysis to the monitoring of urban area evolution. The need for the analysis of more time periods and a comparative analysis between many urban areas would be fruitful, and the application of fractal analysis and the focusing on the variation of fractal dimension across space and through time constitute a major challenge of further investigation.

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Predicting the Urban Spread Using Spatio-morphological Models

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Abstract. This paper proposes a new modelling approach which deals with the spatial spreading of built-up areas. The aim is twofold: first, to predict the broad outlines of a built-up areas extension on a regional scale, secondly, to provide decision makers with a tool which allows them to explore spatial consequences of different urbanization policies. Our spatial modelling is similar to cellular automata but differs in the use of image processing method and mathematical morphology algorithms. In this model, the spatial spread process depends on both proximity and morphology of the built-up areas located in a space whose configuration also determines the shape of the spatial spread. These features explain the "spatio morphological" qualifier given to this model. The distinctive features of the both methods will be discussed before focusing the attention on the spatio-morphological modelling and detailing the stages of the approach. The model will be then applied to simulate the built-up areas spread on a coastal region of the Southern France.

Keywords: Image analysis, Mathematical Morphology, Simulation, Spatio-morphological model, Urban spread.

1 Introduction

This paper presents a new modelling approach which deals with the spatial spreading of built-up areas. This modelling aims to predict the broad outlines of a built-up areas extension on a regional or local scale which confronts us with two types of problems. The first problem concerns the accuracy of the spatial spread. If the projected step is to be achieved on a micro scale, the future built-up areas must be exactly located. Now, at the pixel level, important differences can occur between the observed built-up locations and those predicted by the model. The bigger the spatial scale is the higher the local variability of the modelled phenomenon will be. The second difficulty is related to the increasing gap between the sophistication of the models and the know-how of the potential users. Indeed, the spatial spreading models are generally made by experts and their relative complexity restricts their use for basic local players. New methods of spatial modelling, coupled with GIS, are needed to provide decision-makers with a convenient tool which should allow them to explore the possible spatial consequences of proposed actions or alternative policy on a local scale. Our spatial model has been conceived with this goal in mind. The aim is twofold: to be general enough to apply everywhere and, on the other hand, to be able to precisely

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locate the most important part of the future built-up areas. The challenge consists of finding a good compromise between the level of generalisation wanted and the level of accuracy useful to territorial managers.

The proposed approach belongs to the set of methods that assign a strong relevance to the configurations of neighbourhood and to spatial interactions which are assumed to be the key factors of the spatial dynamics. Cellular Automata are ranked among them. Our modelling has several features in common with CA but it differs by the use of Mathematical Morphology as an image processing method. The distinctive features of the both methods will be discussed before focusing the attention on the spatio-morphological modelling and detailing the stages of the approach. The model will be then applied to simulate the built-up areas spread on a coastal region of the Southern France subjected to a strong residential pressure.

2 Modelling Using Image Processing and Mathematical Morphology

2.1 Cellular Automata and Image Processing Method

During the last ten years, CA have become the most frequently used tools for simulating spatial phenomena as fire propagations, land-use changes or urban development. Helen Couclelis has drawn the fundamental framework of CA application on geography (Couclelis 1985 1988 1989 1997). Numerous researches have integrated CA and GIS (Feng et al. 2007; Wagner 1997; White and Engelen 1994; White et al. 1997; Yeh and Li 1998). More recently, researchers worked on models linking CA and remote sensing (Wang 2001) and simulated urban growth using CA and Multi-Agent System (Liu and Chen 2006). We can also stress the significance of the SLEUTH model (Clarke et al. 1997) which has been applied to several American and European cities and succeeded in reproducing their urban dynamics accurately. However the main problem of CA relates to the grid of cell. This arbitrary partition of the simulated territory generates spatial units without correspondence with the size, the shape and the extent of the neighbourhood of the real spatial units. The sensitivity of CA to the spatial and temporal scales has been studied by several researchers (Chen and Mynett 2003; Dietzel and Clarke 2006; Jantz and Goetz 2005; Kocabas and Dragicevic 2006; Ménard and Marceau 2005; Samat 2006). Their works demonstrated that the results of simulations can be influenced by the variations of three scale-components: the size of the cell, its shape and the extent of the neighbourhood taken into account. This problem is known as MAUP (Modifiable Areal Unit Problem) (Openshaw 1984). In principle, until now there is no reliable method for determining the granularity in space and time most appropriate to a given territory (Marceau et al. 2008). Some of these problems are avoided by image analysis and processing using Mathematical Morphology (MM) algorithms.

This method was created in the mid-‘60s in France at the Ecole des Mines de Paris in Fontainebleau by G. Matheron (Matheron 1967) and J. Serra (Serra 1982 1988) and it is still being developed. MM is both a theory and a toolbox. The objects of a digitalised image are only a set of points on a grid. They have lost their integrity during the stage of acquisition so the purpose of the Mathematical Morphology method is organising the information contained in each pixel, designing their arrangement and providing quantitative and qualitative descriptions of geometrical structures of images and three-dimensional objects.

Unlike most of image processing methods which use linear mathematical operations, MM is essentially based on min-max operators. Distance plays a central role in morphological operations. Most of them are based on expanding and shrinking the sets under the study (Haralick et al. 1987). The relationships between pixels are analysed through the use of geometric shapes (circle, hexagon, vector…) called *structuring elements*. In order to perform isotropic morphological transformations a hexagonal grid is preferred to a square one. The neighbourhood relationships between objects are studied by means of structuring elements which are chosen according to the goal to be reached. The distance is not the cell-near but the pixel-near and the extent of the neighbourhood is determined by the size and the shape of the structuring element.

If the image resolution is hexagonal and the structuring element B an elementary hexagon, the neighbourhood Bp of pixel p consists of the seven points of the elementary hexagon Hp centred at the point p. The basic operation is that of an *erosion*. Suppose X is a set (*i.e.* a binary image) and sB is a structuring element of a size s. The erosion of X by sB is defined to be the set of all pixel locations for which the translate of sB is contained in X. It is denoted by:

$$X \ominus sB$$

The dilation of X is the erosion of the complement of X. If X^c stands for the complement of X, then the dilation of the set X is defined by:

$$(X^c \ominus sB)^c$$

2.2 Using Mathematical Morphology for Spread Processing

MM is an efficient image processing method that offers several advantages over other techniques, in particular it preserves edge information, it uses shape-based processing and it is computationally efficient. MM is relevant for analysing phenomena where both the structural description and the determination of laws co-exist and have to be studied together, so it is found to be well adapted to spatial analysis and modelling (Voiron-Canicio 1995). It differs from other methods in that its gives less importance

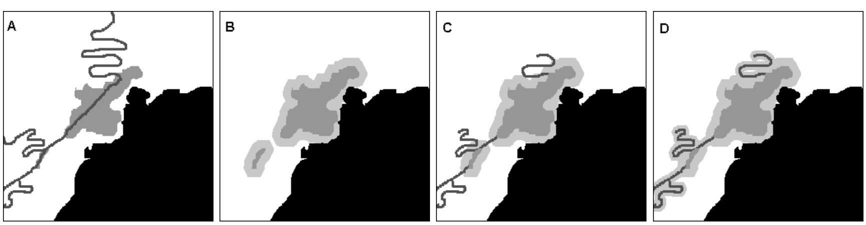

Fig. 1. Example of a spread process using conditional and geodesic dilations. *A*: an urban region. *B*: a conditional dilation size 10 of the city. *C*: the results of a geodesic dilation inside the space of the roads. *D*: the extent of the spread around the city and on both sides of the roads.

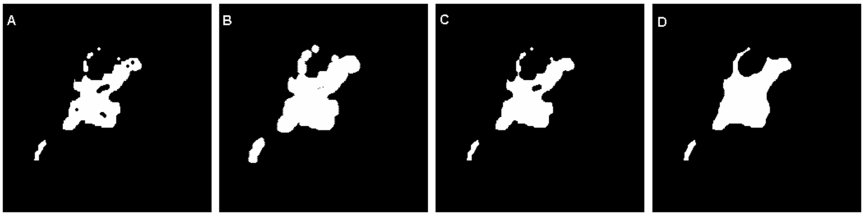

Fig. 2. The closing transformation. *A*: initial set; *B*: a dilation of A (size 3); *C*: an erosion of B (size 3) and the result of the closing size 3; *D*: a closing size 12 of A.

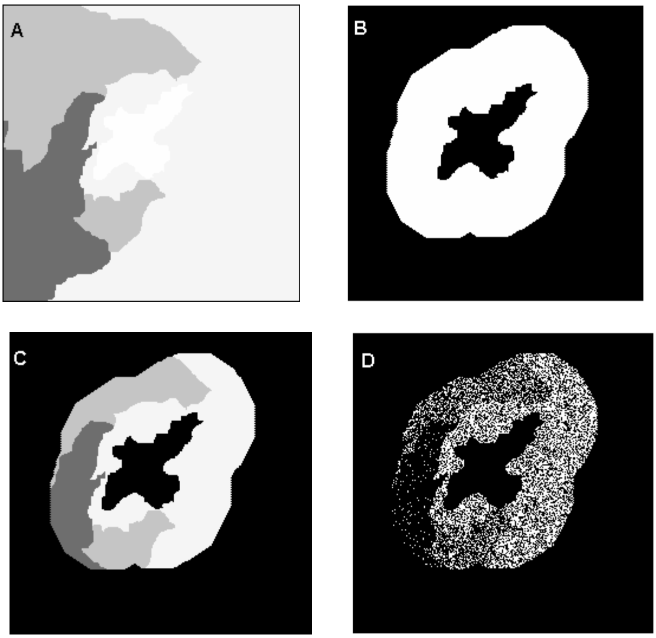

Fig. 3. Example of random spread by image processing. *A*: a city and its surrounding region. *B*: the extent of a dilation size 50 of the city; *C*: Zones with different constraints falling into the dilated area; *D*: the result showing the three sets of Poisson points.

to the pixel value itself than to the relationships with its neighbourhood therefore this method is suited to all questions about spread problems, spatial propagation simulations and has already been applied to simulating spatial risks, flooding, epidemics and fires (Serra 2007).

Image processing is implemented by means of MicroMorph version 1.4, a software developed at the Centre de Morphologie Mathématique of the Ecole des Mines in Paris. MicroMorph software runs on Windows System and does not require lengthy training.

Erosion and dilation operators serve as a base for other more elaborate ones. We will present now three morphological transformations which are useful in simulating the growth or the spatial spread of geographical phenomena.

In Figure 1, two sizes of dilation are performed to simulate a spatial growth process with different speeds: the first around an urban area, the second along the main roads where the spread is supposed to grow more quickly. The former is a conditional dilation (size 10) of urban area and the result of dilation is intersected with the field under study. The later is called a geodesic dilation, *i.e.* a size 50 dilation performed from urban area and propagating inside the roads space solely.

Figure 2 illustrates a *closing* transformation. A *closing* is a dilation of a given size s followed by an erosion of the same size. The two main properties of this extensive operation are firstly the clustering of the parts of the set from less than s apart and secondly its hole filling action.

If we want introduce a part of randomness in the spread process we can combine the urban extension modelled by dilations with a randomisation of the new built-up areas by means of Poisson points. The densities of the points can vary according to the zones of relief or hypotheses of local constraints which are supposed to slow down the spread. Figure 3A depicts a region with a city in white and 3 zones which have a different probability to get new built-up areas. Then, the growth of the urban area is modelled by a dilation of the city (Figure 3B). The spread process is simulated by points randomly scattered in each zone of the dilated area (Figures 3C and 3D).

3 An Example of Spatio-morphological Modelling: Simulating the Spread of Built-Up Areas in the Coastal Region of Languedoc

We will now present an example of spatio-morphological modelling. In our approach, the spatial spread process depends on both proximity and morphology of the built-up areas. These features explain the "spatio-morphological" qualifier given to this model. We chose to base the spreading process of the built-up areas on dilations and closings transformations.

3.1 The Protocol of the Spatio-morphological Modelling

We deal with BMP image format with a hexagonal grid resolution of 1152 x 816 pixels. The pixel size is 37 metres.

The model is carried out with data relating to 1977 and 1990. Five images are needed:

- The regional field on which the spread occurs.
- The state of the built-up areas surfaces in 1977 and in 1990.
- The roads.
- The extent of the protected natural zones.

The modelling step involves four stages:

1. understanding the modalities of the extension of the built-up areas in the study zone of in order to determine the spatial rules which are later introduced in the model;
2. simulating in a retrospective way the progressive extension of the built-up areas by using image analysis and mathematical morphology;
3. validating the model;
4. using the validated model to simulate the future extension of built-up areas.

The model is deterministic. The spatial modelling approach assumes that the spreading process is essentially complied with an elementary rule of distance to the built-up areas, which explains the major part of the spreading process and goes beyond the prescriptions registered in the documents of town planning.

The analysis of the evolution of the coastal urbanisation of Languedoc, between 1977 and 1990, indicates that the new built-up elements have sprawled from the already built-up spaces (98% of the new surfaces) meanwhile 0.5% have spread in the nearest neighbourhood. Only 1.5% of new surfaces have been built-up in no urbanized area. Furthermore, we notice that the spatial spreading is neither continuous nor isotropic. It seems to be heading for the directions where the built-up areas already exist and to occur faster or slower depending on their spacing. Therefore, the spatial diffusion mode is that of "expansion diffusion" according to the term given by Cliff et al. (Cliff et al. 1981) to the spread where the spreading phenomenon has a source and diffuses outwards into new areas. Usually, the road network is supposed to guide the spread. In this part of Languedoc, the correlation between roads and urbanization is only observed along the coast and in the hinterland, along the main road leading from the city of Montpellier to the sea. The region of study is a very flat coastal plain, so the relief variable has not been introduced into the model. These features suggest the following modelling rules:

- The new built-up areas can spread from the existing built-up elements only.
- The extension of built-up areas occurs by the progressive connection of the nearest elements. The proximity is defined by the size of the closing operation performed with a circular structuring element.
- The spread is forbidden wherever protected natural zones exist.

We outline that these rules are in accordance with the directives imposed by the legislative frame. Indeed, the options which prevail henceforth are those which try to reconcile urbanisation and sustainable development, by reducing the growth of artificial surfaces, by avoiding the scattering of buildings and by protecting the sensitive spaces. Since 2000, European Union has strongly recommended the reduction of urban sprawl. It has asked its members to take legislative measures for reducing the spread of scattered built-up areas to the detriment of the natural and agricultural zones. In most European countries, the growth of density within the city is preferred to urban sprawl, so the new urbanised areas are only allowed in a zone close to already developed areas. The French law only permits an extension of urbanisation which is in continuity with a town or a village. The new constructions have to be contiguous to already built-up zones or located within a buffer of 100 metres from the urbanised areas.

3.2 Simulating the Spread of the Built-Up Areas

We deal with the built-up areas image of 1977. Closings of increasing sizes are used to simulate the spread during the period of 1977-1990. The flow chart (Figure 4) summarises the steps of the modelling by image processing. Each step of simulation consists of closing the built-up set (Image A1). The closing is *conditional*, *i.e* the closed set (Image B) is intersected with the permitted region in the field, in order to eliminate pixels falling into the sea, into the ponds or into zones where urbanization is not allowed. Such a conditional closing is repeated. At each step, the new built-up areas predicted (image C) are compared with the new built-up areas observed in 1990 (image A2). The criterion for stopping the spread process is the value of a coefficient of similarity, simil, calculated on the new built-up areas only.

$$\text{simil (A2,C) = surface of intersection (A2,C) / surface of union (A2,C)} . \quad (1)$$

$$\begin{aligned} \text{d(A2,C)} &= \text{surface of union (A2,C) - surface of intersection (A2,C)} \\ &= [1\text{-simil (A2,C)}] * \text{surface of union (A2,C)} . \end{aligned} \quad (2)$$

The coefficient simil is related to the distance d but unlike it, simil does not sdepend on images size . We outline that simil (A2,C) is different of simil ($A2^c$, C^c). Its value is 0 when distance d is maximum and 1 when d is equal to zero.

The matching is performed for all probable sizes of closing and the one which maximizes the coefficient simil is taken.

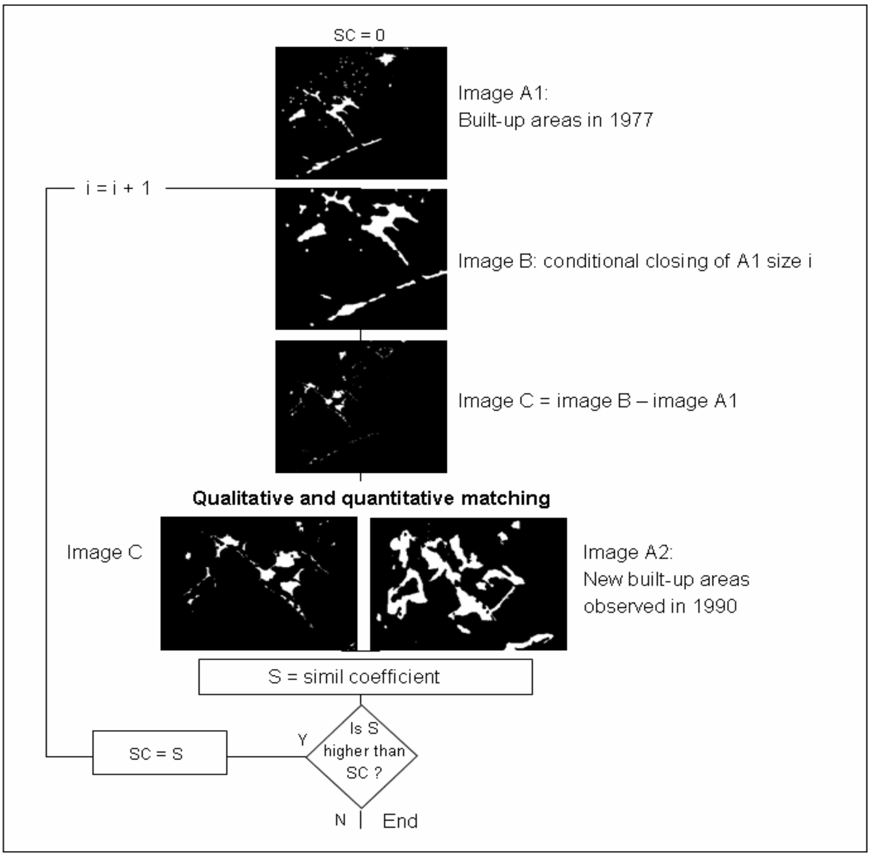

Fig. 4. Flow chart of image processing

3.3 Validating the Simulation Outputs

Generally, map comparisons of observed and predicted states are used to evaluate the outputs of spatial models. Traditional pixel-by-pixel comparisons involve overlaying mappings to evaluate the similarity between two maps (Pontius 2000; Visser and de Nijs 2006).The "classical" comparison approach is based on the Kappa statistics and its variants (Hagen 2002). Recently, methods making use of fuzzy set approach have been developed (Power et al. 2001). The advantages and the disadvantages of procedures expressing the degree of resemblance between two maps numerically were discussed by several authors (Hagen 2002; Metternich 1999; Power et al. 2001; Veregin 1989). Our purpose is to present an alternative comparison procedure which is adapted to the context of image analysis and which is based on resemblance measures (simil coefficient), intersection operations, and visual comparisons.

The result of the intersection between predicted and observed new surfaces gives the proportion of new built-up areas correctly located by the predictive model. However, as discussed above, the variability at the pixel scale is always high. We agree with Power, Simms and White (Power et al. 2001) who consider that "the predictive models are not expected to be accurate at the pixel scale. They are expected to predict the approximate shapes and locations of the phenomenon under study". Therefore, we have also decided to evaluate the similarity by taking into account a margin of error of three pixels (111 metres). The step consists of dilating the new predicted surfaces by 1, 2 or 3 pixels successively, before performing the intersection with the new observed surfaces.

The output of the intersection between predicted and observed new surfaces gives information about the built-up areas correctly located by the predictive model. This output image enables us to detect both regions of agreement and of disagreement. Generally, this visual comparison is very useful because it contributes to improving the model by giving rise to new spread hypothesis, as we will see in section 4.1.

4 Simulations on Period 1977-1990

4.1 Basic Model

The best coefficient simil calculated on the new built-up areas equals 0.257. It is obtained for the closing size 18. 27651 pixels, corresponding to new built-up areas, are predicted by the model comparatively to 20172 pixels for the areas built-up between 1977 and 1990. The percentage of surfaces correctly located is 48.5% at the pixel scale and 71% with a margin of error of three pixels (Table 1).

The results of this first model are reported in Figure 5. We can precisely detect zones of discrepancy. In general, in the Northern part of the field, the spread process is over-estimated by the connection of the small built-up elements. At the opposite, the circular growth of the villages is under-estimated. We also note that along the central axis Montpellier-Carnon and the coastal zone, the urbanisation growth was higher than predicted by the model. In this basic model, the diffusion process is the same for the whole field. However, the observations of the outputs suggest the need of local calibrations. The model has to be improved by modifying both the shape and the speed of diffusion process.

4.2 Improved Model

The improved spatial diffusion process will now take into account two built-up subsets, namely the built-up zones which are supposed to exert a strong attraction, and the rest of the built-up elements. The new procedure consists of two stages.

Firstly, we deal with elements of high attractivity. We have to separate them from the rest of built-up areas. To do so, the big villages of the hinterland are first extracted using an *opening-reconstruction* of size three. This sequence of morphological transformations discriminates the built-up elements by suppressing the smaller ones.

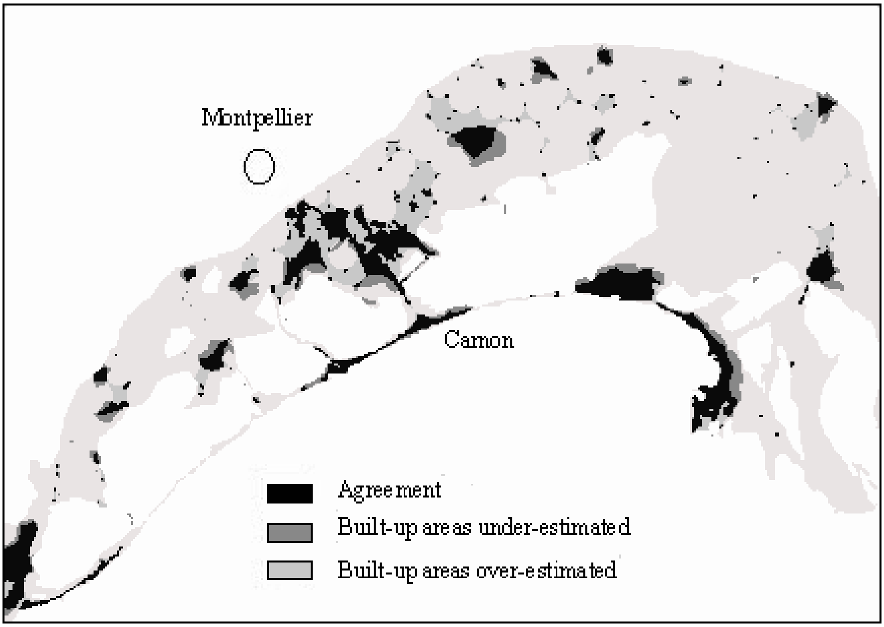

Fig. 5. Output image of the basic model: comparison between observed and predicted built-up areas in 1990

On the output, only remain the elements whose size is larger than three pixels (111 meters). Then, a first buffer of 150 meters located on the coastline and another centered on the axis Montpellier-Carnon are made in order to retain the built-up areas falling within the buffers only. The union of those elements and the big villages results in a new subset whose elements are supposed to grow more quickly than the others. This hypothesis starts the spread process by dilating first this specific subset. Secondly, the union of that dilated subset and the rest of the built-up areas is performed. Then, the protocol used for the basic model is applied to that union. The best coefficient simil is obtained by dilating of size four the specific subset and then by performing a closing of size 5 on the result of the union. The coefficient simil now reaches the value of 0.41.

Table 1. Percentage of built-up areas correctly located by the model

	Pixel scale	Margin of error 1 pixel	Margin of error 2 pixels	Margin of error 3 pixels
Basic model	48.5%	58%	65%	71%
Improved model	58%	65%	72%	77%

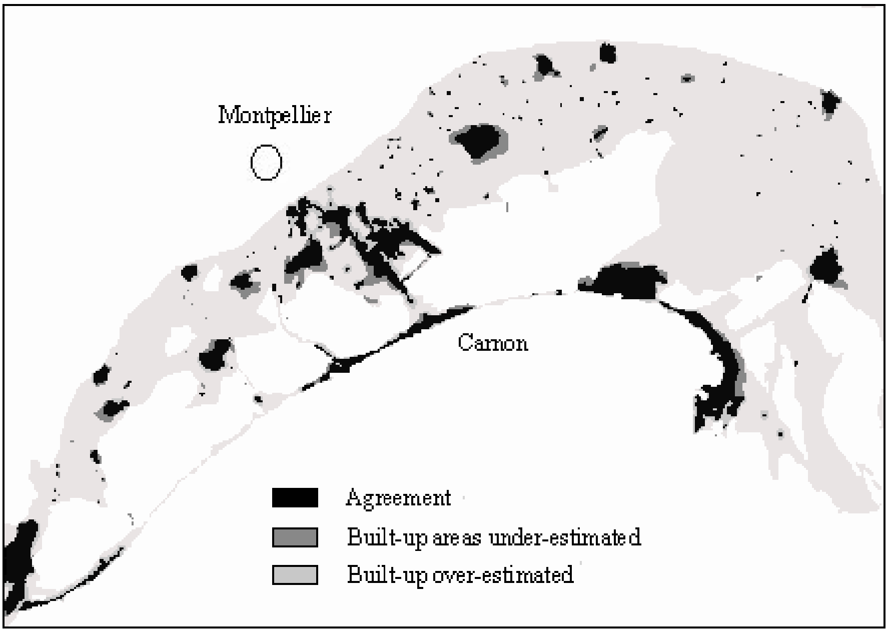

Fig. 6. Output image of the improved model: comparison between observed and predicted built-up areas in 1990

Such an improved procedure leads to better results (Figure 6). The proportion of built-up areas correctly located is 58% at the pixel scale and 77% with a margin of error of 3 pixels (Table 1). The gaps of location have been reduced but they persist around the big villages and in the central part of the field.

5 Predicting the Future Spread of the Built-Up Areas (1990-2010)

This improved model is applied to seek the broad outlines of the future built-up surfaces, up to 2010. The modelling process is driven from the built-up areas map of 1990. Two spread rates were tested. The first one equals 0.06 which is the average annual growth rate of the built-up during the period 1977-1990. With such a rate, the built-up areas would be multiplied three times. As the current territorial policies try to

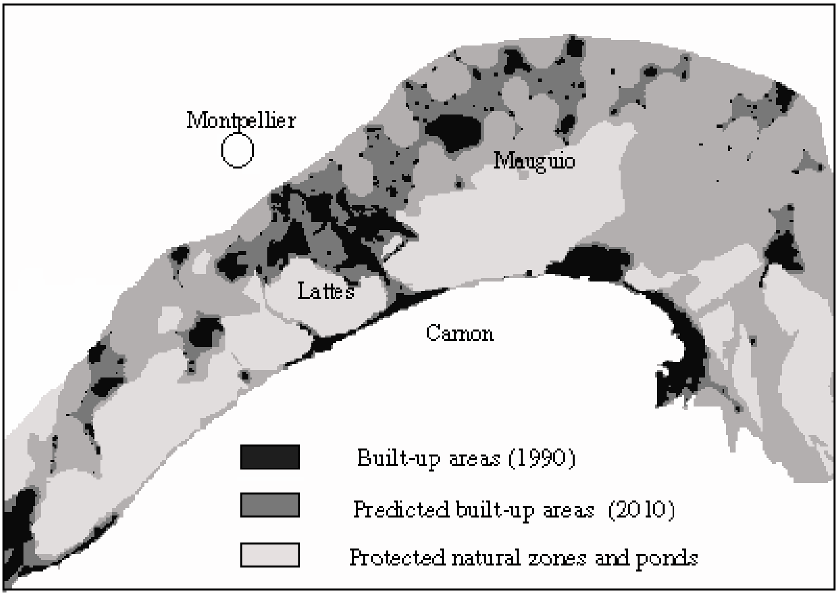

Fig. 7. Output of the model: predicted built-up areas for 2010, growth rate 0.03

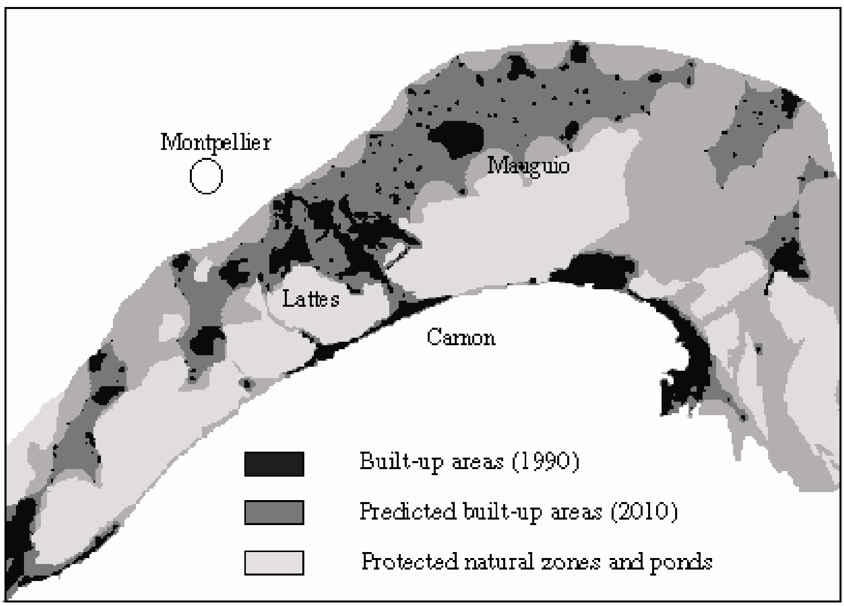

Fig. 8. Output of the model: predicted built-up areas for 2010, growth rate 0.06

slow down the urban sprawling, we have alternatively divided the growth rate by two and taken the value of 0.03. This new growth rate results in doubling the built-up areas in 2010. The spread process is repeated until the number of pixels of the new built-up areas predicted by the model is close to the number expected according to the chosen growth rate.

The results of the simulation are shown in Figures 7 and 8. We notice that the urbanisation would be contained by the protected zones located along the coast and around the ponds. On the other hand, the spread would propagate in the northerly zone, on both sides of the axis Montpellier-Carnon, towards the little town of Lattes and with a large extension Northeast. Indeed, in this zone, the pressure of urbanisation is already intense. The urban spread would be strong if land protections are not created in the meantime to contain it.

6 Conclusion

Modelling by image processing is not frequently used in geography though this approach is rich in potential. It enables us to work on various data sources and on maps imported from GIS layers. The output images can be easily exported to GIS. Image transformations are performed quickly what allows to multiply simulations. The spatio-morphological model presented above provides interesting results which demonstrate that spatial rules simply based on notions of distance, shape and neighbourhood suffise to describe the major part of the built-up areas spread, independently of town planning constraints. Predicted surfaces for 2010 can be crossed with land-use maps, water reserves or risks maps in order to help policy-makers anticipate the environmental impacts of the urban spread and choose the best territorial policy options.

However, the model has still to be improved. In the field of study, namely the coastal part of Languedoc, the topography is flat. However in other regions where relief exists, the altitudes and the slopes generally modify the spreading process. Then, relief constraints have to be introduced into the spatial variables of the model as well as the road network. The model presented is deterministic but we are also working on random spread models based on a urban spread randomisation by means of dilations and Poisson points (Voiron-Canicio 2006).

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A Multi-Agent Geosimulation Infrastructure for Planning

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Abstract. Urban planning is confronted with multifaceted complexities, related to the complex nature of phenomena, dynamics and processes it has to deal with. We argue that good tools for planning must be informed by these complexities, and therefore must have specific characteristics, in terms of modularity, flexibility, user-friendliness, generality, adaptability, computational efficiency and cost-effectiveness. In this chapter we present and try to make the case for a multi-agent geosimulation infrastructure framework called MAGI, showing how it delivers as such a tool for planning. The modelling and simulation infrastructure MAGI possesses characteristics, features and computational strategies particularly relevant for strongly geo-spatially oriented agent-based simulations. The infrastructure is composed of a development environment for building and executing simulation models, and a class library based on open source components. Differently from most of the existing tools for geosimulation, both raster and vector representation of simulated entities are allowed and managed with efficiency. This is obtained through the integration of a geometry engine implementing a core set of operations on spatial data through robust geometric algorithms, and an efficient spatial indexing strategy for moving agents.

Keywords: Geosimulation, Multi-agent systems, Cellular Automata, Urban modelling, Urban simulation.

1 Introduction: Models for Planning

Urban planning has to deal with many complexities adding up one to another: cities are complex systems by nature and their complexity grows further for the fact that they are *social* complex systems, whose dynamics and phenomena intrinsically relate to the *autonomy* and *free choices* of individual agents. Furthermore, the planning process can itself become complex, given that it involves a rich web of relations among public decision-makers, experts, citizens and stakeholders of various kind. Such multifaceted complexities should induce us to draw some ideas about the properties good "tools for planning" ought to have (Cecchini 1999; Cecchini and Trunfio 2007).

We believe that to the concept of bounded rationality proposed by Simon (Simon 1981) and to all the discussion of complexity (the outcome of which was mainly to propose models based on a bottom-up rather than on a top-down paradigm) must also be added the concept of ecological rationality (Gigerenzer et al. 1999), suggesting that a heuristic is rational if well adapted to the structure of its environment. In other words, what is needed is a "toolbox" with "fast and frugal" tools that work well and rapidly.

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To say it more explicitly (Cecchini 1999), urban planning should be supported by models that are modular and friendly, which means that all the participants of the planning should be able to use and understand them (avoiding the use of black boxes, unless strictly necessary); beside that, models should be flexible, i.e. adaptable to different circumstances and to different phases of the planning process; multilevel, i.e. usable and useful in coping with different levels of complexity and interoperability; low-cost, i.e. of common use, usable when they are required and with costs being just a modest fraction of the total planning process costs.

We hold, and our experience corroborates that belief, that Multi-agent geosimulation may play a role to deliver such kind of tools and models.

1.1 Multi-Agent Geosimulation

Multi-agent geosimulation (MAG) is a simulation technique for modelling phenomena which take place in geographical environments, through the use of agent-based approach in high-resolution spatial models (Benenson and Torrens 2004; Castle and Crooks 2006; Kwon et al. 2005; Tayeb et al. 1998; Torrens and Benenson 2005). A typical MAG model uses GIS geo-spatial datasets (related to entities in space such as buildings, infrastructures, terrain elements) to represent the environment within which mobile artificial agents (Ferber 1999) behave, thus simulating human beings (e.g. pedestrians, consumers) or other real-world entities (e.g. households, vehicles). The use of advanced characteristics of artificial agents (as autonomy, pro-activity, ability to perceive the space, mobility, etc.) combined with explicit and faithful representations of the geographical space make the MAG approach an effective technique for simulating complex systems with agents interacting among each other and with the geographical environment.

Indeed, in recent years it has been recognised that such approach may be of great potential for verifying and evaluating hypotheses about how real spatial complex systems operate, and is therefore frequently considered one of the key computer-based tools for decision support (Benenson and Torrens 2004).

Recent research in the field of geosimulation focused mainly on techniques to improve models of spatial processes, to propose new conceptualisations of spatial entities and their mutual relationships, to apply simulation models to real-world problems and to develop new software tools for supporting the process of modelling. This latter research direction has produced modelling and simulation frameworks – like Swarm, Repast, OBEUS, among others (see Benenson and Torrens 2004 for a review) – supporting various forms of integration of geo-spatial data. However, the interoperability with GIS offered by existing tools is still limited. The Multi Agent Geosimulation Infrastructure (MAGI) presented here has been designed and developed for the purpose of supporting the process of MAG model building, while in the same time offering a rich environment for executing simulations and conducting controlled experiments.

MAGI is an integrated environment that allows users to build *ad hoc* agent-based geosimulation models. The main strength of the tool lies in the generality of the underlying meta-model, embodying the possibility to model a large variety of real systems.

As we shall see, besides modelling "mobile" agents, the generality of the meta-model covers also the family of cellular automata-like models with "static" agents, without making compromises to the simplicity and elegance of the modelling practice.

The modelling environment has many features for developing and executing simulation models, conceived consistently with the requirements of "good models for planning" mentioned above.

The main objective of this chapter is to present several characteristics and features of MAGI environment relevant for strongly geo-spatially oriented agent-based simulations which make MAGI an effective modelling and simulation environment, namely: generality, user-friendliness and modelling flexibility, interoperability with GIS datasets and computational efficiency.

The chapter is organised as follows. The next section outlines the main characteristics of MAGI. The subsequent section 3 focuses on the approach implemented in MAGI for handling agents' spatial perception in a vector data context. Finally, section 4 offers few conclusive notes and directions for future work.

2 A General Overview of MAGI

MAGI is constituted of two components: *(i)* a model building and simulation environment (DS environment) (Figure 1) and *(ii)* a class library developed in C++ language which can be used for deriving specific models.

The DS environment has two working modes, the *design mode* and the *simulation mode*. As shown in Figure 2, the design mode allows the user to define and fully specify the model with all its input-output constraints, and its domain and preconditions of application. The simulation mode is used to execute the model for specific scenarios. In general, a scenario is defined by a set of parameters and by a set of geo-spatial layers, with their initial and boundary conditions.

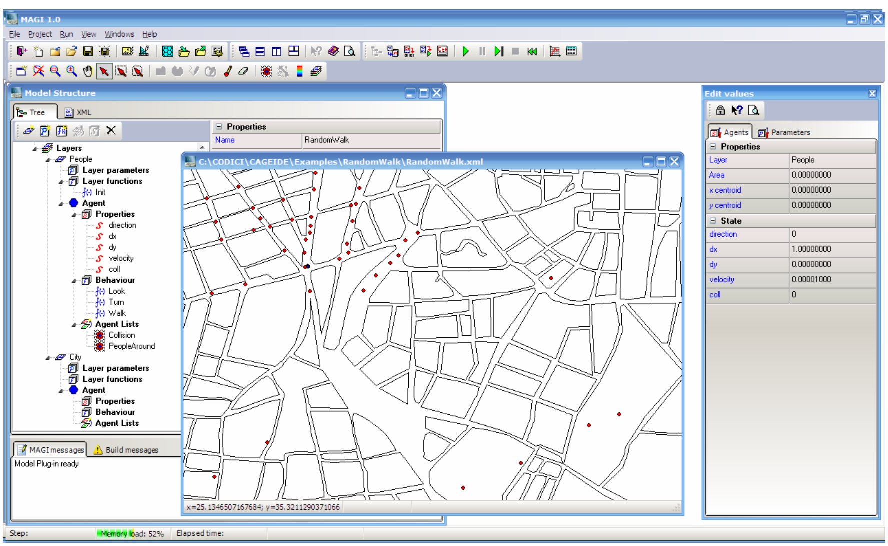

Fig. 1. A screen capture of MAGI

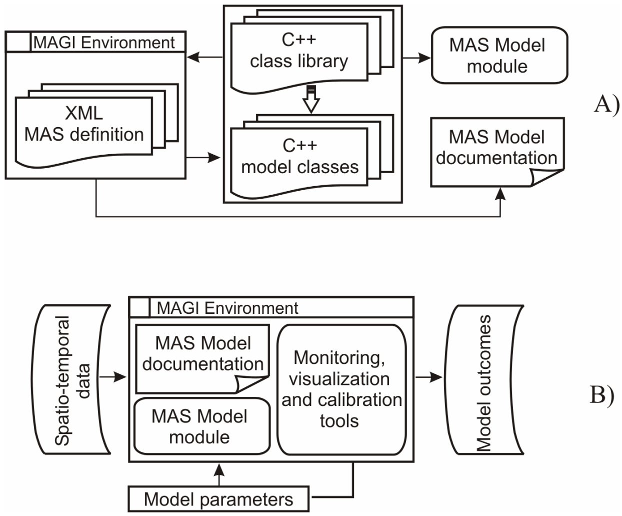

Fig. 2. A scheme of MAGI: A) Modelling phase; B) Simulation phase

The C++ class library can be used by software developers as a stand-alone library for deriving and implementing models, independently from the MAGI DS environment. However, the DS environment offers some useful features and graphical user interfaces for an effective and compact definition of models. In fact, the model specified in the design mode is saved in XML format (Houlding 2001), with a declarative markup syntax that allows convenient and readable representation while maintaining enough semantic flexibility to represent widely different objects. That XML scheme is subsequently used by the framework to generate a skeleton of the C++ source code of the model, on the basis of the MAGI C++ class library (Figure 2). After that, the C++ source code generated by the framework can be imported into a standard C++ development environment for further coding and debugging (MAGI automatically produces the project file for the open source C++ development environment *Code::Blocks*).

The main advantage of this approach lies in the greater simplicity of model designing phase in comparison to a from-the-scratch development. Indeed, in the beginning, the modeller needs only to specify the model components, and is relieved from a number of implementation details and complications. In addition, the use of the XML standard permits an easy merging of different sub-models, simplifying and promoting the collaboration among different experts. Another important implication of the use of XML consists in high readability of the model structure, which is reputed important for avoiding black-box effects.

Once the model has been specified and compiled, MAGI can be switched into the simulation mode in order to execute and manipulate the model, and to perform data analysis and visualisation. For this purpose, as mentioned before, the user must define a scenario or import it from a GIS.

It is important to emphasise here that MAGI has been specifically designed to allow an easy and effective importation of geo-spatial datasets from standard GIS formats.

The integration of simulation engines into existing GIS systems has been proposed elsewhere (e.g. loose coupling based on the Remote Procedure Call paradigm or other proprietary protocols) (Clarke and Gaydos 1998; Wagner 1997; Wu 1999). However, as will be better discussed later, a loose coupling of simulation engines with proprietary GIS can hardly provide the necessary modelling flexibility and a satisfactory computational efficiency. For this reason we believe that what makes the strength of MAGI is its purpose-oriented, consistent and robust model-building user interface with functionalities for: *(i)* creating entities (i.e. objects and agents) from features of vector data files; *(ii)* mapping the feature attributes directly into agents' states and objects' properties; *(iii)* importing raster files as cellular spaces where cells' attributes can correspond to pixels samples, (*iv*) powerful importing capabilities from common GIS formats, and (*v*) the integration of specific computational strategies for efficiency and robustness.

2.1 The MAGI Meta-model

From the modelling point of view, the agent-based meta-model in the MAGI class library is basically a set of objects and agents organised in layers, where each layer can host one specific type of entity. Formally, the environment Env is defined as:

$$Env = < P_G, F_G, \mathscr{L} > \tag{1}$$

where:

- each element p_i of P_G is a *global parameter*, which is a scalar quantity constant in space;
- set F_G groups together a series of *global functions* f_g;
- $\mathscr{L}$ is a set of layers of entities.

In particular, a layer L in $\mathscr{L}$ is defined as:

$$L = < P_L, F_L, \mathscr{A} > \tag{2}$$

where:

- each element p_i of P_L is a *layer parameter*;
- set F_L collects a series of *layer functions* f_L;
- $\mathscr{A}$ is a set of model entities (i.e. either agents or simpler objects like static entities or CA cells).

The global and layer parameters can affect the behaviour of objects which populate the environment. This permits forms of global steering of the MAG model evolution, which has been recognised as important for simulation of phenomena not completely reducible to local interactions (i.e. factors outside the local spatial context can be accounted for in the entities' behaviour). A well known example of the parameter-dependent approach are the constrained Cellular Automata (CAs) used for simulation of land-use evolution (White and Engelen 1993), where time-dependent parameters, often estimated with demographical and economical macro-models, may indicate the amount of cells to allocate for each land-use category at every time step. An example in this category is the well known SLEUTH (Clarke et al. 1997) model, where five global parameters control the different types of urban grow.

Moreover, in the MAGI meta-model, parameters may also be a way to hold aggregate information from a layer, and used as such in other layers. For example, thanks to the global and layer-level functions, the local evolution of a phenomenon evolving on layer L_i may depend on some global indicators of the phenomena evolving in L_j. In fact, during the simulation, global and layer functions are scheduled for execution together with other layer components. In particular, each of the functions in F_G: *(i)* can read and update global parameters; (*ii*) can read layer parameters (which represent part of the external interface of each layer); (*ii*) can potentially execute any kind of algorithm or invoke external or remote programs or procedures in order to perform a piece of computation (thus, global parameters can be an interface between the automaton and other models). Similarly, each function in F_L: (*ii*) can read global parameters as well as parameters of different layers; (*ii*) can read and update parameters of the same layer; (*iii*) can perform internal or external computations, just as global functions do.

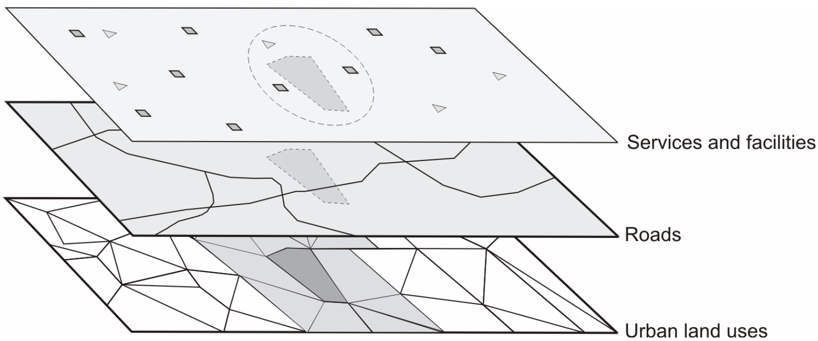

Fig. 3. A MAG model organised in layers

The multi-layer approach presents many advantages in spatial modelling. Among these:

- it allows a simpler coupling of many spatial models of dynamic phenomena evolving in the same geographical space (e.g. regional and urban models requiring different spatial and temporal resolution);
- models belonging to different layers, especially if developed by different field experts, can more easily be integrated together;
- the correspondence to the layer-based structure of spatial data in GIS simplify the acquisition of model inputs and the exportation of model results.

It is important to point out that the meta-model in discussion includes the possibility of having "degenerated" layers containing only static objects or defining cellular spaces. This may prove very useful for urban modelling, for example in order to account for the proximity effects of urban entities such as roads, services, facilities and infrastructures (Figure 3). In the hereby presented approach, the modelling of such interactions is possible because each entity can have access to objects belonging to different layers, including possible auxiliary layers with only static objects representing relevant urban entities.

The most complex type of entity that can populate a layer is the agent a_τ of type τ which is defined as:

$$a_\tau := < s, g, C > \tag{3}$$

where:

- s is an internal data structure describing agent's state and history. During the simulation, s can change, as a result of interactions with other agents, between the agent and its environment, and due to its behavioural specification.
- g is a data structure defining agent's geo-spatial attributes. It includes both a vector geometrical shape (like point, line, polygon, circle), representative of the agent (belonging to a set G_τ of possible shapes), as well as its localisation aspects (i.e. position and rotation) possibly geo-referenced, if necessary. The set G_τ contains shapes of the same type, in the sense that its elements differ only by an affine geometrical transformation. Clearly, during the simulation g can be updated (for example the agent can change its position).
- C is the current *spatial context* of the agent a_τ, represented by a set of references to objects and agents being observed by a_τ, and therefore potentially subject to its actions or requests for action. Clearly, during the simulation, every C can be dynamically updated by the agent as a result of its perception activity.

Formally, an agent type τ is defined as:

$$\tau := < S_\tau, G_\tau, \Sigma_\tau, \Theta_\tau, \delta_\tau, \gamma_\tau > \tag{4}$$

where:

- S_τ is the set of possible agent's internal data structures s
- G_τ is the set of admissible shapes;
- Σ_τ is the set of possible actions defining behavioural specification. Actions can modify internal states and geo-spatial attributes of agents.
- Θ_τ is the set of *perception functions* which can be used by agents to perceive their environment. A function $\theta_i \in \Theta_\tau$ maps the environment to agent's context C. The perception activity is of particular importance for agents in a geo-spatial environment, since it is one of the main components of their spatial cognitive capabilities.
- δ_τ is the *decision function*. Based on its current state and context, this function is used by agents at every turn in order to decide which operation to execute. An operation may be one of agent's own actions and/or requests to other agents/objects to execute their actions.
- γ_τ is the *agreement function*. This function is used by agents to decide, based on their state and context, whether to agree on the execution of an action from Σ_τ, when requested to do so by other agents or objects.

Like agents, objects can also be represented by geo-referenced geometrical objects and can have a state, but are endowed only with a reactive behaviour. As a consequence of this, the agreement on actions asked to objects is decided through a specific agreement function directly belonging to the environment.

The most simple type of objects available in MAGI are *cells* which can be used for modelling the environment as a CA. MAGI's CA-cells are endowed with generic shape and dynamic multiple neighbourhoods. Moreover, the library makes available a rich set of functions for building regular lattices consisting of rectangular or hexagonal cells with standard or custom neighbourhoods.

Even if the great majority of CA applications successfully adopt a strict local neighbourhood, spatial interactions in geographical phenomena can often take place over greater distances. For this reason, accordingly with the notion of the proximal space deriving from the research in "cellular geography" (Tobler 1979), in CAs developed in MAGI every cell can have a different neighbourhood defined by relations of proximity of spatial geographical entities, where proximity can be both a topological relation or a generic functional influence. In other words, similarly to the spatial context of an agent defined above, the neighbourhood of a CA cell can be defined as a generic set of entities whose states can influence the variation of the cell's state. In addition, such generalised neighbourhoods can be non-stationary (as they can vary in size and shape during the system's evolution) thanks to the reiteration of the spatial queries attached to the cell. In general, depending on the model requirements, various queries can be associated to each cell, so that different possible neighbourhoods, even belonging to different layers, correspond respectively to different rules of the transition function.

Many other aspects of the MAGI's meta-model would deserve a detailed discussion, such as agents' scheduling and action synchronisation. However, this chapter is focused on one of the distinctive aspects of multi-agent geosimulation models, namely the process of agents' spatial perception.

3 Agents' Spatial Perception

As mentioned before, the spatial perception of agents represents one of the main components of their spatial cognitive capabilities in geosimulation models. An agent must be able to perceive objects and other surrounding agents in order to build an internal representation of its spatial context, and to use it in the decision-making process. In some cases, spatial perception implies not only detecting presence/absence of entities, but also estimating their geometric characteristics (e.g. the distance from them, the relative distances among different objects, objects' areas or shape types).

Of particular importance for many models (for example those involving pedestrian movements or traffic models) is the ability of *visual perception*, which is based on the determination of the visibility of entities lying within agent's field of vision (an entity is visible only if it falls within the field of vision and is not occluded by any other entity). Visual perception represents a typical computation-intensive task that can dominate the computational effort in a simulation. Thus, when the objective is to produce real-time simulations on standard computers involving thousands of agents, some approximate treatment is usually adopted (e.g. see Moulin et al. 2003).

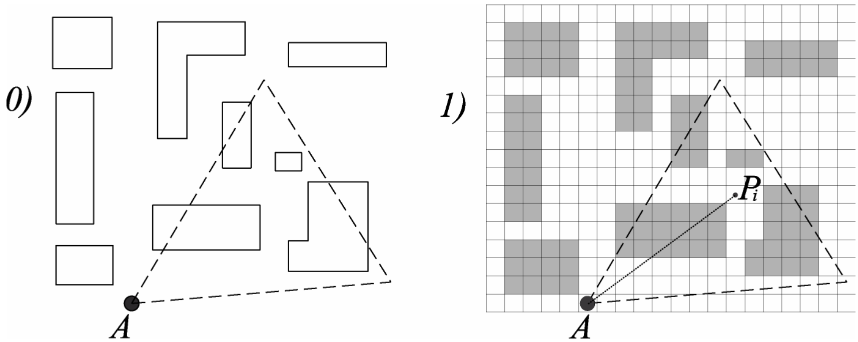

Fig. 4. Visual perception in most raster contexts. First, the problem in 0) is represented in the raster space 1). Then, in 1) for each cell P_i in the agent's field of vision, the line of sight AP_i is computed; if the line AP_i intercepts an object, then the cell P_i is not visible.

In most geo-spatially explicit simulation models, agents are constrained to move to adjacent sites, often represented by the vertices of a graph (Bandini et al. 2006) or by the cells of a grid (i.e. in a raster environment) (Moulin et al. 2003). In such an approach, the way in which the environment is structured determines the way in which spatial indexing is performed, which in turn influences the way in which agents' spatial perception engine must be implemented. For example, in a raster space, an agent's perception of immediately surrounding objects could simply be based on an exploration of immediately neighbouring cells. For farther entities, the visual perception can be based on the computation of the line of sight between the agent's position and the target cell, for every cell in agent's field of vision (Figure 4) (Moulin et al. 2003).

As described in section 2, in MAGI all entities in the environment are associated to a geometrical shape with a vector representation. This however does not eliminate the possibility to use raster layers as cellular spaces. In addition, agents can in the line of principle move to any position (although using some specific types of agents in MAGI, the action *move* must be evaluated by the environment, and its execution is not guaranteed in general).

The possibility to use vector shapes allows more realistic simulations and offers greater flexibility, as well as better interoperability with GIS applications. In models based entirely on cellular spaces, the dimension of cells determines both the accuracy of the representation of complex shapes (e.g. buildings in a city) and the spatial resolution of agents' movements. However, such a rigidity is not present in models using vector shapes for representing entities, be they static objects or agents capable of movement. Furthermore, the accuracy of spatial perception engine based on vector representation can take significant advantages from the existing algorithms of computational geometry. Another manifest benefit offered by the possibility to treat with vector entities lies in a greater simplicity of use and interoperability with most spatial data (e.g. demographic data, land-uses, buildings shapes, etc.) managed by GIS or CAD software, without the need to previously rasterise them. In fact, the geo-spatial features can directly be mapped to objects and agents of the model, and vice versa.

However, to these advantages could correspond greater computational costs of algorithms managing agents' movements and spatial perception. In many situations this may not be of crucial importance (for example when the model involves only few agents or when its purpose is to analyse a complex system without the need for real-time simulation). Nevertheless, the containment of computational requirements is still important, since it allows the use of more detailed models (e.g. more evolved agents) with given computational resources. In order to obtain such objectives of efficiency, the process of agents' spatial perception in MAGI is grounded on two important features: a specific purpose-oriented spatial indexing technique for moving objects, and a fast and robust geometry engine.

3.1 Indexing Moving Agents

MAGI class library implements a simple but efficient data structure known as R-Tree (Beckmann 1990; Guttman 1984) which is widely adopted with many variations (e.g. Kollios et al. 1999; Kriegel et al. 1993; Roussopoulos and Leifker 1985) for indexing spatial data in GIS and CAD applications.

Briefly, an R-tree (the "R" stands for "Rectangle") is a tree-like data structure where: *(i)* each leaf node contains a variable number of pointers to spatial objects (e.g. buildings, pedestrians, cars) together with their minimum bounding rectangle (MBR); *(ii)* every non-leaf node contains a variable number of pointers to child nodes together with the bounding box of all their MBRs (Figure 5). In practice, an R-tree corresponds to a variable number of MBRs hierarchically nested but with the possibility of spatial overlapping (minimising such overlapping is of crucial importance for the efficiency of an R-tree query). The insertion procedure uses MBRs to ensure that two objects close enough in the space are also placed in the same leaf node. If the maximum number of entries for a leaf node is reached during the insertion, then that leaf node is split into two nodes according to some heuristics, and such a split can propagate along the tree. The clear advantage of this kind of spatial indexing structure emerges when the searching algorithms use bounding boxes to decide whether or not to search inside a child node. In fact, in such a searching strategy, most of the tree's nodes are never visited thanks to a computationally cheap geometric tests on rectangles. In addition, in MAGI the R-tree is stored in the main memory and this further increases the efficiency of the application.

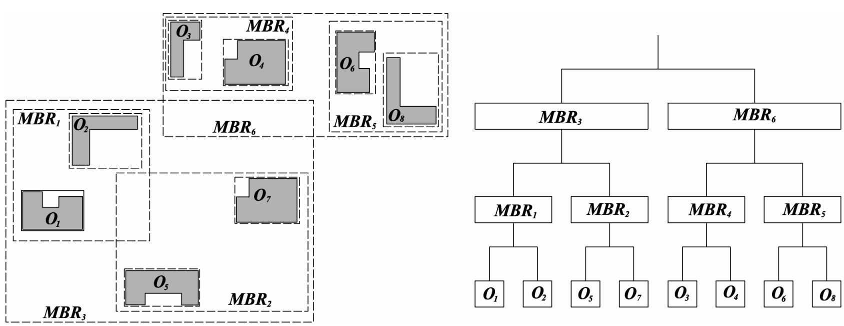

Fig. 5. R-tree spatial indexing scheme

As with the execution of spatial queries in most GIS applications (Kriegel et al. 1993), the process of agents' spatial perception in MAGI is divided into two steps: a filtering step and a refinement step. The filtering step uses the bounding boxes of shapes of entities being analysed. The objective of this step is to restrict the set of candidate objects for the subsequent refinement step, which then solves the final part of the perception process through the exact geometric representation of spatial objects using specific algorithms which sometimes may be computationally expensive.

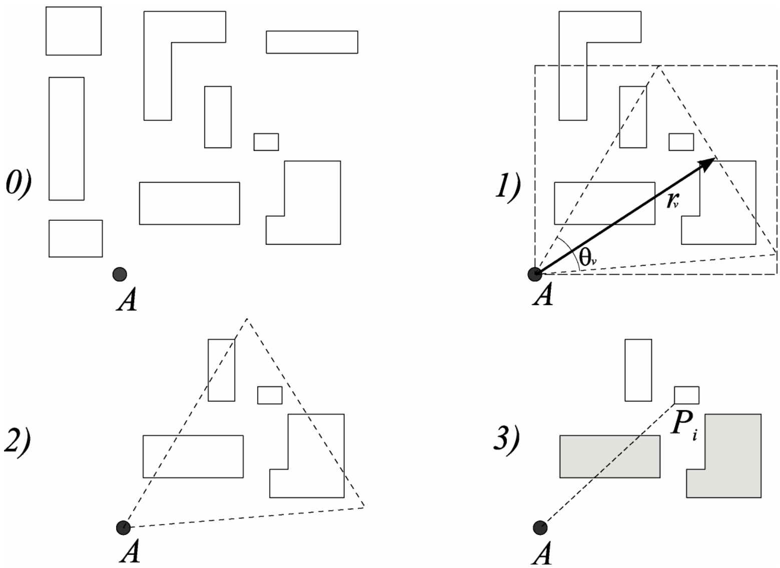

Fig. 6. Visual perception in MAGI. In the filtering phase 1) the object whose MBR does not overlap the field of vision MBR are discarded; in 2), by exact geometric computation, only the object overlapping the field of vision MBR are retained; in 3) the visibility test on control points allows to select the visible objects and to compute the visibility parameter ε .

For example, in a standard process of visual perception, agent's field of vision is represented by an isosceles triangle, with two equal sides converging to the agent's location, defined by a vector $\mathbf{r}_v$ and an angle θ_v (Figure 6). Thereafter, the perception process proceeds as follows:

1. the triangle defining the field of vision is constructed (typically, on the basis of the agent's direction of movement) as well as its MBR. Through a range-query (Kriegel et al. 1993) based on the R-tree and on the triangle's MBR, a selection of all candidate objects is performed and stored in a set $V^{(0)}$ (practically, the candidate objects are those MBRs overlapping the MBR of the field of vision). In this phase, most of the entities of the environment are discarded with high efficiency;

2. those objects actually overlapping with the triangle representing agent's field of vision are selected by exact geometric computations from the set $V^{(1)}$, and are stored in a set $V^{(2)}$;
3. for each shape $\mathbf{s}_i \in V^{(2)}$ a test is performed to assess the visibility of control points $P_i \in \mathbf{s}_i$ including, at least, its vertices (clearly, more control points imply greater accuracy, but also greater computational costs). The visibility of a point P_i is checked by an intersection test constructing the straight-line segment connecting the point P_i and the agent's position A: every element in $\mathbf{s}_j \in V^{(2)}$ is tested for intersection with the segment AP_i. If an intersection occurs then there is no visibility between A and P_i; otherwise, they are visible to each other. If at least one control point is visible then the shape is visible.

For each element $\mathbf{s} \in V^{(2)}$, this method allows to define an useful *visibility parameter* $\varepsilon \in [0,1]$ as the ratio between the number of visible control points and the total number of its control points.

While the implemented algorithm for agent's visual perception is still referred to a planar world (e.g. for modelling pedestrian or cars in a plane urban context or people inside a floor of a building), an extension to objects characterised by height and elevation is under development.

There are also other types of spatial perception that can take advantage of the spatial indexing structure available in MAGI. For example, in assessing the physical admissibility of agent's movement, the agent itself (or a specific environment function) must check if the desired trajectory intersects objects or other agents.

It is worth mentioning that the algorithms of spatial perception in MAGI consider all agents with their actual bi-dimensional shapes (circles, segments, polygons, ...), so agents may reduce or block the view to each other. Therefore, agents' shapes must be indexed in the R-tree as any other entity in the environment. However, since agents can move, the update operations are necessary for maintaining the coherence and efficiency of the spatial indexing structure. Unfortunately, since the change of object position in a standard R-tree corresponds to one remove and one insert operation (potentially with the need to split or merge nodes), that would become significantly expensive for simulating models with many thousands of moving agents. Indeed, one of the reasons of reduced efficiency of geosimulation models developed in most GIS is related to the use of therein available indexing structures which were conceived mainly for static spatial data and therefore exhibit poor update performances.

Since the problem of efficiently indexing the actual position of moving objects arises in many applications (e.g. real-time traffic monitoring, transportation managements, mobile computing) (Wolfson et al. 1998), it has been subject to great attention in recent years. To reduce the number of update operations, many existing approaches (e.g. Kollios et al. 1999; Tayeb et al. 1998) use a function to describe movements of objects and then update the data structure only when the parameters of that function change (e.g. when the speed or the direction of a car or a pedestrian change). However, frequently there is no good enough function available to describe specific movements. For this reason, other alternatives to the standard indexing scheme techniques have been proposed for faster updating operations. One such an indexing scheme which fits well to the characteristics of moving agents has been implemented in MAGI. It is based on processing updates in the R-tree using a bottom-up approach instead of the standard top-down procedure (Kwon et al. 2002; Kwon et al. 2005, Lee et al. 2003). Specifically, this approach processes an update from the leaf node of the old entry to be updated, and tries to insert the new entry into the same leaf node or into its sibling node. For accessing the leaf node, a secondary index (i.e. a direct link) is maintained for all objects. In particular, in the scheme implemented in MAGI, called LUR-tree (Leaf-prior Update R-tree) (Kwon et al. 2005):

- the structure of the index is updated only when an agent moves out of the MBR which includes all agents belonging to the same leaf (i.e. the leaf-MBR, which in our case is stored in the parent node). If the new position of an agent is still within the leaf-MBR, then only the agent's MBR in the leaf node is updated.
- in order to avoid the continuous deletions and insertions for agents moving closely around the boundaries of an MBR, a slightly larger bounding rectangle is used instead of the native MBR. Such extended MBRs (EMBRs), used only for bounding leaf nodes, are obtained by adding an appropriate extension value δ to the sides of the original MBR.

It is worth noting that a too large value of δ increases the overlapping among EMBRs and consequently decreases the search performances (e.g. the overlapping among MBRs affect the filter phase of the visual perception process described above). As pointed out in (Kwon et al. 2005), there is a trade-off between the gain in update performance and the loss in search performance. In MAGI, the value of δ must account for the average length of agents' movements. Since the LUR-tree is stored at layer level, the extension value is also assigned at layer level. This allows to establish an optimal extension for every type of agents (e.g. the optimal extension of MBRs for cars is generally higher than that for pedestrians).

3.2 The Geometry Engine

Given the vector representation of objects associated to entities in the environment, both spatial perception and spatial reasoning require the use of a geometry engine. Such engine must provide: *(i)* the capability of creating and using geometrical objects; *(ii)* suitable computational geometry algorithms for dealing with these objects (e.g. computation of spatial relationships and properties, shape combinations, overlay, buffer operations, among others).

For this purpose, the GEOS (Geometry Engine - Open Source) class library (GEOS 2008) has been integrated into MAGI, together with a simple wrapper interface. GEOS provides a complete model for specifying 2-D linear geometry and implements a set of operations on spatial data using robust geometry algorithms.

The main reasons for integrating GEOS in a geosimulation class library are:

- *Robusteness*. Geometry algorithms are susceptible to problems of robustness, i.e. an inexact behaviour due to round-off errors and numerical errors propagation. In GEOS, the fundamental geometric operations (e.g. line intersections), on which most of other operations are based, are implemented using robust algorithms. In addition, the binary predicate algorithm, which is particularly important for the process of agents' spatial perception, is fully robust as well. Many other algorithms in GEOS minimise the problems of robustness and those known not to be fully robust (i.e. spatial overlay and buffer algorithms) are rarely used in agent modelling and work correctly in the majority of cases.

- *Computational requirements*. As geosimulation models may deal with thousands of agents, the computational complexity of every geometric operation used by agents can greatly affect the overall requirements of computational resources. Unfortunately, robust geometric algorithms often present poor computational performances. GEOS uses specific techniques to produce good performance when operating on common types of input data (e.g. sophisticated methods for structuring data).
- *Rich set of available features and spatial operations*. In terms of the spatial model, geometric objects and method definitions, GEOS complies quite well with the OpenGIS Simple Features Specification (Open GIS Consortium 2007). In particular, it provides a set of boolean predicates for computing common spatial relationships (such as *disjoint*, *intersects*, *crosses*, *within*, *contains*, *overlaps*, *touches*, *equals*, among others) as well as common algorithms for the computation of intersections, distances, areas and many others.

Thanks to the interface made available in MAGI, it becomes easy to access GEOS functionalities and to use them for the development of complex spatial reasoning algorithms.

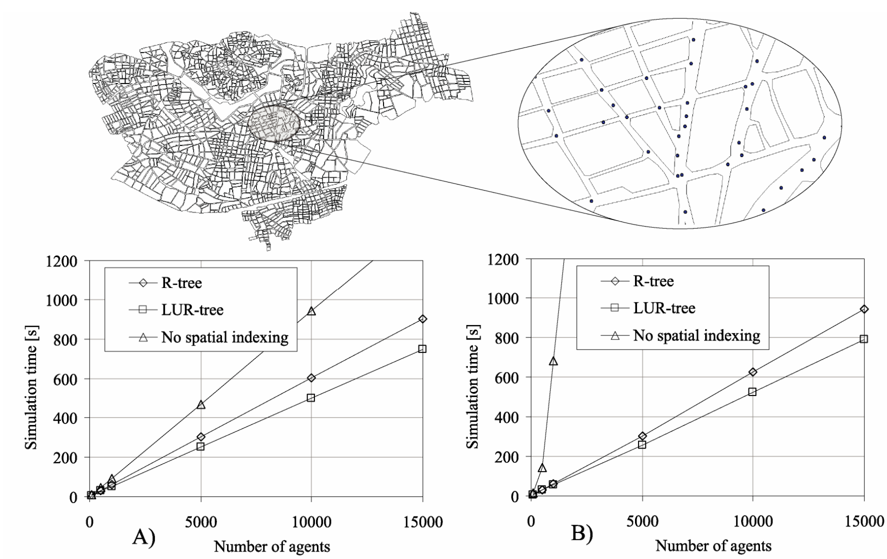

Fig. 7. Results of the test on walking agents. In A) agents walk avoiding collisions but ignoring other agents; in B) agents walk avoiding collisions and perceiving the presence of other agents in their field of vision.

3.3 A Scalability Test

We have undertaken various tests in order to assess the suitability of the implemented approach for geosimulation applications. In Figure 7 we report the results of an assessment of scalability with respect to the number of agents used. The test model used is a simple simulation of agents walking in an urban environment with two possible levels of spatial perception capability. In case *A*, agents can avoid static obstacles (e.g. buildings) ignoring the presence of other agents in their proximity. In case *B*, agents can also perceive other agents. At each step of the simulation, every agent makes a single spatial movement following a direction chosen to avoid collisions.

The experiment was conducted on a standard 1.8 Ghz PC, with a fixed number of 200 simulation steps, starting from scenarios populated with different number of agents, from 1000 to 15.000.

Clearly, case *A* does not produce significant computational problems with the growth of the number of agents. Indeed, the model scales linearly even with naïve implementations (i.e. without any spatial indexing technique), although the computational time is about 90% greater than with the implementation using R-tree.

As expected, in case *B* where agents need to perceive the presence and the position of other agents, the naïve approach leads to the impossibility to simulate systems with thousands of agents within reasonable time, since the computational complexity of perception is $O(n^2)$, where n is the number of the agents. On the contrary, the computational time, obtained through the use of standard algorithms available in MAGI, exhibits a linear dependence on the number of agents.

In both cases the use of the LUR-tree approach leads to a computational time of about 16% lower than that of the standard R-tree.

On the whole, these tests show that the advantages deriving from vector-based geosimulation models using thousands of agents can effectively be put in action with MAGI, at affordable computational costs.

4 Conclusions and Future Developments

Multi-agent geosimulation may be computationally quite a demanding simulation technique, and therefore requires the use of an articulated "ecology" of techniques, tools and computational strategies which have to be integrated into a well organised software infrastructure. In this paper we have shown how MAGI implements and purposely integrates a series of approaches, tools and strategies in order not only to be user friendly and sufficiently general to host a large variety of model types, but also to provide high computational efficiency and robustness. We have presented few situations and cases, such as the modelling of processes of vision and spatial interaction among agents, where such techniques and strategies offered by MAGI can effectively be put in action. In particular, we have discussed one of the crucial cognitive capability of agents in geosimulation models, namely the problem of agents' spatial perception. The algorithms for spatial perception may be characterised by very high computational costs, especially in models with vector representation for entities. Notwithstanding, in MAGI agents can operate in a vector space, but can still sense the environment rather efficiently thanks to the use of a robust and efficient geometric engine together with a specifically implemented spatial indexing technique.

Taking into consideration actual use experiences of MAGI – notwithstanding they have still been quite limited in number –different aspects of MAGI are fairly competitive with other agent-based simulation frameworks (as Swarm, Repast and OBEUS) with respect to characteristics such as user-friedliness, interoperability with GIS, and computational efficiency due to the adoption of optimized libraries, specifically implemented computational approaches and the use of a more efficient programming infrastructure (C++). However, we still need to undertake a more systematic and extensive experimental effort of comparison and benchmarking, which is going to be an objective of our future work.

Also, from the point of view of perspectives of extending the system, in future we plan to focus on the development of a support tool for calibrating and validating geosimulation models, as well as on few other implementational aspects of MAGI, such as the development of a version using thread-pooling techniques, capable of taking greater advantage of multi-core processors.

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A Participative Multi Agent System for Urban Sustainable Mobility

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Abstract. The current research deals with the development of a Multi Agent System able to analyse and simulate the dynamics of urban system sustainable mobility as derived from millions of choices performed by the individuals belonging to the system itself. In this research an Activity Based Model is devised in order to reconstruct urban mobility. With the objective to perform a dynamic decision support system for the comprehension of phenomena influencing mobility at urban scale, this research tries to gather in the model both the territorial features, by the construction of a detailed spatial database able to contain all the services the city offers, and the direct extraction of citizens behavioural rules from survey data by Artificial Intelligence tools. To this end the population sample questionnaire structuring, the "temporal" geodatabase construction and the agents behavioural rules extraction, via two different Data Mining techniques, represent the most relevant innovations experimented till now.

Keywords: Multi Agent System, GIS, Artificial Intelligence, Urban Mobility.

1 Introduction

The urban mobility issue, defined as the set of transfers covering a distance lower than 20 km, over the last years has been going through radical changes, also due to the increasing problems emerging in metropolitan areas (Carminucci et al. 2005; Rotondo 2005): a rising rate of uninhabitability, due to an excessive use of cars, a persistent traffic congestion with the connected pollution and stress conditions, and all the effects that a society based on a massive car use may cause to individual mobility behaviours.

Italian urban mobility data are provided by the italian transport research centre called "Audimob". Data related to the first semester of 2007 show an increasing mobility demand, in particular as number of trips, travel length and trips duration. In fact the number of trips is increasing significantly together with the average duration: for daily trips it goes from 59,8 minutes to 65,2 minutes and with an average lenght from 31,6 km to 36,6 km. In the first six months of 2007 all these indicators reach their highest value in accordance to Audimob statistical survey: regular and daily trips are decreasing, that's to say trips directed to work or to study.

Absolute and relative growth of motorized mobility is due almost entirely to individual vehicles, showing a trend in contrast to the rest of Europe.

The mobility analysis shows an higher travel demand for young age groups (Figure 1a) and in particular for students or employed (Figure 1b).

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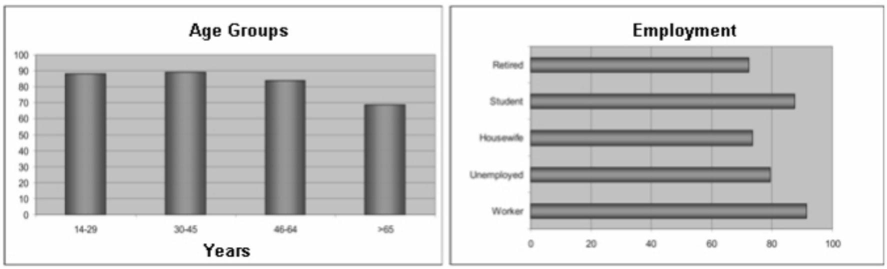

Fig. 1. a) Mobile people for age groups, b) Mobile people for employment status. (Source: ISFORT, Audimob 2006).

Most of researches support methods for urban mobility planning which are generally classifiable into two groups:

Statistical approach starting from a quantitative and qualitative analysis of the network (ISTAT 2008; Curtin et al. 2008);

Architectural approach which places greater emphasis on functional continuity, sustainable urban environments with the presence of green spaces and equipped areas (Cumuli 2006).

These two approaches need to be integrated in a unique method able to quantify the quality and the sustainability of urban mobility. Therefore, the influence of transport systems on individual life quality has to be analyzed.

"Audiomed" research centre has undertaken, since 2000, the study of individual preferences and lifestyles and it identified in daily habits a very important explanation in mobility choice and a justification of the observed daily behaviours, often sub optimal but always repeated.

There are other studies that are directed towards individual motivational analysis (Chiarello 2004) but once again none of these introduce the space-time variable as a survey component, i.e. the analysis of the city "life-time" (for example: shopping hours, parking tolls and more) or the influence of urban activities location on population lifestyles (Miller 2004).

A first attempt to link location to behaviour in space can be found in the European project called GeoPKDD (Geographic Privacy-aware Knowledge Discovery and Delivery) directed by the "ISTI CNR Pisa" Institute research centre (Giannotti and Pedreschi 2008). This research makes use of large distributed sources of geographic data, referenced in space and time and derived from mobile phones that record information on space - time trajectories and individual movements. All information is processed via data mining to identify behavioural patterns to be used for many reasons, as traffic management, sustainable mobility incentives, or to study the accessibility to city services.

Even though this attempt is quite significant, the complexity of the information related both to transport modes and to those activities that generated the agents' displacement, can not easily be extracted: for example a pedestrian, moving or queuing in a car, can have the same space-time track.

The approach proposed in the present work tries to answer to the above mentioned problems by means of on-line surveys and web-gis applications able to record space-time information and citizens' individual mobility preferences in order to understand mobility behavioural rules to be inserted in a Multi Agent System and, more in general, to help decision makers and public authorities to develop sustainable mobility policies.

1.1 Why an Activity Based Model?

The Activity Based micro-simulation has only recently been introduced in transportation model and more in general in the field of territorial planning.

The spell of micro-simulation, in short, consists in the possibility of obtaining the behaviour of a complex urban system at meso or macro scale as derived from millions of choices performed by the individuals belonging to the system itself. This kind of bottom-up approach seems to overcome, from many points of view, the traditional top-down approach in which some behavioural choice rules of groups of individuals are assumed and formalized and the model is calibrated on the case study data.

Therefore, in our opinion, most of micro-simulation experiments carried out (using Multi Agent Systems, Cellular Automata, etc.) is undermined by the definition of the individual choice rules adopted for the simulations (US EPA 2000). Indeed, such behavioural rules are often very similar to those adopted in top-down approaches, i.e. behavioural rules, known at the meso-scale, are used at the micro-scale too. This would allow the generalization of the models structure, but is it correct to attribute the same individual choice rules to people living in Pisa, or in London or in Rome? (Petri et al. 2006). Moreover the use of a top-down approach in the construction of individual behavioural rules may force the agents' behaviours to be adapted to the framework of a mathematical equation.

The micro-scale approach can be used only when a micro-scale database is available containing sufficiently detailed information about individuals: this requires direct surveys with appropriately designed questionnaires.

As this database has to be very large and has to contain a great number of variables among which the analysis of correlations type is quite complex to be investigated, usual statistical tools are not adequate to deepen those links and to extract the agents' behavioural rules needed for model implementation: it is, then, necessary to consider more advanced tools as Decision Trees, Bayesian Networks, etc. Such tools allow the extraction of a set of elements which determine each individual behavioural choice.

Against the time, costs and technical skills involved in such surveys and in their elaboration, the utility of such work is relevant for a number of planning and assessment problems not solved yet and is important to implement a real integrated planning support system.

In the context of territory-transport planning, the activity-based approach is very suitable because it provides a general model framework which is very flexible and able to implement the extracted behavioural rules at each decisional step. Moreover the Activity-Based micro-simulation approach allows to simulate the not-systematic trips (the systematic ones are home-work-home or home-school-home) which have been greatly increased in the urban context, particularly those including shopping and leisure activities that are quite adverse to be modeled. Beside that, the Activity-Based approach presents some important strong points in comparison with the classic four step model approach (trip generation, trip distribution, modal split and traffic route assignment). In order to point out the advantages of an activity-based model, some examples will be described that highlight the power of this approach.

First of all, it gives the possibility of considering family members interactions which alter trip types and number. For instance, when a family member takes her/his child to school not being able to pick her/him up later, a second family member has to go and then takes the opportunity to do some shopping on the way back home, further increasing the traffic conditions. Another relevant aspect is related to trips duration and, more generally, to time factor issues. While trip-based models consider time only as a cost, i.e. as an impedance factor, in reality it can play a different role for the compilation of the activities daily diary. For instance, if an individual, who planned to shop after work, arrives late at the office because of traffic congestion, on that day he/she will be induced to leave the work place later and, having little time left, they will decide to shop in a store closer to home. Had he/she not been late that morning, they could have gone to a supermarket, covering a longer distance, but probably saving money in their purchases.

All these examples show that the main element subject to a substantial variation is the vehicular flow.

2 Objectives

As pointed out from some important analyses about Italian urban mobility (ISSFORT 2006; ISSFORT and ASSTRA 2004) and its environmental management, in the complexity of the actual analysis there is always a shadow zone: the citizens' preferences which represent the demand point of view.

The aim of this work is to propose a model able to introduce appropriate and detailed analysis useful to clarify and simplify the complex field of Multi Agent Systems (Rabino 2005; Waddel et al. 2003) considering individual preferences and activities as the main factor influencing the mobility structure in a urban context (Petri et al. 2006).

With the purpose to analyze the complexity of urban systems and its interactions a model logical framework is structured in order to understand local urban dynamics.

The final objective of this model is to act as an effective and robust decision support system thanks to the possibility to simulate the global effect on urban traffic due to a great number of actions, as shops opening times variation, urban vehicular traffic change, public transportation demand and price fluctuation, parking tolls, location changes and so on.

The present model, introducing a greater detail when compared with traditional spatial interaction models, adopts a higher number of variables in the simulation providing, as a consequence, a wider number of operative solutions within urban mobility issues. Some important innovations are introduced as described below:

- The model implementation inside a GIS platform which is able to guarantee an efficient database management (updating itself during the simulation by "on the fly" geoprocessing steps) and a dynamic display of simulation evolution (Longley et al. 2001);

- The individual (resident or commuters) behavioural rules implementation which represent the agent choice rules extracted directly from a dedicated survey.

A real case study prototype was performed on Pisa city centre and the possibility to refer surveys both to residents and to commuters allows a more realistic view of the urban system complexity.

The present mobility state in a small historical city centre such as Pisa (inhabitants number lower than 100.000) is characterized by an increasing congestion of the already scarce fast flowing roads and, consequently, by an increasing deterioration of life quality.

3 Methodology

In this research the problem of urban sustainable mobility in an historic city centre (Pisa) is studied in relation to real inhabitants behaviours and daily activities.

For the Multi Agent model structuring three main elements have to be conceived: a territorial *environment*, the *urban agents* and a set of *rules* regulating the dynamics; the last two model "components" require a dedicated population survey (Figure 2).

In order to build up the above mentioned model components, a general framework was devised consisting of several steps (Figure 3).

In the first step, the *preprocessing phase*, are collected both spatio-temporal information on private activities and public services delivered over time. This step enables the *construction of a "temporal" Geodatabase* representing the territorial information base on which the model has to be founded. The Geodatabase contains "temporal" information about urban facilities in order to simulate how the city "lives" and to realize

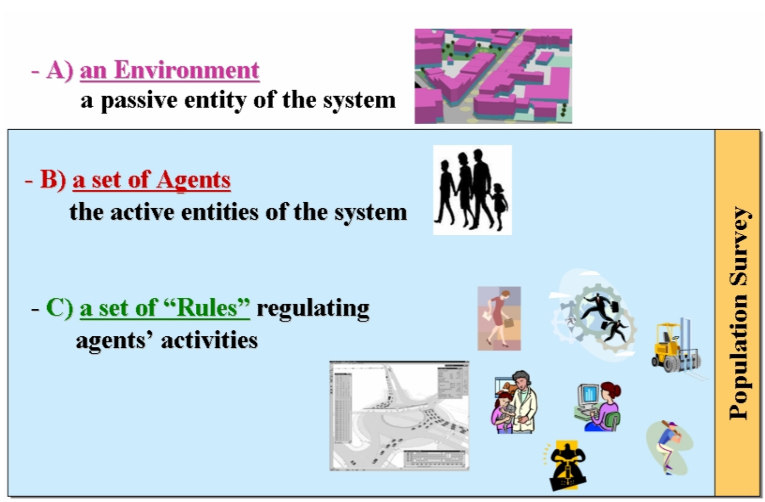

Fig. 2. The Multi Agent System Model Components

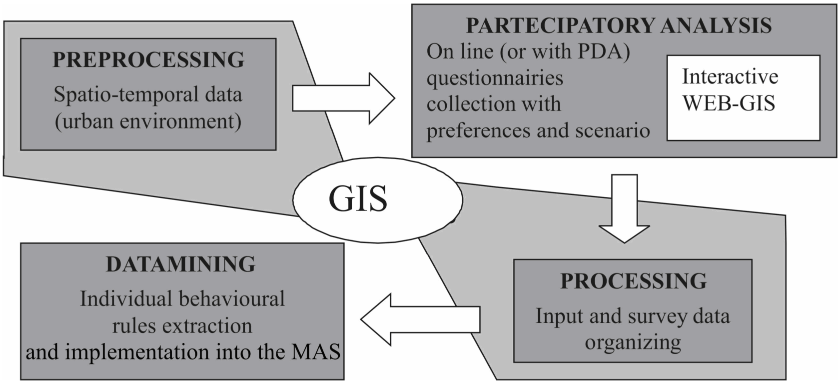

Fig. 3. The Model Methodological Framework

which services are activated in each daily time band. In this way the city itself becomes a "living organism", therefore as another agent interacting with the whole system (Gilbert and Terna 1999), characterized by proper attributes (as attractiveness and centrality) and able to provide different services in each daily time band.

Afterwards *participatory methods* are introduced to reconstruct citizens' preferences and mobility demand. This step is implemented through the devising, the distribution and the collection of a *population sample dedicated questionnaire,* in order to procure the necessary information on individual peculiarities and activities. In this step both a paper questionnaire and an on-line one are designed; the second one was accompanied by a WEB-GIS application for the spatial location of journeys and the recording of their attributes.

Then, all the collected information, i.e. the input data from the preprocessing phase and the survey data, together with spatial attributes are processed by Geographic Information Systems which allow the routing analysis in multimodal networks with the initial space-time information.

In the final step both territorial data and the information extracted from population sample constitute the input for the *Data-Mining* tools necessary to extract knowledge and information useful to understand urban mobility dynamics at local scale in relation to people preferences and expectations In this stage two different Data Mining techniques are used: at first *Decision Trees* are used for the exploratory phase and the rules extracted in an IF-THEN form allow to identify the important variables connected to each target choice; in a second phase the most relevant variables are employed as input data for the *Bayesian Networks* able to extract conditional probability distribution tables necessary for the model implementation.

In the following paragraphs the most important steps of the model are discussed, starting from the participatory phase devise, then describing the behavioural rules extraction procedure and finally analyzing the whole structure of the Activity Based Model approach.

3.1 The Participatory Planning

Participatory planning defines a new set of concepts and methodologies which are consolidating in planning processes where policy makers are confronted with complex and socially relevant problems due to insufficient knowledge of citizens' preferences (Cecchini 2003). Participatory processes favour interactions, supply information on problems and stimulate experiments and learning. In this way, policy makers want to increase the quality of their policy and realise a broader support to understand actions.

Table 1. Methodologies and tools for citizens' involvement

Methodologies to listening	Active listening Brainstorming Walk neighbourhood Survey Outreach Focus Group
Methodologies to share decisions	Open Space Tecnology Planning for real SWOT EASW
Methodologies to resolve conflicts	Jury of Citiziens Indipendent Authority

In this field, specially in the recent years, many methodologies and tools (Table 1) have been designed and implemented in order to let people know policy makers actions, to share decisions and to create partnership and interactions between the various involved stakeholders, to resolve conflicts, and, in general, to stimulate citizens' involvement in public policy choices (Bobbio 2004). The spread of public participation in the planning activity can vary from very little to a great deal (Arnstein 1969): different participation levels are appropriate at different stages of the planning process, but the crucial element is the possibility to activate and diffuse a participative approach since the initial steps. In this work, the choice to design a *survey on-line*, which belongs to listening techniques, allows to know both individual and family socio-economic characteristics and to understand mobility preferences (ANCI 2006; OECD 2001). A web-gis application enables to record personal addresses, workplace locations and all the attributes of each daily activity (Miller 2004), indicating also the adopted transportation mean.

3.2 The Behavioural Rules Extraction via Data Mining

The agents' behavioural rules are extracted from daily diaries, from personal data of interviewed people and from space-time environmental information collected for the urban context. The whole process is implemented through Knowledge Discovery in Databases (KDD) tools (Bonchi and Pecori 2004) and, more in detail, two different Data Mining techniques are used: at first the Decision Tree Induction are used for the exploratory phase and, after, the Bayesian Networks are introduced for the modelling phase (Witten and Frank 2000).

For the present case study, both survey data and information derived from the pre-processing phase (Figure 3) are at first analyzed by graphical statistical techniques EDA (Exploratory Data Analysis) and then they are processed via more complex tools belonging to the field of Machine Learning.

The whole analysis includes fourteen activity types in each daily diary: this allows the extraction of complex interactions and spatial-temporal dependences between activities. A wide list of attributes is considered in relation to individual characteristics and to activities features both derived from the population sample questionnaire. Once the most significant statistical correlations between input variables are identified, the behavioural rules extraction and implementation are carried out by Machine Learning tools.

In the first stage *Decision Tree techniques* (Lombardo et al. 2005) are considered as they enable to build up a systematic and structured additional knowledge extracted from the whole dataset and expressed in an IF-THEN form. In fact the rules structure presents an IF part (condition) where all socio-economic attributes and daily activities, related to each individual agent and to their family, are taken into account and a THEN part (execution) where the decision tree "target attribute" is considered. The target attribute may be represented by each decisional choice (e.g. the possibility to conduct an outdoor activity, its type, the transportation mean etc). For instance, if the transportation mean is considered as the target attribute, the general framework of a decision tree induction rule can be formalized as follows:

<u>IF</u> (Age band = X, and Income = Y, and.. .and Total daily activities number = Z)
<u>THEN</u> (transportation mean = T)

The extracted decision tree allows to find out the important variables related to the choice of the transportation mean (target variable).

Decision Trees are important to extract structured knowledge in a pre-processing phase, but they are not particularly suited for the "on the fly" modeling in a Multi Agent System dynamics; in this case it would be necessary to compare the attributes of the record to be classified with all the attributes included in every extracted rule: this is clearly a great computational cost.

Another important issue for the research here presented consists in the necessity to apply the rules, extracted from the sample, to the whole population. It is possible, indeed, that a combination of conditional attributes, never occurred in the extracted rules (IF part), may come out.

In this case, the probability of the considered decision variables to be conjointly present in the population universe would be useful; in other words, the point is to compute a conditional probability distribution.

After all, the possibility not to find out a rule exactly identical (in the IF part) to the record to be classified seems to be solved only by the research of an attribute set which is nearer to the one to be classified.

For all these reasons, in a subsequent phase, the *Bayesian Network approach* is employed in order to extract the conditional probability distribution to be implemented in the Multi Agent System.

Individual attributes and activity planning weights, classified in three classes (A = high value, M = middle value, B = low value) are considered for the Bayesian Network analysis (see examples in section 4.3); several trials are conducted changing the order of the input variables in the learning algorithm and choosing the network with the highest Marginal Log Likelihood value: in this case the highest accuracy network is used for the analysis.

The construction of an individual activity-weights vector is performed: each agent creates a ranking among all the activities performed during the day, assigning greater importance to those that have higher priority in relation to both the family structure and the specific activity schedule.

After that, Machine Learning tools are used to model each daily decision step: for instance which activity to engage, for how much time, with whom, by witch transport mode, in which daily time band etc.

Bayesian Network technique has the great advantage to introduce in a simple way the probability inside the behavioural rules of the agents and this element makes the model more realistic; in fact in real life it is possible to have different urban system evolutions starting from the same decision attribute values.

3.3 The Activity Based Modelling

Activity Based models allow the conversion of a daily "activity program" to a daily "activity pattern" where a sequence of activities is completely defined in terms of localisation, type, transportation mean, schedule, duration and possible sharing. This transformation, from a generic list to an ordinate sequence of daily activities, implies a set of decisions as, for example, which activity to carry out, where, when, with whom and by which transportation mean.

Figure 4 shows an example of a daily diary (relative to the previous working day) adopted in the Activity Based model; the sequence of activities is considered for two types of agents moving in a urban environment: residents and commuters.

Fig. 4. Example of activity pattern in a urban context for both resident and commuters

In a MAS dynamics, the first daily decision each agent makes is the specification of the activity list to be carried out: this idea is explicated by the indication, for each activity, of an importance weights, directly assigned by the agents and recorded in every questionnaire. Analyzing these weights it is possible to construct the individual conceptual maps in relation to the different importance given by agents to each activity type. The possibility to keep each computation inside a GIS platform provides the entire instrument to be much more flexible and easily integrable with others systems: this element represents a significant advantage because avoids computational problems related to the difficulty of exporting data from a software to another and gives the opportunity to easily display simulation results by geographical maps and interfaces. The complexity of urban planning decision problems requires, in fact, models able not only to simulate agents dynamics, but also to represent results in a clear and transparent form, so that they can be easily communicated to scientists, local authorities and stakeholders (Zunino 1998; Booth et al. 2002).

4 The Case Study

The study area is located inside Pisa municipality and includes the urban and the peri-urban areas neighbouring the historic city centre (Figure 5).

Pisa city centre has approximately 82.000 residents placed on a surface of 7.600 hectares; the historic and academic distinctiveness of the town is very evident, in fact within this small area are located three well known Universities (Pisa, S. Anna and Normale) with several departments and excellence centres that attract thousands of students and researchers from the whole of Italy and also from different European Countries.

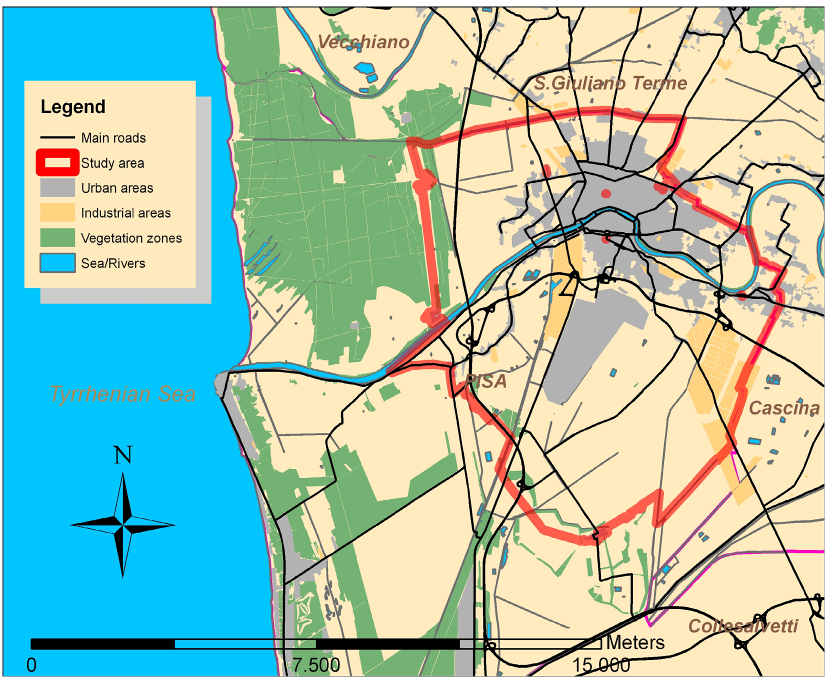

Fig. 5. The study area

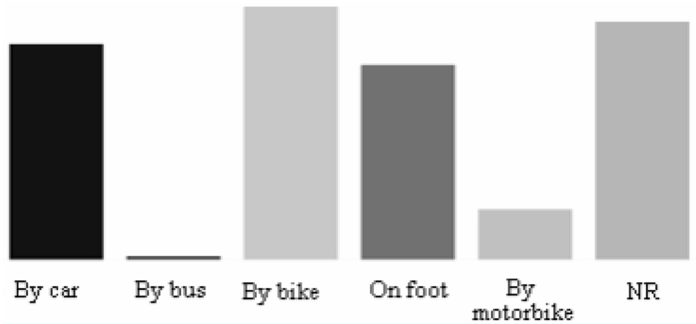

Fig. 6. Frequency histogram of the variable "means of transport" for Pisa city centre

In the historic part of the study area are also located some of the most important nerve centres of the city, as the museums, the notorious leaning tower, the hospital, the train stations.

Besides, the periurban area comprises many commercial areas, business centres, public utilites, industrial activities and the airport.

In relation to urban mobility issues, the first 20% of the entire population sample (they represent the individual interviewed up to now) points out that, in the study area, the most used transport mean is the bicycle, followed by the car and by on foot travels, while it seems clear the modest use of public transport (Figure 6).

4.1 The City as a Living Organism: A Dynamic GeoDatabase

This is the most demanding phase, from a computational point of view, as it requires at first the construction of "ad hoc" geographical data and then their loading in complex storage structures necessary for the subsequent analysis (Arentze and Timmermans 2000).

For the temporal Geodatabase construction the following data were processed:

- Road graph;
- Activities location (trade, tourism, services, resident, etc) in each street and for each street number;
- Street and square parking areas mapping, specifying their numbers and if free or paying;
- Road sweeping times;

The city centre road graph is employed to build a detailed Network Dataset (ESRI 2005) containing information about restrictions on road access and detours, one-ways, etc.

Furthermore, the Network features do not remain unaltered during the simulation, but are modified, according to personal experiences, in a sort of "mental maps": every mental map (Caratù 2005) reflects the idea each agent has (his cognitive level) of road distance coverage times (Curtin et al. 2003). At the initial stages, mental maps correspond to physical and functional network characteristics, as, in the subsequent phases, the model dynamics, articulated in three minutes cycles, simulates the individual displacement induced by each agent daily activity.

For each Network road arc, the information about carrying capacity is stored. When this threshold is exceeded, traffic congestion phenomena occur and increase time coverage distance only within the individual "mental maps" of those people involved in this traffic jam, while it does not happen for all the agents unaffected by the congestion. At the end of each day, every agent updates her/his "perceived network" taking into account also family members experiences: this phase can be considered as the agents training process.

This aspect makes more realistic the transfers simulation when compared to traditional models where, under a congestion event, trips coverage times simultaneously vary for each agent, implicitly assuming a global information flow among them. Once the Network is developed, the "locations" feature Datasets are built: they identify both the route destinations (i.e. all available activities) and the route origins (i.e. residences, etc).

Such Network allows to build up the isochrones related to each activity and to compute its closest stops. The last stored piece of information deals with possible mobility "constraints" due to the real parking availability or to transit hold up over a whole road section caused by midweek markets, road sweeping etc.

All data, introduced in a Geodatabase (Booth et al. 2002) and linked each others through "relationship classes" in order to dynamically display all available activities (commerce, services, tertiary etc.) and parking supplies throughout the working week and inside each daily time band.

An "urban time clock" is designed in order to generate a temporal articulation of all facilities the city offers. The system creates all the isochrones related to the different activities (distinguished by typology), automatically displaying both available and not available services within them for every single time step: this result represents itself a first important base point to understand the "life" of a city and becomes a fundamental tool to support decision makers when planning effective sustainable mobility actions.

4.2 The Population Sample Structuring and the Questionnaire Devise via a Web-Gis Application

For the purposes of analyzing and further reconstructing a synthetic population for the urban mobility dynamics, the construction of a representative (both from the individual attributes and from the geographic structure point of view) population sample is necessary. As this population sample has to be interviewed, in order to distinguish residents and commuters behaviours for the MAS model implementation, two different samples were singled out: one for residents and one for commuters.

In fact, while residents register both intra and extra urban activities, indicating, in this second case, the origin/destination point of this "macro-transfer", commuters provide information about their arrival point in the city centre (e.g. train station, long stay parking, bus station, etc.), about the adopted transportation mean and about the activities carried out only in Pisa city centre, as they are useful for Pisa urban mobility dynamics analysis.

The resident population sample (approximately 2000 individuals) is singled out by cross-referencing two of the most influent variables available from 2001 National Population Census. Selected variables are sex and age, as they mainly affect the transportation mean choice, while an accessibility index is calculated in order to include in the population sample individuals living in areas characterized by a different centrality degree. This aspect is very important as accessibility influences individual activities in terms of types, sequence and relative attributes.

The commuters population sample (approximately 2000 individuals) is derived from the direct contact with the biggest firms located inside the study area: those firms with more than 40 employees provided us all the data about their working commuters and then we contacted each one of them.

All the interviews, conducted by means of a questionnaire, are carried out both distributing a paper form and building a dedicated website structured in preset interfaces: such double version is chosen to reach different population classes.

The questionnaire is articulated in three parts.

- *Part 1*: Individual personal data (age class, civil status, occupation, educational qualification, etc.) and family information (number of family members, number of children, cars and driving licenses number, etc.);
- *Part 2*: Most recent working day activities diary, recorded by a Web-Gis application;
- *Part 3*: Individual preferences in relation to urban mobility and development scenarios. This part contains data on citizens' mobility preferences (i.e. shorter travel duration, safety conditions, possibility to accomplish more activities along the same path, etc) and on mobility policies (i.e. High Occupancy Vehicle lanes in public transportation, incentives to adopt ecological means of transport, etc.).

In many of the questions, present in the questionnaire, the possibility to give a vote from 1 to 10 is introduced; this type of choice facilitates both the questionnaire compilation phase and the processing phase, allowing to rank hypothetical alternatives in order of preferences.

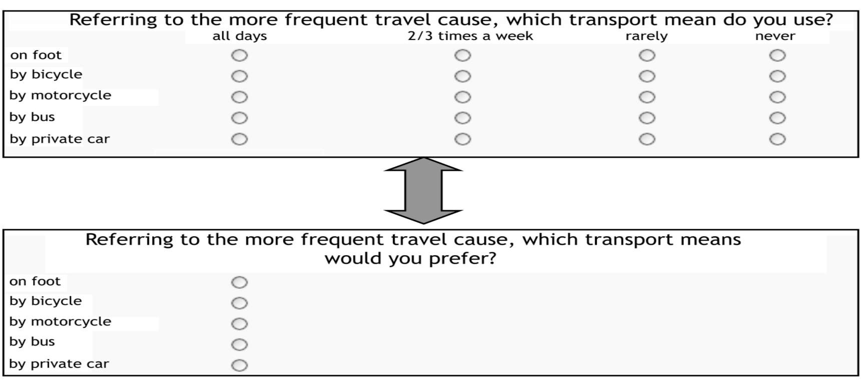

Fig. 7. Questions on urban mobility inserted in the questionnaire: most adopted and most preferred transport means

The survey provides both multiple choices questions and open answer questions; the latter will be used for subsequent analysis by text mining methods that are innovative techniques related to Data Mining and directed to individualize patterns in natural language text. Text Mining may, in fact, be defined as the process of analyzing text to extract information for particular purposes.

With regard to sustainable mobility, specific question are inserted in the questionnaire in order to consider the correlation between individual preferences and their real mobility choices.

To this aim two specular questions are introduced regarding both the most preferred and the most used transport mean adopted more frequently in daily displacements (Figure 7).

With reference to the first 20% of the entire population sample (the individuals interviewed up to now), the answers to the two previous questions consent to get a matrix which immediately enables a comparison between real and desired choices about transportation mean which reveal important information on citizen's travelling satisfaction (Table 2).

The above matrix shows, on its diagonal cells, the amount of satisfied people able to use the preferred transport mean, while in the other cells the dissatisfied ones are represented. In this way the values of not diagonal cells may be considered both as dissatisfaction indicators and as preference indices of daily transport means.

Table 2. Example of choice matrix

Choice Matrix		Used Transportation mean				
		Foot	Byke	Motorbike	Bus	Car
Preferred Transportation Mean	Foot	84	25	6	4	8
	Byke	48	85	25	8	42
	Motorbike	15	35	46	2	7
	Bus	12	20	8	6	55
	Car	25	75	35	12	112

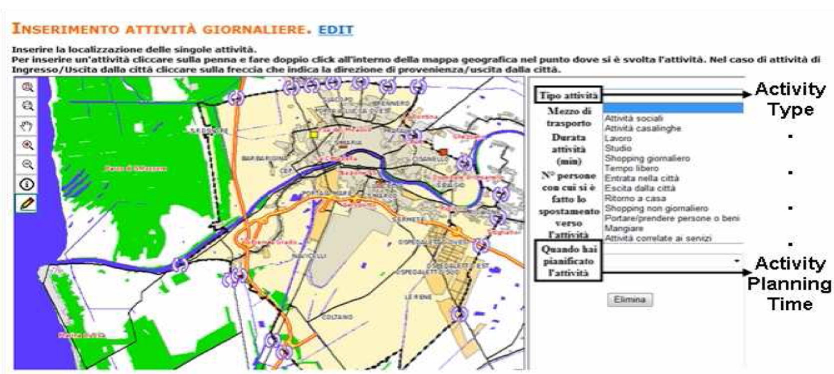

Fig. 8. The Web-GIS application

The example of Table 2 indicates that, among the 800 individuals interviewed till now, 42 use the car willing to use the bike, while 55 drive the car but would prefer the bus. The choice matrix can be used to suppose people's availability to welcome changes relative to urban transport and also to help decision makers to define target policies. All the questionnaire data are collected and stored in a database, then a Web-GIS application is implemented to record geographical data about activity locations (Figure 8). The devised application, displaying the city-map, allows to identify and represent by punctual element the residence location, the workplaces, the arrival zone to the city (for commuters) and the position of the activities carried out by the agents.

The system enables the geograpical editing of new activities, inserting the necessary information in the corresponding attribute table as reported below:

- Agent activity-type;
- Agent activity start time;
- Agent activity duration;
- Transport mean used by the individual to arrive to the activity;
- Number of travelling companion;
- When and if the activity was planned.

For each individual, interviewed through the above described questionnaire, all data are recorded in a daily spatial activity DataBase (Table 3).

Table 3. Example of daily activity table

N° Act	Activity type	Start	End	Duration	Travel time	Address-Zone	Transport mean
1a	Sleeping	3:00	7:24	4h, 24	0	Home-via Rossi	-
2a	Not domicil. work	7:36	13:40	6h, 04	12'	Via Volta	By bus
3a	Eating	13:53	14:54	1h, 01	13'	Home-Via Rossi	By bus
4a	Daily shopping	15:04	15:22	18'	5'	Borgo stretto	On foot
5a	Not domicil. work	15:27	19:27	4h	5'	Via Volta	By bus
6a	Service activity	19:32	20:32	1h	5'	Via S.Maria	On foot
7a	Social activity	21:12	23:12	2h	40'	Livorno	By car
8a	Return home and Sleeping	23:47	3:00	3h, 13	35'	Home-Via Rossi	By car

4.3 Ongoing Results and Discussion

As the entire system for the urban dynamics simulation and the sample survey, necessary for the model implementation, are still ongoing, in the following paragraph some important exemplifications are presented in order to make more clear the wideness of the analysis carried out up to now and the capacity that such approach offers when dealing with the complexity of a real urban mobility system.

The first exemplifications are conducted by means of *decision tree induction* techniques in order to analyze the links between the variables adopted for the study of sustainable mobility dynamics. Among the different activities each interviewed agent can perform and report in his daily diary, at this initial stage the attention is focused on *recreational and social activities* (called "leisure activities") as they are not obligatory, do not present a fix schedule during the week and are able to reveal citizen's habits in relation to agents' family structure and income.

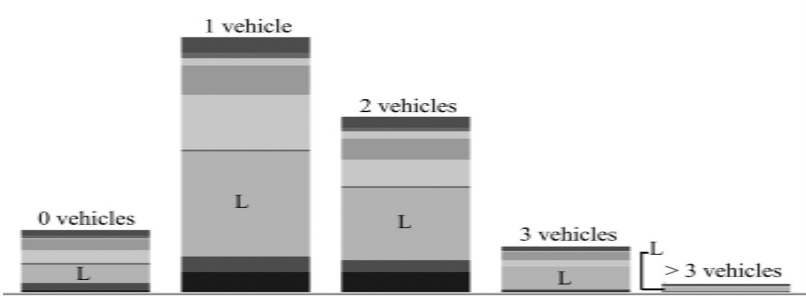

Fig. 9. Number of vehicles in each household (number at the top of each bar) – Activities percentage (the L sector indicates the leisure activity)

Another important element to which the research has been directed till now concerns the *bike mobility* study and the necessity to implement sustainable policies for the development and the design of new and adequate cycle tracks. The realization of those cycle infrastructures would represent a sustainable and adequate answer to citizen's mobility preferences, as testified from the population sample survey (Figure 6 and Table 2). In relation to the first issue, Figure 9 describes the results of an EDA analysis related to the so called "leisure activities": each histogram bar comprises the various activity types reported in different grey scale colors.

Comparing the leisure activity density with the total performed activities (Figure 9) it is possible to notice that the former increases with the total number of vehicles in the household. In fact people owning many vehicles have more accessibility to recreational activities and generally correspond to high ranking population classes.

Detailed correlation analyses were extended to all the variables under study. A decision tree allows to find out the influential variables related to each target variable considered: in this case it is represented by the choice of leisure activity in the agent daily diary. Figure 10 reports the most significant decision rules related to the recreational and social activities (out of a total of 83 extracted rules).

IF	THEN	Support
DURATION in (50,75) AND NUMB_BABY = 2 ACCOMP = 2 AND MARRIED	Activity = Leisure Activity = Leisure	50% 42%
DURATION > 93 AND START_AT = 20:30 - 03:00 AND AGE_HEAD = 55/59	Activity = Leisure	50%
ACCOMP = 5	Activity = Leisure	50%
DURATION > 45 AND START_AT = 15 - 17	Activity = Leisure	42%
DURATION > 75 AND START_AT = 19 - 20:30 AND PLANNED = Days before	Activity = Leisure	50%
DURATION > 75 AND START_AT = 20:30 - 03:00 AND OCCUPATI = Employee	Activity = Leisure	33%
START_AT = 19 - 20:30 AND NUMB_BABY = 0 AND DURATION in (115,165]	Activity = Leisure	86%
START_AT = 17 - 19 AND TRANS_MO = Walking	Activity = Leisure	45%
ACCOMP = 0 AND NUMB_BABY = 0 AND AGE_HEAD = 60/64	Activity = Leisure	50%
START_AT = 20:30 - 03:00 AND DURATION > 90	Activity = Social activity	71%
TRANS_MO = private car AND OCCUPATI = Dependent worker	Activity = Leisure	50%
AGE_HEAD = 55/59 AND INCOME = < 15000 €	Activity = Leisure	71%
LEGEND NUM_BABY = number of children in the household TRANS_MO = transport mode ACCOMP = number of companion people AGE_HEAD = age of househead OCCUPATI = type of work DURATION = duration of activity (minutes)		

Fig. 10. Decision rules extracted by a Decision Tree algorithm (leisure activity case)

In order to highlight the capacity of this analytic technique, some important remarks, derived from the decision rules present in Figure 10:

- The duration of leisure activities can be classified as short or medium for individuals with children;
- Individuals without children practice long duration leisure activities and generally before dinner;

- In early afternoon people carry out leisure activities if they are localized near their residence;
- After dinner, people mainly engage themselves to carry out leisure and social activities if their duration is medium;
- Dependent workers prefer to use their private car to carry out leisure activities.

With regards to the analysis of bike mobility development, some important studies have been carried out.

Figure 11 shows an orthogram where the main variable is the activity type, while the grey colours identify the different transport means: the "B" character indicates bicycle use.

The orthogram shows higher bike use density for the activities "eat" and " bring things" and a high value for bike use also to perform housewife activities and leisure activities. On the considered sub sample of the agent interviewed up to now, the extracted Decision Trees related to the target attribute "transport mean" is represented in Figure 12.

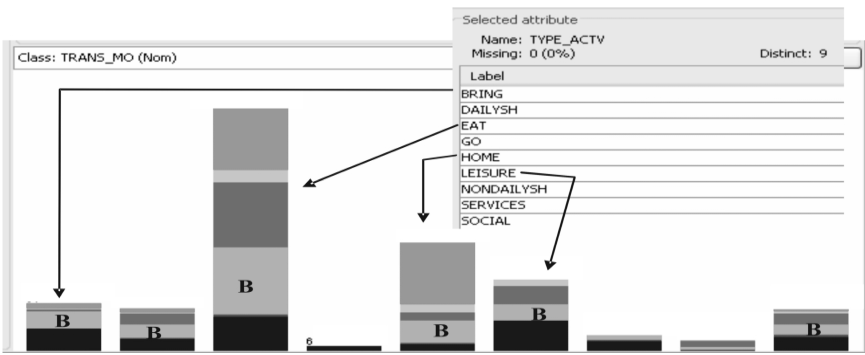

Fig. 11. Orthogram relative to the variables "transport mean" and "activity type"

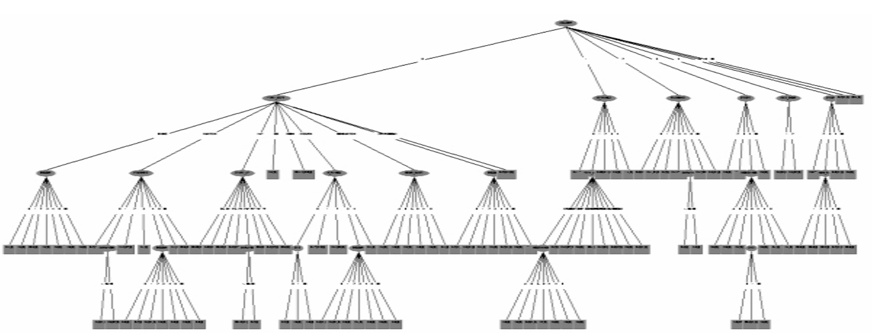

Fig. 12. Extracted decision tree related to the target attribute "transport mean"

Table 4. Example of rules extraction relative to bike use

IF	THEN	Support
Trip companion = 0 AND Activity = Bring Things AND Income = Low	Transport mean = bike	70
Trip companion = 0 AND Activity = Daily Shopping AND Planned = Just in Time AND Time <= 45 min	Transport mean = bike	55
Trip companion = 0 AND Activity = To Eat AND time begin activity = Time Lunch	Transport mean = bike	94
Trip companion = 0 AND Activity = Leisure AND Number cars owned = 0 AND Sex = F (M)	Transport mean = bike (Transport mean = motorbike)	53
Trip companion = 0 AND Activity = No Daily Shopping AND Number Childrens = 0	Transport mean = bike	50
Trip companion = 0 AND Activity = Service AND Income = Low (High)	Transport mean = bike (Transport mean = on foot)	64
Trip companion >= 3 AND Activity = To Study	Transport mean = bike	54
Trip companion = 0 AND Activity = Daily Shopping AND Planned = Just in Time AND Time <= 45 min	Transport mean = bike	55

Among all the 110 extracted rules, the ones concerning bike use and containing an high "support" value are reported in Table 4. The rules show that the bike use is mainly individual (trip companion = 0) and this habit is not respected only in case of studying activities. The ongoing results on Pisa case study confirm a well known situation related to national analysis (Rotondo 2005; ISSFORT 2006; ISSFORT and ASSTRA 2004): bike is mainly used in central period of day, for extra-working activities (daily shopping, eat, free time) or for short-term entertainment activities. From the interviews collected up to now is also evident that women use bicycles more than men, and that bike are the most used transportation mean in the case of no planned activity.

After this interpretation phase the analysis are then conducted by means of *Bayesian Network* employed to extract the conditional probability distribution to be implemented in the Multi Agent System and using the important variables underlined from *Decision Trees* for each individual target choices.

The first important network is related with the daily activity programming and so agents' personal attributes and activities attributes importance weights (coming from the preferences phase of the questionnaire) are considered. The resulting network (Figure 13) shows that individual attributes, as sex or work type, are not correlated with the activity attribute weights recorded in the interviews.

Besides, the activities called "work", "eat" and "sleep" are disconnected from the main network because they are considered extremely important (high weight) for all the agents interviewed up to now, independently from their individual attributes: these activities are in fact called "fixed activities".

The variables affecting the activity planning are derived by a statistical process called "forward inference"; in this process the individual target variables are considered as deterministic, fixing a likelihood equal to 1 (Figure 14). The number of children (living in the household) variable appears to be the one mostly correlated with the variables called "leisure" and "bring person", both relative to the correspondent agent activity.

Considering the weights assigned to the social activities (e.g. visits to friends or relatives), through the "forward inference" technique, it is possible to derive that social activities and leisure activities are closely linked.

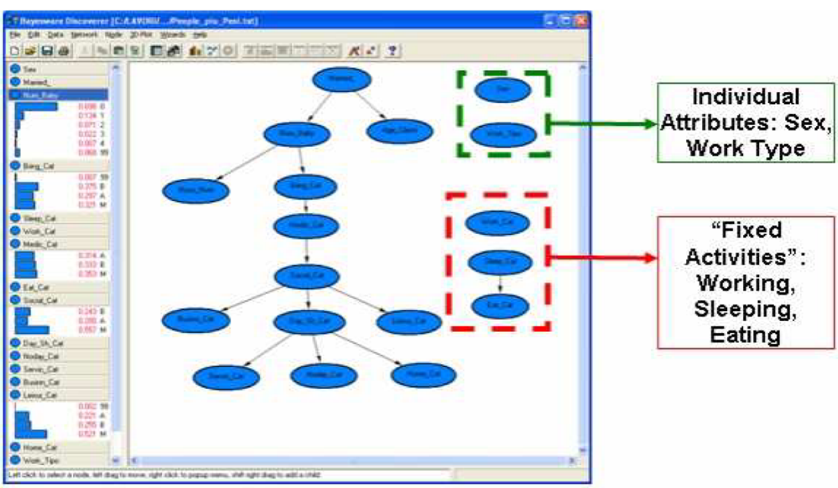

Fig. 13. The extracted Bayesian Network with highlight on fixed activities

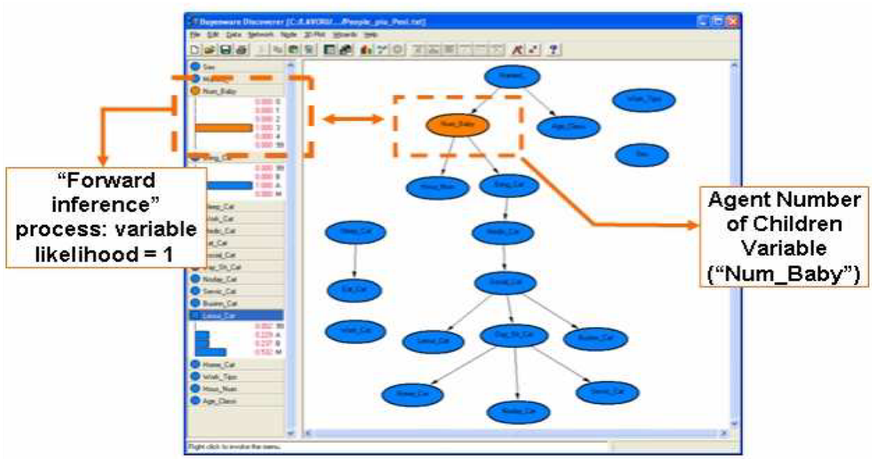

Fig. 14. The extracted Bayesian Network with highlight on the forward inference for the variable identified as number of children (“Num_Baby”)

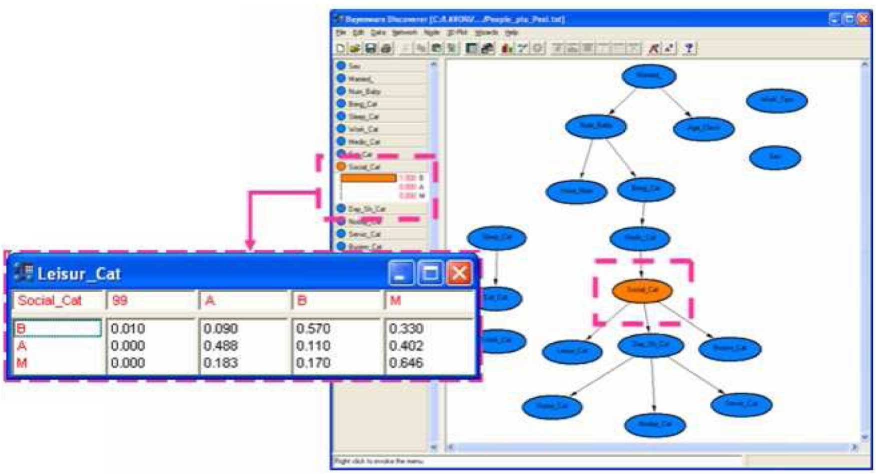

Fig. 15. The forward inference from the variable Social Activities (“Social_Cat”)

As a matter of fact, people assigning a low or an high weight to social activities attribute, respectively, a low or an high importance to leisure activities as well. Figure 15 shows the forward inference and the resulting conditional probability distribution.

With reference to Figure 13, we verified the influence of the target variable both on the parent attributes (weights of social activities) and on the grandfather variables (weights of medical activities); high values for the target variable only influence values of parent variables, while low values of target variables influence the values of all the aforementioned variables: low values of leisure activities increase the weights of business, daily shopping and other type of activities.

We tried to explain this negative correlation by analyzing separately the attributes of people giving a low or an high weight to leisure activities: people assigning an high value are mainly young men between 15 and 24 years old, while people considering leisure activities less important are more uniformly distributed.

From this example it is clear that Bayesian Networks allow the model control and interpretation such that expert knowledge assumptions can be verified: this possibility is a very critical analysis element and it can not be accomplished using tools as Neural Networks.

Finally for each extracted network (relative to each individual choice variable) the conditional probability distribution of the variable was recorded in the Multi Agent System. For example, Figure 16 shows that the likelihood to engage in leisure activities increases if the duration of the activity exceeds about 80 minutes.

In the daily activities planning, after the scheduling of fixed activities (i.e. eat, work and sleep), it is possible to calculate the likelihood to engage in each type of

Probability Distribution Table For DURATION

TYPE_ACTV	'(-inf-41.5]'	'(41.5-82.5]'	'(82.5-inf)'
BRING	0,733	0,181	0,086
DAILYSH	0,441	0,376	0,183
EAT	0,276	0,546	0,178
GO	0,867	0,067	0,067
HOME	0,085	0,255	0,66
LEISURE	0,076	0,263	0,661
NONDAILYSH	0,023	0,395	0,581
SERVICES	0,677	0,097	0,226
SOCIAL	0,074	0,2	0,726

Fig. 16. Conditional probability distribution related to duration of activity conditioned to type of activity

Probability Distribution Table For START_AT

TYPE_ACTV	DC	DE	PC	PE	PM	PP	TM	TP
BRING	0,027	0,082	0,082	0,027	0,464	0,191	0,009	0,118
DAILYSH	0,112	0,031	0,276	0,01	0,092	0,133	0,051	0,296
EAT	0,173	0,266	0,247	0,229	0,046	0,017	0,017	0,006
GO	0,35	0,15	0,05	0,05	0,05	0,15	0,05	0,15
HOME	0,377	0,044	0,099	0,012	0,187	0,067	0,012	0,202
LEISURE	0,324	0,051	0,222	0,028	0,074	0,074	0,006	0,222
NONDAILYSH	0,021	0,021	0,104	0,021	0,021	0,146	0,062	0,604
SERVICES	0,139	0,194	0,028	0,083	0,25	0,083	0,083	0,139
SOCIAL	0,37	0,01	0,31	0,01	0,03	0,01	0,01	0,25

Fig. 17. Conditional probability distribution related to activity starting time, conditioned to type of activity (DC = after dinner, DE = after lunch, PC = before dinner, PE = before lunch, PM = early morning, PP = early afternoon, TM = late morning, TP = late afternoon)

activity with regard to the time-windows remaining between the scheduled fixed activities. Figure 17 shows the conditional probability distributions related to the to the variable called “activity start time”. The information contained in Figure 17 allows to estimate the likelihood of each activity type for each time band.

5 Conclusions

A Multi Agent System is here presented with its structural innovations and its first implementation. The population sample questionnaire structuring, the temporal database construction, the agents behavioural rules extraction and modeling via two different Data Mining techniques represent the principal innovations experimented. The model elaboration, currently in progress, its testing on Pisa case study and the tools implemented till now already represent a new decision support system useful both to plan sustainable mobility policies and to locate new activities inside the city centre in order to improve the quality of present services.

The results presented in this research refer to a population sample comprising 20% of the universe of individuals to be interviewed for the urban mobility analysis relative to the Pisa case study. Those results show that the devised system is able to extract detailed knowledge from available data and, above all, is capable to catch the local behaviours specificities. This last feature gave us the incentive to further implement artificial intelligent tools despite their demanding and time consuming data collection and processing, and despite the difficulties for data-mining results implementation within a multi-agent system.

The current research, starting from a comparative analysis of the existent Multi Agent System including both their limits and their most interesting aspects (Lombardo and Petri 2005; Joh et al. 2001), aims at creating a general and replicable structure in order to propose a tool able to support urban planning beginning from agent’s life habits, their personal characteristics and the preferences of those actually living the city life. This turns out to be a real bottom-up approach providing local authorities and decision makers the effective knowledge required for developing sustainable urban mobility policies.

Future developments envisage the integration of the behavioural system into a software engine able to process both detailed data on transportation infrastructure and geoprocessing operation in a GIS environment; to this end a testing and benchmarking phase on different software frameworks is currently in progress.

The comprehensive framework of the devised activity based mobility model represents a significant step forward in dynamics and phenomena comprehension at urban scale and an attempt to develop a real integrated urban planning system.

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