Policy Modelling and Governance Tools for Sustainable Urban Development

State-of-the-art and Future Challenges

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Contents

Executive summary

Cities embody the twofold challenge currently facing the European Union: how to improve competitiveness while achieving social cohesion and environmental sustainability. They are fertile ground for science and technology, innovation and cultural activity, but also places where problems such as environmental pollution, unemployment, segregation and poverty are concentrated.

INSIGHT aims to investigate how ICT, with particular focus on data science and complexity theory, can help European cities formulate and evaluate policies to stimulate a balanced economic recovery and a sustainable urban development. The objectives of the project are the following:

1. to investigate how data from multiple distributed sources available in the context of the open data, the big data and the smart city movements, can be managed, analysed and visualised to understand urban development patterns;
2. to apply these data mining functionalities to characterise the drivers of the spatial distribution of activities in European cities, focusing on the retail, housing, and public services sectors, and paying special attention to the impact of the current economic crisis;
3. to develop enhanced spatial interaction and location models for retail, housing, and public services;
4. to integrate the new theoretical models into state-of-the-art urban simulation tools, in order to develop decision support systems able to provide scientific evidence in support of policy options for post-crisis urban development;
5. to develop innovative visualisation tools to enable stakeholder interaction with the new urban simulation and decision support tools and facilitate the analysis and interpretation of the simulation outcomes;
6. to develop methodological procedures for the use of the tools in policy design processes, and evaluate and demonstrate the capabilities of the tools through four case studies carried out in cooperation with the cities of Barcelona, Madrid, London, and Rotterdam.

The INSIGHT Consortium is composed by the Research Centre for Applied ICTs (CeDInt) and the Transport Research Centre (TRANSyT) at the Technical University of Madrid (UPM), Nommon Solutions and Technologies, the Centre for Advanced Spatial Analysis at University College London (CASA-UCL), the Technical University of Eindhoven (TU/e), the Institute for Cross-Disciplinary Physics and Complex Systems at the University of the Balearic Islands (IFISC-UIB), and the Barcelona City Council.

1. Introduction

Cities embody the twofold challenge currently facing the European Union: how to improve competitiveness while achieving social cohesion and environmental sustainability. Cities are fertile ground for science and technology, innovation and cultural activity, but at the same time, they are also places where problems such as environmental pollution, unemployment, segregation and poverty are concentrated [Com11]. Complex problems like these require a holistic approach to urban development, together with an assessment of urban policies in terms of a comprehensive set of economic, social, and environmental sustainability indicators.

1.1 The policy context and the European vision of the city of tomorrow

Urban planning is not itself a European policy competence. However, European economic, social, environmental, and territorial policies all have a strong urban dimension, as made clear in a variety of policy documents, such as the European Spatial Development Perspective (ESDP) [Com99], the Community Strategic Guidelines [Com05], the Thematic Strategy on the Urban Environment [Com06], the Territorial Agenda of the European Union (TAEU) [Eur07a], the Leipzig Charter on Sustainable European Cities [Eur07b], the Toledo Declaration on Urban Development [Eur10], or the revised Territorial Agenda of the European Union 2020 (TA2020) [Eur11]. Cities are considered to be at the heart of EU sustainable development efforts and are seen as the main engines for the achievement of the headline targets of the EU 2020 strategy [Com10]: creating employment; promoting research and innovation; achieving the 20/20/20 climate change and energy targets; improving education; and combating poverty.

The policy making and planning bodies directly or indirectly relevant to urban development span (vertically) from local, regional, and national authorities (including their related planning agencies) to global, supra-national political authorities, like the European Commission, the Parliament, the Council, or the Committee of Regions; as well as (horizontally) across services in charge of transport, energy, environment, land use, etc. Successive EU Presidencies have forged a common European vision of urban development, recognising the need for coordination at all levels of government and for an integrated and cross-sectoral approach, as well as the importance of cooperation and networking between cities, in order to ensure effective multi-level governance, coherent strategies and efficient spending of public resources.

In terms of aims, objectives and values, there is a shared vision of the European city of tomorrow as a place of advanced social progress, with a high degree of social cohesion; a platform for democracy, cultural dialogue and diversity; an opportunity for energy savings and environmental regeneration; and an engine of economic growth. Integrated, smart, sustainable, cohesive, and inclusive urban development is seen as the only way to achieve a greater economic competitiveness, eco-efficiency, social cohesion and civic progress in European cities, and to guarantee citizens' quality of life and welfare in the present and in the future [Eur10].

1.2 Challenges for European urban development and governance

The current financial and economic crisis is having a deep impact on European cities. Cities are not growing the way they did in the last decades, and a lot of new urban developments have failed to achieve the activity they were supposed to have. Simultaneously, the decreasing economic activity of some consolidated urban areas is degrading the quality of life in many neighbourhoods, and the crisis is limiting investment in public services. As highlighted in the Toledo Declaration adopted by the Informal Meeting of Urban Development Ministers held in Toledo, Spain, in June 2010 with the core topic of "integrated urban regeneration" [Eur10], in the short and medium term European cities are facing the major challenge of overcoming this crisis and emerging stronger from it; but they are also facing other structural and long term challenges, such as globalisation, climate change, pressure on resources, migrations, and demographic change.

In 2010, the European Commission launched a series of consultations and workshops bringing together urban experts and representatives of European cities to discuss the European model of urban development; better understand the strengths, weaknesses, opportunities and threats to this model; and propose new coordinated approaches in a multi-level governance framework. The outcome of that reflection was the report 'Cities of tomorrow' [Com11], which identifies a number of challenges that European cities will face in the years ahead:

- Urban ecosystems are under pressure, and there is a **growing concern about sustainable development**. In addition to the challenges posed by energy scarcity and climate change, soil sealing reduces biodiversity and increases the risk of flooding and water scarcity. Land is not only an economic resource, but also one of the most valuable natural assets that we have. Urban sprawl and suburbanisation threaten sustainable territorial development, making infrastructures and public services more costly and difficult to provide, leading to the overexploitation of natural resources, and increasing the energy and environmental cost of transport. In the past few years, and increasingly since the advent of the economic crisis, many urban planners are advocating a focus of attention from urban growth to urban regeneration, including rehabilitation of industrial sites and contaminated land areas, urban regeneration projects, clean urban transport, or energy efficient buildings.
- As a result of the financial crisis of 2008 and the subsequent **economic downturn**, which have led to the deepest recession suffered by the European economy since the 1930s, cities are suffering from high levels of unemployment and lower business survival rates, among other effects. Cities act as the main engines of the economy, and are therefore crucial for driving economic recovery. Competitiveness in the global economy has to be combined with sustainable local economies by fostering innovation and developing key competences and resources.
- **Social polarisation and segregation** are increasing. The European economy is currently unable to provide jobs for all, weakening links between economic growth, employment and social progress, and the cuts in public budget are having a strong impact on the welfare state. An increasing number of neighbourhoods are suffering from poor housing, low-quality education, unemployment, and difficulties to access certain services, such as health, transport, or ICT. There is a need to find more effective solutions to preserve the provision of essential public services and ensure a decent life for those left outside the labour market.

- **Demographic changes**, including an increasing longevity and declining fertility, changing family structures and migration, give rise to a series of challenges, such as ageing population or migrants' integration. Cities will have to be both elderly- and family-friendly, as well as places of tolerance and respect, able to exploit the potential of socio-economic, cultural and generational diversity as a source of innovation.
- **Social and behavioural changes** are modifying location and mobility patterns in cities. The emergence of new social media and electronic communications, for example, is leading to profound changes in social relationships, as well as to the introduction of new activities such as e-shopping or telework.

To empower city governments and their citizens to address these challenges and design sustainable urban development policies, policy makers and urban planners shall be provided with data, models and decision support tools allowing the assessment of the possible future impacts of a range of policies and trends. It is necessary to develop new tools and methodologies, or adapt the existing ones, to address the requirements stemming from this new landscape.

1.3 Urban modelling in spatial planning and policy design

When addressing issues as complex as urban development, policy makers and society at large face three fundamental, intermingled problems: i) the many components of the natural, social, economic, cultural and political urban ecosystems are strongly interwoven, giving rise to complex dynamics which are often difficult to grasp; ii) the limited understanding of urban dynamics makes it difficult to anticipate the impact and unintended consequences of public action; and iii) urban development policies are subject to highly distributed, multi-level decision processes and have a profound impact on a wide variety of stakeholders, often with conflicting or contradictory objectives.

Urban models are mathematical representations of the 'real world' —typically implemented through computational simulation tools— that describe, explain, and forecast the behaviour of and interactions between different elements of the urban system. Urban models serve various functions, which can help address the three abovementioned fundamental problems: i) models help develop a better understanding of urban dynamics (in a scientific explanatory role); they enable virtual experimentation, providing scientific evidence of the impact of new policies (in a predictive and policy design role); and iii) models are powerful tools to enable collaborative policy assessment process, allowing the empowerment and participation of societal stakeholders and facilitating the construction of shared visions and objectives (in a narrative and deliberative role).

Cities were first formally treated as 'systems' several decades ago [Bat12a]. These initial approaches considered cities as distinct collections of interacting entities, usually in equilibrium, with explicit functions that could enable their control from the top down [McL69, Cha71]. During the last 20 years, however, there has been a shift in the way we think about human systems in general, and about cities in particular: complexity theory has raised the notion that systems are never in equilibrium [Hep12], and the image of a city as a 'mechanistic system' has been replaced by that of a 'living, self-organising system' that evolves organically from the bottom up [Bat12a, Bat12b]. Cities are now understood as complex adaptive systems in which location and activity patterns emerge from the actions and interactions between a manifold of entities (individuals, households, firms…), and such patterns themselves feed back to influence the subsequent development of those interactions. As our conception of urban systems changes, urban planning is moving from a centralised, top-down approach to a decentralised, bottom-up perspective [Bat07], in which the role of policy makers and urban planners is that of nurturing positive emergent phenomena and minimising negative emergent properties. As any policy planned for a certain sector will end up affecting the others in one way or another, a good understanding of urban dynamics, as a pre-condition for an integrated planning of transport, housing, work areas, public spaces and services, is key for a successful, sustainable urban development.

1.4 The role of ICT and smart cities

The concept of the 'smart city' emerged during the last decade as a fusion of ideas about how information and communication technologies (ICT) might improve the functioning of cities, enhancing their efficiency, improving their competitiveness, and providing new ways of creating sustainable development and high quality of life [Bat12d]. Initially shaped as a very technocentric concept, critical voices soon arose asking for a responsible and critical use of ICT, informed by a citizen-centric approach [Sen12, Mor13]. Currently the central role of ICT in the operation of the future city lies at the core of the concept, but the term 'smart city' goes now beyond the idea of ICT-driven cities and is generally understood as a concept embracing the use, coordination and integration of modern technologies (including transport or energy technologies, in addition to ICT), but also the investment in human, social, and environmental capital [Car09]. Giffinger et al. [Gif07] define a smart city as a city performing well along six main axes or dimensions: smart economy, smart mobility, smart environment, smart people, smart living, and smart governance. Thought the label 'smart city' is still quite a fuzzy concept and is used in ways that are not always consistent, from here onwards we will adopt this holistic vision.

In the field of spatial planning and urban policy design, recent developments in ICT and the concept of the smart city open new research avenues with the potential to make progress in several complementary directions:

1. **Urban data systems**. With the emergence of the open data movement, public administrations are beginning to open up data available in many different formats. In parallel, the increasing penetration of modern ICT, such as smart phones, e-transactions, Internet social networks or smart card technologies, allows the automatic collection of a vast amount of spatial and temporal data, which combined with more traditional, cross sectional demographic and economic activity databases (e.g. census data), can be used to extract relevant information about urban dynamics. To achieve this purpose, it is necessary to develop new methods and tools for the acquisition, integration, management, analysis and visualisation of data originated from multiple distributed sources, which connects with the research currently being undertaken under the umbrella of the big data movement.
2. **Urban modelling and simulation**. The explosion of available data and the development of new forms of data analysis can in turn inform the development of better urban theories and simulation models. Further research is needed, for example, to develop a better understanding of the response of urban systems to the financial crisis, the spatial behaviour of firms, the impact of public services on

innovation, the interaction between location and activity patterns and social networks, or the impact of ICT on housing markets, labour markets, economic development or travel demand. With the emergence of big data, some authors have raised concerns about the risk of focusing on descriptive work and predictive, non-explanatory models, abandoning theory [Boy10, Gra12]. An integrative approach, promoting an intense interaction between data analysis and theoretical modelling, can help overcome this problem and take advantage of the opportunities offered by big data for the formulation, calibration, and testing of new models of location and activity behaviour. Recent advances in areas such as network theory or agent-based computational modelling, and more generally the intrinsically holistic and eclectic approach advocated by complexity science [Mil07], appear as a suitable framework for the integration of different modelling approaches — coming from fields such as urban economics or social physics — into a comprehensive toolkit to address the many different questions related to urban development [Bat12a].

3. **Policy interfaces and visualisation tools**. Cities will only be truly smart if these advances in terms of data and models are properly integrated into governance processes. While simulation models have been widely applied in areas like transportation planning and traffic engineering, in other areas like land use planning the potential of advanced, state-of-the-art urban models is still largely unexploited. In many cases, the potential users do not have the skills to use such models or are not convinced of the benefits. To bridge this gap, the development of the models needs to be user-driven and based on a continuous dialogue between scientists and policy makers [Bra08]. Particularly relevant is the role of new forms of information visualisation and visual analytics, which can make model results more accessible to policy makers and urban planners, lowering the barriers for the operational use of advanced urban simulation tools.
4. **Link with societal actors and participatory governance**. Finally, ICT opens the door to the development of new ways of citizens' engagement in the design and planning of their cities. New ICT tools can help capture the inputs from the community (e.g. algorithms for reconstructing citizens' opinion from data resources distributed throughout the Internet) and support an increased participation of citizens (e.g. through applications that allow citizens to monitor and report the system status in real time). User-specific interfaces and tools for the visualisation of policy impacts in an intuitive and graphical manner can facilitate collaborative, multi-stakeholder policy assessment and decision making processes in which societal actors collaborate with experts in the generation and analysis of urban policies.

In this paper we propose an integrated approach encompassing these four dimensions (data analytics, theoretical models, software tools and organisational forms), with the main focus on understanding the impact of the economic crisis on European cities and devising new urban policies for growth and sustainability.

2. ICT in urban planning

Urban planning is a technical and political process concerned with the control of land use and the design of the urban environment to ensure the orderly development of settlements and communities. It encompasses research and analysis, strategic thinking, architecture, urban design, public consultation, policy recommendations, implementation and management [Tay07]. Ebenezer Howard and Patrick Geddes are probably the two most influential early thinkers in modern planning [Hal92]. Their contributions set the basis of the so-called 'blueprint planning', which dominated the first part of the 20th century. Blueprint planning gave planning a logical structure by developing the survey-analysis-plan sequence, and was characterised by highly normative models emphasising the pre-eminent role of the planner. The main shortcoming of these approaches comes from the fact that "they were not concerned with planning as a continuous process which has to accommodate subtle and changing forces" [Hal92], but with the generation of fixed plans, assuming the predictability of the world and ignoring uncertainty [Web83, Fal93]. In the late 1950s and 1960s, 'synoptic planning' began to examine problems from a systems viewpoint, using conceptual or mathematical models relating ends (objectives) to means (resources and constraints), with heavy reliance on quantitative analysis [McL69, Hud79, Hal83]. It was in the context of systems planning that the calls for public participation were first heard [Fal73], though limited to the development of the planning objectives, as part of a process led by the planner [Hal83]. The main critique to synoptic planning is that it still assumed the idea of a unitary public interest model, ignoring that there are costs and benefits of planning interventions unequally shared by different societal groups [Kie83]. The contemporary era is characterised by a variety of tendencies aiming at integrating a plurality of interests and an active public engagement. These tendencies include 'transactive planning' [Fri73], 'advocacy planning [Maz82], 'bargaining' [Dor86, McD89], or 'communicative planning' [Hea96]. A comprehensive review of these approaches can be found in [Lan05].

Urban planning shares many interests with **urban economics**. Urban economics can be broadly defined as the economic study of urban areas or, more narrowly, as the branch of microeconomics that studies urban spatial structure and the location of households and firms [Qui08]. While most other forms of economics do not account for spatial relationships, urban economics focuses on these spatial relationships to understand the motivations underlying the formation, functioning, and development of cities. Although economists were among the early contributors to the literature on urban planning, there has been a historical divergence between urban planning and urban economics, both in terms of perspectives and methods. The situation is progressively changing and there is now a trend towards more interdisciplinary approaches broaching how urban planning and economics can inform each other to address the critical issues facing contemporary cities, e.g. the prosperity of urban economies, the provision of urban services, or the proper allocation of land [Bro11].

Over the last decades, **information and communication technologies (ICT)** have had an increasing impact on urban planning, urban economics, and more broadly on the study of cities. Indeed, the emergence of modern information processing is closely linked to the concern about collecting census data at the end of the 19th century, which led Herman Hollerith to the development of punched card data processing technology, providing the primary basis for the company that would later on become IBM [Pug95]. Computers soon allowed the collection and management of huge amounts of data, and the 1960s saw the first computerised **Geographic Information System (GIS)**: the Canada Geographic Information System (CGIS) developed in Ontario, Canada, by the Federal Department of Forestry and Rural Development, under the direction of Roger Tomlinson [Tom67]. Other key contributors in this pioneering age were Howard Fischer in the Harvard Laboratory for Computer Graphics — which developed a number of important theoretical concepts in spatial data handling and seminal software systems such as SYMAP, GRID, and ODYSSEY — and Jack Dangermond, founder of the Environmental Systems Research Institute (ESRI) [Cop91]. The first works dealt with the aggregation and visualisation of ecological, sociological, transport or demographic data. With the increasing ability to capture and handle spatial data and the progressive integration of GIS with new technological data sources, like satellite remote-sensing data or urban traffic flow data, research was soon extended to **urban spatial analysis**. Spatial analysis can be broadly defined as the formal quantitative study of phenomena that manifest themselves in space [Ans93], and has traditionally been concerned with the development of statistical methods for the analysis of geographical phenomena. Some researchers (see e.g. [Mar00]) have recently been calling for the concept to be broadened to embrace **modelling and simulation**[1]. The first integrated land use-transport interaction (LUTI) models, which brought together urban form and travel analysis, appeared in the United Stated in the 1960s. These early efforts failed in their goals due to technical restrictions: data collection, calibration and validation difficulties, and insufficient computing power [Weg10]. There were also serious drawbacks in the conception of the models, which were essentially static and suffered from an excessive spatial aggregation [Siv07]. After a near total abandonment in the 1970s and the 1980s, the 1990s and the 2000s brought a new boom in urban modelling, boosted by advances in GIS, parallel computing, data mining, or agent-based modelling. More recently, in parallel to the trend towards participatory planning approaches, ICT has begun to offer tools for public engagement through new forms of **data representation** [Han07], as well as new **ICT-enabled social participation techniques**, such as charrettes, brainstorming and buzz sessions, synectic sessions, or take-part workshops supported by Planning Support Systems, Participatory Planning GIS, simulation and role-paying games [Inn00, San00, Con09, Ste12].

In the last few years, the role of ICT in urban planning has been successively framed by concepts like digital city, wired city, intelligent city, and the more recent, worldwide spread term of **smart city**. The emphasis on social and environmental capital distinguishes smart cities from more technology-centric concepts, and drives the new goals of ICT as a vector to fuel sustainable economic development, a high quality of life, and a wise management of natural resources. In the next three sections, we discuss more in depth the state-of-the-art in the four main areas addressed by INSIGHT: spatial analysis and data mining; the modelling and simulation of urban systems; information visualisation and visual analytics; and ICT tools for participatory governance.

[1] For the purpose of document structuring, along the rest of this paper we will keep the somewhat artificial frontier between spatial data analysis and modelling activities; this without prejudice of the integrative thinking adopted by the INSIGHT project with a view to facilitate a constant interaction and exploit the synergies between both disciplines.

2.1 Spatial analysis and data mining

Spatial analysis includes a collection of techniques which study entities using their topological, geometric, or geographic properties. The phrase is often used in a more restricted sense to describe techniques applied to the visualisation, exploration and analysis of geographic data [Ans04]. Unlike other areas of data science, where all the relevant information is contained in the observations, the results of spatial analysis will not be the same under re-arrangements of the spatial distribution of values or reconfiguration of the spatial structure [Goo04]. The complexity of spatial data and implicit spatial relationships limit the usefulness of conventional data analysis techniques, and requires specific data pre-processing, data mining, and post-processing techniques to extract useful and understandable patterns.

The pioneering work in spatial data analysis was conducted in the 1950s and 1960s. Greig-Smith set the basis for the development of statistics to test for spatial randomness [Gre52]; Whittle extended autoregressive models, fundamental in time series analysis, to spatial data, leading to spatially autoregressive models, which were the first statistical models for formally representing spatial variation [Whi54]; and Matheron extended Wiener-Kolmogorov stochastic process prediction theory to spatial processes defined on continuous geographic space [Mat63]. The 1970s and early 1980s saw further significant advances in what was becoming known as spatial statistics. Besag provided the basis for conditional probability models of spatial processes [Bes74]. Ripley proposed the use of the K function for the description of a point pattern (random, regular, or clustered) at a range of scales [Rip77]; the K function is particularly suitable to model spatial patterns that show a combination of effects, e.g. clustering at large scales and regularity at small scales. Cliff and Ord [Cli73, Cli81] generalised tests for spatial autocorrelation on irregular areal units. Cressie and Haining developed methods to detect possible errors in spatial data sets [Cre84, Hai90]. In the 1990s, significant effort was devoted to developing tests to recognise the heterogeneity of what are termed whole-map properties, such as testing for clustering [Bes91, Kul95] or Anselin's local indicators of spatial association (LISA), which test for localised structures of spatial autocorrelation [Ans95]. These numerical methods were complemented by the development of visualisation methods for spatial data, shifting from seeing maps purely as tools to display findings, to using automated mapping and GIS as a tool for exploring data and suggesting hypotheses. In the 2000s, research focused on the representation of time, which turns out to be far more complex than the simple addition of a third (or fourth) dimension to the two (or three) of spatial representations [Goo04]. In parallel, international efforts such as the Data Documentation Initiative (http://www.ddialliance.org) defined standards for the collection, description, processing, distribution, and analysis of data from the social sciences, and a massive investment was made to support the sharing of geographic information through online mapping. The 2000s also saw the development of specialised software for spatial data analysis, ranging from commercial statistical and GIS packages to abundant open source resources using software environments such as R, Java, or Python.

Today, spatial analysis encompasses a variety of techniques. **Exploratory spatial data analysis (ESDA)** includes techniques such as visualisation (box plots, histograms, scatter plots, etc.) or factor analysis [Cre11]. **Spatial autocorrelation** analyses the degree of dependency among observations in a geographic space. Global autocorrelation statistics, such as Moran's I, Geary's C or Getis's G, are used to detect departures from spatial randomness, i.e. to answer the question of whether there a spatial pattern, whereas local autocorrelation, e.g. Anselin's LISA [Ans95], allows the identification of local regions of strong autocorrelation, such as hot spots; Ripley's K function summarises the spatial dependence over a range of distances [Rip77]. **Spatial interpolation** estimates values at unobserved locations based on the values at observed locations. It includes basic methods, e.g. inverse distance weighting, as well as more sophisticated methods like kriging [Cre11]. **Spatial regression** captures spatial dependency between variables. The models used in urban and regional studies include regression models with spatially correlated errors, regression models with spatially averaged (or lagged) independent or predictor variables, or regression models with a spatially averaged (or lagged) response variable [Goo04]. Geographically weighted regression (GWR) is a local version of spatial regression that generates parameters disaggregated by the spatial units of analysis [Fot98]. The particularity of GWR is that the coefficients of the predictors vary for each location. GWR operates by assigning a weight to each observation depending on its distance from a specific geographical location. The weights are generated from a kernel function which uses a bandwidth found by optimising a goodness-of-fit criterion. Recent developments in spatial statistics include the use of non-Euclidean distances, which has been proved to be more adequate for the analysis of urban areas [Lu11]. Spatial statistics has traditionally assumed that the phenomena under study can be located in any place of a 2D planar space. Yet, in some cases it is important to consider a network structure [Mil94]. Yamada and Thill [Yam04] compared Euclidean and network-based K function analysis, concluding that the former overestimates the clustering tendency. Okabe et al. [Oka06] implemented a network-based toolbox called SANET in which network distances are integrated into different spatial analysis tools. Yamada and Thill [Yam07] also developed a network-based K function for the local analysis of event-based data, and Steenberghen et al. [Ste10] contributed to the field with the inclusion of a moving window, so that events that are the result of movements along the network are properly acknowledged and the boundary effect is eliminated. Lu et al. [Lu11] implemented the network constraint approach in the geographically regression model, which aims at modelling local spatial relationships between variables. Dai [Dai12] admits the current early stage condition of network-constrained spatial analysis, and indicates the need of further exploring network-based clustering tools.

Spatial networks is the name given to a discipline derived from graph theory that deals with similar problems from a different but complementary perspective. The application of networks to social systems has a long tradition of almost a century [Fre04, Cal07, New10]. The nodes represent people and the connections correspond to social interactions. The graphs reflect thus the complexity of the system and are adequate to be subjected to elaborated mathematical treatments. The information obtained through these mathematical methods brings further understanding of the structure and mechanisms behind the evolution of these intricate multi-agent systems. The same conceptual framework can be applied to spatially extended systems where the nodes represent items that are geographically localised, such as transport centres, stations, local services, companies, etc., and the connections or relations between them. These constitute the so-called spatial networks. They differ from other type of networks in that the distance plays now a central role as a variable defining the presence and the intensity of the connections. Even though the area of network research has experienced a large boost of activity in the last decade, the analysis of spatial networks has received comparatively less attention. A recent review summarising the advances in the field is [Bar11]. The first systems to be studied were transport networks of different types such as airport networks [Bar04, Gui05, Sal07, Bal09, Fle13], port networks [Kal10], and closer to the urban environment, the networks formed by metro lines [Lat01, Sie05, Fer09, Rot11] or commuters [Cho03, Mon07, Bal09]. The nodes of these networks are transportation centres such as stations, airports, harbours, municipalities, etc., and the (weighted and directed) connections bear information on the traffic sustained between two centres in a certain time period. Several properties of these networks have been considered including topological features, relation between traffic and topology, and clustering and modules. The information of real transportation networks has been also used for modelling propagation processes as disease or malfunction spreading [Bal09, Fle13]. The topology of other type of infrastructures such as roads and streets networks has been studied as well using these techniques [Buh06, Car06, Lam06, Lev06]. Finally, regarding urban areas, the use of mobile devices such as smart phones or the access to online social networks like FourSquare have also been employed as proxies to monitor human activity in delimited zones of the cities [Hos12, Nou12]. It is estimated that by 2015, there will be more than 2 billion smart phone users globally, which makes the research based on mobile devices a promising tool for a better characterisation of the spatio-temporal characteristics of human activity.

2.2 Urban modelling

Cities have been treated as systems for several decades, aiming to model the spatial and temporal patterns of land conversion and to understand the causes and consequences of these changes. Land use models intend to predict changes in land use, socio-economic and demographic data, based on economic theories and social behaviours. In the early 1960s urban planners began to recognise the complex interactions between the transport network and the rest of the urban system and the first integrated mathematical models of urban land use and transport appeared. Land use-transport interaction (LUTI) models bring together urban form and travel analysis[2]. Indeed, land use and transportation systems are closely intertwined: land use patterns influence travel needs, mobility patterns, and the evolution of transport infrastructure; and the transport system, in turn, influences where people engage in activities and how the urban form changes. LUTI models are also referred to as integrated land use-transport models or, more simply, as integrated urban models. The early LUTI models were equilibrium-seeking rather than dynamic. Recently the approach has changed from aggregate equilibrium systems to complex, evolving systems of systems which seek to represent cities in more disaggregated and heterogeneous terms [Bat76, Art88, Zha93, Fuj99, Kru91, Bat07, Hep12]. The dominant trend has evolved towards disaggregation of population and employment groups by various socio-economic attributes, and there has been a shift towards bottom-up approaches (activity-based and agent-based models) relying on data of single households and their members, together with their daily activities and the resulting transportation needs. Other classes of land use models have been developed based on physical evolution of locational patterns and morphologies in cities [Sul86, Whi88], in particular cellular automata models. At the same time, various more ad hoc agent-based models of particular urban sectors such as residential location, housing markets, or retail choice, have also been developed [Bat08, Hep12].

[2] The term LUTI model is sometimes used interchangeably with land use model. This is potentially confusing because, within the group of land use models, the degree of integration with travel demand models varies considerably. Some include, or are fully integrated with, transportation models, while others incorporate transportation-related measures in a much more indirect, static manner.

Land use and land use transport interaction models

The evolution of land use models has followed two main paths: economically driven models and physical land development models. It is not until lately that the two paths started to merge by integrating in the models space, social and economic interactions.

Microeconomic-based, computable general equilibrium (CGE) models have their roots in Alonso's bid-choice land use model [Alo64], which assumes that firms or households are willing to pay higher rents if they report larger benefits in terms of production and transport cost balance [Alo64]. Firms or households bid for space up to a maximum value, trying to maximise the difference between their willingness to pay and the rent they actually pay; and landlords rent to the highest bidder. The model assumes a static equilibrium in which supply equals demand. The model's ability to explain spatially disaggregated land use patterns is limited, partly because it considers the space as a featureless plane and it reduces its role to a simple measure of distance from the urban centre. An example of this type of model is MUSSA [Mar96]. Another model type considering economic aspects as the driving variables for land use changes are **spatial interaction (Lowry-type) models**. The first of these models to gain notice was Lowry's model of Metropolis [Low64]. Spatial interaction models estimate flows between locations as a function proportional to the size and attraction of origins and destinations, and inversely proportional to the travel time and/or cost, as in the gravity model underlying many travel demand models. Inversely, population is concentrated in areas with high accessibility to employment, and employment is concentrated in areas with high accessibility to population. The land use model provides population and employment distributions based on assumed travel impedances to the travel model, which calculates updated impedance to be fed back into the land use model; the loop is iterated until reaching equilibrium. An extension of gravity models are entropy-maximising models, which introduced the concept of non-linear increase of perceived travel cost with travel distance [Wil10]. A widely used spatial interaction LUTI model is DRAM/EMPAL [Put95]. **Spatial input-output models** can also be considered as economically driven models. They account for producers and consumers of goods and services and their interactions. Households are included as both producers and consumers: they supply labour to employers (resulting in work trips) and consume goods and services (resulting e.g. in shopping trips). Land is considered a non-transportable production factor. Production factors are allocated to zones according to zonal production costs (including land prices) and travel impedances to zones of consumption. Land prices are determined endogenously through an iterative procedure which aligns land demand (elastic to price) with land supply. Examples of models of this type are MEPLAN [Ech90], TRANUS [Bar05], and PECAS [Hun03]. Finally, **spatial econometric models** have been widely developed in the tradition of aggregate modelling [Ans88]. They are developed at a scale where statistical averages are stable, which means that the spatial and temporal units must be appropriate for standard statistical inference. The dynamics of these models is well-defined, with the equilibrium properties being well-known in terms of their stationarity. Emergent behaviours are not a feature of such models, but the distinction between exogenous and endogenous variables, as in much economic modelling, is strong.

In contrast to standard economic models, in which complex patterns are generated by imposing external conditions, **cellular automata models** demonstrate how complex structures arise from the interactions between individual cells. The space is divided into a lattice of cells of the same size and shape which can be either empty or occupied. The state of a cell and its behaviour is determined by the state of other cells in close proximity at a previous time step, by a set of local rules, and by the cell itself [Ben04, Tor03, Wol02]. They simulate the spatial diffusion from a point to immediate neighbours to reproduce regional patterns of urbanisation. However, the underlying dynamics leading to the interaction rules between cells is not explicitly addressed, failing to differentiate the effect of interaction from the exogenously determined variables which may generate the same patterns. Hence, they are not able to predict land use changes when the conditions of the surrounding areas are drastically modified. One advantage of these models is that they take explicitly into account the time evolution of the system. Considering the dynamic nature of land use, systems dynamics models have also been developed [Bat12c]. These models are based on coupled difference equations whose structure is such that they lead to exponential growth followed by damped oscillations around fixed resource limits. They can be quite disaggregated dealing with different sectors, but the environment is entirely absorbed in the population as there is usually no spatial variation. The dynamic behaviour of these models is well-defined. The links to the wider environment are structured in terms of control over resource limits [Bat12c]. An example of these models is MARS [Pfa08]. More disaggregated dynamical models, which share some of the properties of cellular automata but are able to adapt to environmental changes and social interactions, are **agent-based models**. The key difference with cellular automata is that agents are heterogeneous mobile entities which control their own actions based on their knowledge of the environment and the interactions with the other agents [Bir12]. Agent-based microsimulation models are activity-based models with the individual (or household, firm, or any other agent in the urban system) as the unit of analysis. They integrate naturally with agent-based transport models, allowing the simulation of urban systems at an extremely fine level of detail and fidelity. Activity patterns are modelled from the bottom up, generating emergent spatial and temporal patterns at more aggregate levels. Examples of models in this category are UrbanSim [Wad03], ILUTE [Sal05], or ILUMASS [Str05]. It is with agent-based models that land physical interaction models and economically driven models merge into a more unified approach.

Housing, retail, and public services location models

Models of housing choice have a long tradition and have been used in many countries as tools supporting housing policies. Different model types can be distinguished on the basis of the kind of data used as input to the model. Most models rely on surveys about housing preferences and housing choice histories. These data sets report the characteristics of the current house (and environment) and possibly of previous houses. Housing choice models based on such revealed preference data predict the probability of choosing a house as a function of its attributes and a set of socio-demographic variables. Concepts such as random utility and hedonic prices [Ros74, Tay08] are central in this approach. The basic model is the multinomial logit model; more advanced models considering spatial dependency, history and similarity of options have been applied [lan66, Ros74]. In addition, the mixed logit model has been used to incorporate heterogeneity [Mal03, Bar08] and spatial dependence [Chi95, Bas98, Dub98, Gel98, Pac98, Bow01, Mal03] in utility functions. A disadvantage of revealed preference models is that they rely on historical data, and hence they are not adequate for predicting choice of new types of housing. A second approach relies on stated preference data obtained by asking individuals about their preference or latent choice for attribute profiles that are systematically varied using principles of experimental design. The application of this approach is progressively increasing, following lines developed in fields such as transportation research, environmental economics, or marketing.

Models of retail structure were first developed based on the application of the gravity law to define hinterlands or trade areas around cities. Reilly's law was developed in the 1930s to determine the extent of trade areas around cities so that the market area of a commercial centre could be determined. These models then evolved in the 1960s into retail shopping models where these trade areas were relaxed on the premise that at every location in the city, there was a finite probability that a consumer would visit any retail centre [Buk67]. These were simulated using extended spatial interaction models based first on gravitation hypotheses and then on discrete choice theory where the numbers of consumers buying goods at different retail centres was modelled. These models were used by many retailing organisations, e.g. supermarket chains such as Tesco in the UK, as well as public planning agencies, to assess the impact of new retail centres, and are still widely used. The critical issue that has emerged in European towns and cities is that retailing is leaking onto online systems, whose distribution centres are no longer clustered in the way commercial and retail centres have been historically. Town centres are in massive decline, some of this decline being also attributable to the current recession.

Models of public services location can be divided into efficiency-oriented and equity-oriented models [Mur10]. Public services can be provided either by public administrations or by private firms. The spatial distribution of publicly and privately held services usually obeys to different factors, private sector typically putting more emphasis on efficiency. Following the same assumptions as in the retail sector and substituting retail centres by public facilities, gravity [Con01, Wil90, Sa03] and entropy maximising [Eas75, Web75] models have also been used for public services allocation. Additionally location-allocation models have been developed following two main approaches: i) the p-median problem [Hak65], which minimises demand-weighted travel to service facilities; and ii) Location Set Covering Problems (LSCP) [Tor71] and Maximal Covering Location Problems (MCLP) [Chu74]. In LSCP, a minimal set of facilities is sought such that demand points are served within a maximum travel time/distance. In MCLP, p facilities are to be sited so as to maximise demand served within the stipulated standard. Most public facility location models use one of these approaches (or a combination of both). There are numerous examples of application of location-allocation models in a range of public services, including: health care facilities [Ver02, Møl06, Mu09], fire stations [Rev91, Liu06, Mur09], schools [Tei07], recycling depot planning [Val98], incinerators [Alm09], open space planning [Yeh96], and waste disposal [Lis91].

2.3 Information visualisation and visual analytics

Visualisation is a process to communicate content through different pictorial techniques in order to allow users to get information and gain knowledge on a specific topic or process. In the past, research efforts mainly focused on **information visualisation**, i.e. on the development of effective visualisation techniques for abstract data as a function of the data type (e.g., numerical, relationship, hierarchy...). A more recent research area, **visual analytics**, aims at extending the role of visualisation to data analysis. Visual analytics applications include tools for the analysis of spatial and temporal data sets, such as Gapminder (http://www.gapminder.org/), DataPlace (http://www.dataplace.org/), GeoViz

Toolkit (http://www.geovista.psu.edu/geoviztoolkit/), or ESTAT (http://www.geovista.psu.edu/ESTAT/); tools to analyse more abstract information, such as StarLight (http://starlight.pnnl.gov/), Analyst's Notebook (http://www-142.ibm.com/software/products/us/en/analysts-notebook/), or DataMontage (http://www.stottlerhenke.com/datamontage/); as well as tools to follow the flow of a discussion and visualise the arguments proposed by the participants, e.g. DebateGraph (http://debategraph.org) or Rationale (http://rationale.austhink.com/). Recent surveys of the state-of-the-art in visual analytics show how dynamic this research topic is, both in the academic and open source world [Har12] and in professional markets [Zha12]. At the same time, a lot of websites are fully dedicated to discuss and present visualisation examples, software resources and tutorials. A non-exhaustive list includes http://www.visual-analytics.eu/; http://fellinlovewithdata.com/; http://www.floatingsheep.org/; http://www.visualcomplexity.com/vc/; http://flowingdata.com/; or http://www.visualizing.org/.

In the context of spatial analysis and urban modelling, visualisation is mainly used to discover unexpected patterns and relationships among big and often heterogeneous data sets [Yau11] and/or present, evaluate, explore, simulate or play with several facets of the real world [Fuc11, Bim05, Caw08]. The adoption of visualisation and visual analysis methodologies has several benefits, such as facilitating the interpretation of data and the understanding of complex relationships even by non-technical users; evaluating the impact of (a set of) policies in a more effective way; or facilitating the communication between citizens and policy makers.

Traditionally, **geographic visualisation**, or **geovisualisation**, has dealt with the graphical representation of a land area according to a cartographic paradigm. The introduction of Parish maps introduced a different approach, where the geographical elements are not the main features anymore, but they play as the background to map the social, cultural, political, or economic environment of a well-defined place [Per07]. Maps stop being just maps to become services that display other information and create knowledge [Ros12]. Geographic representation has recently received a lot of attention, mainly due to the increasing precision and resolution of geo-referenced data and to new participatory urban planning methodologies. The evolution of GIS and navigation satellite systems has allowed a detailed description of almost every kind of terrestrial environment, leading to very popular services and applications, such as Google Maps and OpenStreetMap, which are helping understand complex phenomena involving both people and the territory they are living in.

Along the last decade, several European projects have begun to integrate geovisualisation and visual analytics into decision support tools for urban and regional policy assessment and collaborative planning. PROPOLIS (http://www.ltcon.fi/propolis/) was one of the first projects that integrated strategic LUTI models and GIS techniques with interactive visual analytics tools, conceived mainly to be used by policy makers for the integrated assessment of land use and transport policies. Several projects recently launched are developing visual interfaces for participatory urban planning: e-POLICY (http://www.epolicy-project.eu/) uses visual analytics components to analyse the results of social simulations, with the aim to inform regional planning processes and present the final conclusions in a form that is understandable for the different stakeholders, through charts, graphs and animated maps; FUPOL (http://www.fupol.eu/) adopts a wider vision aimed at integrating advanced visualisation tools across the entire policy life-cycle and adapting information visualisation to different levels of users' expertise; and UrbanAPI (http://urbanapi.eu/) focuses on interactive visualisations of possible urban planning interventions at different scales, from 3D virtual and augmented reality applications for urban design at neighbourhood scale, to land use simulation at urban and regional scale represented as an overlapping layer on a geographical map or through graphs and charts summarising the main results.

There are also several international initiatives focusing on the collection and visualisation of real-time information on urban dynamics. Two relevant examples are LIVE Singapore! and Ville Vivante. LIVE Singapore! (http://senseable.mit.edu/livesingapore/index.html) aims at creating a set of applications for the collection and distribution of a large number of streams of very different kind of data, such as cell-phone calls and text messages, weather information, or traffic data. Ville Vivante (http://www.villevivante.ch/) is a visualisation project whose main objective is to represent people movements within the city of Geneva through the digital traces created by mobile phones. Other recent works are developing strategies to depict stakeholders' knowledge concerning very specific sites [Fag12, Eis12]; analysing and evaluating the strengths and weaknesses of current GIS tools for participatory governance [McC03, Vos04, McC12]; or investigating how to use Participatory GIS to build a shared vision of local knowledge between different local stakeholders [Rey12].

2.4 Policy design and participatory governance

Collaborative scenario building and policy modelling is a research area focused on the engagement of social stakeholders in policy making. Stakeholders' involvement has several advantages [Ram04, Gil05]: i) it ensures that the problems tackled are relevant for the stakeholders; ii) it raises stakeholders' interest in the topic; iii) stakeholders feel obliged to give feedback to the policy models; iv) it incorporates stakeholders' knowledge about the modelled world; and v) it increases the credibility and acceptability of the conclusions.

Sustainable urban development requires coordinated action in different areas (land use, transport, environment) subject to multi-level, distributed decision processes, from infrastructures and regulation depending on local authorities, to national and European directives. Additionally, urban policies have a profound impact on a wide variety of stakeholders, often with conflicting objectives. Assessing these policies in terms of meaningful indicators and in relation to a set of shared objectives is a challenging task, for which ensuring trust and commitment is as important as providing scientific evidence [Wim11]. The increasing use of the design charrette in urban planning is a response to this complexity [Kwa08]. A charrette can be defined as a policy formulation event that brings together diverse stakeholders to produce policies through collaborative interaction [Con07]. The theory underpinning charrettes is that sustainability requires a holistic integration of all relevant dimensions in a collaborative and interdisciplinary setting [Con09]. Other techniques with a similar approach include brainstorming and buzz sessions, synectic sessions, or take-part workshops [Inn00, San00, Con09]. Recent practical experiences in some major European cities, such as the Madrid Mobility Round Table [Luc10, Luc11], have shown the potential of collaborative processes to increase the quality of policy evaluation and reach consensus on urban policies.

ICT tools for collaborative policy design

ICT has an increasing influence on individual and collective behaviour, and the web is enabling new forms of collective organisation in which opinions are formed and decisions can be tested. The role of ICT in urban policy assessment and governance is therefore not only to support the provision of scientific evidence for public action ('policy informatics'), but also to communicate these scientific evidences, drive societal debates, and facilitate stakeholders' engagement ('societal informatics').

The development of ICT tools for collaborative policy modelling encompasses different research threads [Mis10], including collective data gathering (see e.g. http://www.ushahidi.com/); information management and analysis in order to create shared knowledge for democratic city governance; online social media and e-participation tools (e.g. role-paying games) to gather and visualise data and public opinions, harness collective intelligence (crowd sourcing), and stimulate societal action; or virtual worlds to forecast the societal response to the proposed policy measures. Several FP7 research projects tackling these research threads have recently been launched. Some relevant examples are +Spaces (http://www.positivespaces.eu), which uses social media together with virtual worlds to model real world behaviour; UrbanAPI (http://www.urbanapi.eu/), which addresses the issue of stakeholder engagement in urban planning through the development of virtual reality visualisations of neighbourhood development proposals; IMPACT (www.policy-impact.eu), which seeks to develop computational models to facilitate policy deliberations at a conceptual, language-independent level; OCOPOMO (http://www.ocopomo.eu), which combines e-participation with agent-based social simulation to develop narrative scenarios and transform them into formal policy models; FUPOL (http://www.fupol.eu) and NOMAD (http://www.nomad-project.eu), which aim at developing systems able to automatically collect, analyse and interpret opinions expressed in the Internet; Everyware (http://www.everyaware.eu/), which is combining sensing technologies, networking applications and data-processing tools to enable participatory sensing, develop a shared perception of environmental issues, and drive behavioural changes; or the CSA CROSSROAD (http://crossroad.epu.ntua.gr/), which has produced a roadmap for ICT research in the field of governance and policy modelling.

3. Research challenges and opportunities

The new challenges facing European cities, in many respects different from those faced in the past decades, require a more integrated approach to urban development, able to account for the interrelations and trade-offs between different policy areas. ICT tools for urban planning need to be adapted to this new context. At the same time, this need for adaptation is an opportunity for new emerging technologies to deliver their full potential and contribute to urban prosperity and sustainability. We discuss hereafter the main challenges and opportunities within each of the four main INSIGHT research areas: data integration and analysis, modelling and simulation, visualisation, and integration of ICT tools into policy making processes.

3.1 Challenges and opportunities related to data

Data availability and quality. The calibration and validation of state-of-the-art urban models require abundant and high quality data. Data requirements are not always met, hindering their operational use. GIS are now being integrated with many models, and large scale systems are being developed for new data sources, such as open data initiatives or self-tracing apps employing GPS-enabled smart phones, opening promising venues.

Data integration. Different, heterogeneous data sources, including conventional as well as new ICT-based data sets available in various forms, will have to be coupled into new forms of coherently integrated databases.

Spatio-temporal data analysis. Until recently, most research efforts for the analysis of spatial data had taken a static view. However, as all spatial phenomena evolve over time, temporality is central to our understanding of spatial processes. In recent years, the increasing availability of large sets of data referenced in space and time facilitated by technologies like satellite imaging, cellular phones, or GPS devices, has stimulated a great interest in spatio-temporal data mining. These huge collections of data hide interesting information which classical data mining techniques are unable to discover. The FP7 FET project GeoPKDD (www.geopkdd.eu) was one of the precursors in mining human mobility data and developed various mining methods for spatio-temporal data. Spatio-temporal data mining remains, however, a largely unexplored territory [She11].

3.2 Challenges and opportunities related to modelling and simulation

Adaptation to the European socio-economic landscape. The current generation of urban models was developed in an era when urban growth and sprawl was in the ascendency. We are now facing a wider variety of urban development models, from shrinking cities as Detroit, to fast developments of new metropolis like Songdo or the transformation and regeneration of existing metropolis like Rio de Janeiro. In the case of Europe, it is now clear that the prosperity generated by the 1st and 2nd industrial revolutions has massively slowed and that the recession is having a deep impact on European cities, especially with regard to employment and social cohesion. Other trends include aging, immigration, or the restructuring of the local economies to embrace new varieties of services, in particular ICT-based services. Urban simulation models need to be refashioned to deal with such issues, which are in turn being reflected in changes in transport and spatial interactions.

Integration of sector-specific location models into land use transport interaction models. Most models of housing choice, retail and public services location have been applied in a stand-alone context. The interaction between location patterns and the relationship between long-term decisions (e.g. residential choice) and daily activity-travel patterns have been addressed in a very limited way. Nevertheless, it is obvious that the house and job locations, e.g., act as peg in organising daily activities, while accumulated frustration with daily patterns may lead individuals and households to reconsider their residential situation. These dynamics become particularly relevant under the present financial crisis: not only the activity-travel patterns may change dramatically, but also the uncertainty about the economy and the long-term value of housing may alter the trade-off between long-term and short term decisions. Further work is needed to embed sectoral sub-models into LUTI frameworks and to demonstrate how these new interactions can be successfully handled.

Population synthesisers. Agent-based models require more detailed information than is usually available from surveys or census data [TRB07]. The lack of tools to generate the artificial agent-population is an obstacle for their implementation. Current progress is lowering that hurdle, and 'population synthesisers' are being developed to generate artificial populations statistically equivalent to actual populations [Mül11].

Influence of social contacts on activity-travel patterns. Location and activity decisions are usually modelled as a set of independent decisions across agents. However, intra- and extra-household interactions play a key role in many activities (e.g. leisure trips) and location decisions (e.g. household location choice) that are planned jointly and/or depend on the decisions and location of the social contacts. Recent research has begun to develop the theoretical foundations to incorporate the social context into activity-based models. A key condition is the characterisation of the statistical properties of the underlying social network. The analysis of new data sources, such as online social networks, can complement empirical survey work to help improve the understanding of the interdependencies and co-evolution of the social networks, activity-travel patterns, and urban form.

Multi-level modelling. Urban dynamics exhibits multiple spatial and temporal scales. The increasing sophistication of urban models comes at the expense of computational resources and has serious implications for the calibration and validation of the models, e.g. the need to reduce the number of sensitivity tests to check the plausibility of model behaviour. The identification of the time horizons and spatial resolutions relevant for the analysis of different phenomena and the question of the right level of granularity remain open [Wad09]. In a recent paper [Weg09], Wegener calls for a 'theory of multi-level models', according to which there is an appropriate level of conceptual, spatial, and temporal resolution for each question under investigation.

3.3 Challenges and opportunities related to visualisation

More intuitive, user-specific interfaces. Current visualisation tools are still largely designed for technical experts, limiting the opportunities for a wider user involvement. More intuitive interfaces need to be developed to address the needs and requirements of different communities and achieve a better integration of quantitative and qualitative information.

Real-time interaction and analysis. Big data production rate is growing faster and faster. The analysis capability should keep the pace in terms of effectiveness and efficiency. Real-time interaction and analysis have to be addressed carefully in order to reduce latency [Man12].

Integration between visualisation and analytical functionalities. Geovisualisation is a fast growing area, but there is still little integration with data analysis functionalities. Recent research is tackling the problem of combining data mining tools with iterative visualisation on top of specific geographical representations [Auv07, Moz08, Lan12].

3.4 Challenges and opportunities related to policy assessment processes

Integration of urban simulation into policy making processes. Policy assessment and participatory planning are still largely based on qualitative considerations, and there is a sense among practitioners that LUTI models are immature with respect to institutional integration and operational use [Bra08, Koc09]. The challenge is to integrate state-of-the-art simulation tools in a form that fluidly intersects the multi-stakeholder decision making process [Con09], bridging the gap between implicit and explicit knowledge [Bro10]. The development of these tools needs to be accompanied by new forms of user-model interaction and procedures facilitating stakeholders' participation in the construction and validation of the models.

Transparency and ease of use. Models will not have credibility in controversial domains such as land use, transport, or environmental planning, unless it can be explained in simple terms what they are doing, and why. The term 'black box' has often been used to criticise the lack of transparency. Models must also achieve a threshold of usability that makes it possible for staff within planning agencies to use the model without excessive support. Although there are rapid developments in making urban simulation models more visual and in scaling them down to use in the policy context [Bra08], many sketch planning tools provide simplicity at the cost of sacrificing theoretical soundness and validity. Progress is still needed to conciliate transparency and ease of use with the necessary sophistication required for a realistic modelling of a system as complex as the city.

Professional support. Advanced simulation tools are still in a research and development phase. The lack of professional support is a barrier for many cities with limited in-house capabilities. The situation is beginning to change, and tools are being professionalised in collaboration with various software houses.

4. The INSIGHT project

INSIGHT (www.insight-fp7.eu) is a research project funded under the ICT Theme of the European Union's Seventh Framework Programme. INSIGHT aims to investigate how ICT, with particular focus on data science and complexity theory, can help European cities formulate and evaluate policies to stimulate a balanced economic recovery and a sustainable urban development. The project is conducted by a Consortium composed by the Research Centre for Applied ICTs (CeDInt) (Project Coordinator) and the Transport Research Centre (TRANSyT) at the Technical University of Madrid, Nommon Solutions and Technologies, the Centre for Advanced Spatial Analysis (CASA) at University College London, the Technical University of Eindhoven, the Institute for Cross-Disciplinary Physics and Complex Systems (IFISC) at the University of the Balearic Islands, and the Barcelona City Council.

4.1 Project objectives

INSIGHT pursues the following objectives:

1. to investigate how data from multiple distributed sources available in the context of the open data, the big data and the smart city movements, can be managed, analysed and visualised to understand urban development patterns;
2. to apply these data mining functionalities to characterise the drivers of the spatial distribution of activities in European cities, focusing on the retail, housing, and public services sectors, and paying special attention to the impact of the current economic crisis;
3. to develop enhanced spatial interaction and location models for retail, housing, and public services;
4. to integrate the new theoretical models into state-of-the-art urban simulation tools, in order to develop decision support systems able to provide scientific evidence in support of policy options for post-crisis urban development;
5. to develop innovative visualisation tools to facilitate stakeholder interaction with the new urban simulation and decision support tools and the analysis and interpretation of the simulation outcomes;
6. to develop methodological procedures for the use of the tools in policy design processes, and evaluate and demonstrate the capabilities of the tools through four case studies carried out in cooperation with the cities of Barcelona, Madrid, London, and Rotterdam.

4.2 Approach

The approach that will be followed by INSIGHT relies on six main pillars, which mirror the objectives described in the previous section: i) acquisition and integration of data from multiple distributed sources; ii) data analysis; iii) theoretical modelling; iv) urban simulation; v) policy interfaces and visualisation tools; and vi) case studies. Hereafter we outline the strategy proposed for each of these building blocks.

Acquisition and integration of data from multiple distributed sources. INSIGHT has as one of its cornerstones the integration of massive repositories of traditional and new spatio-temporal data coming from modern ICT. Access to these data is essential for the success of the project. Significant effort has been devoted to ensuring access to a vast amount of heterogeneous data sets. The first source of data will be public databases (land use data, population, socio-economic data, data on economic activities, etc.) that will be available upon request or accessible through open data initiatives. The project will also rely on the involvement of the municipal authorities of Barcelona, Madrid, London and Rotterdam, which will provide more detailed and disaggregated data. The Barcelona City Council is a member of the INSIGHT Consortium, while Madrid, London (through the Greater London Group) and Rotterdam are already collaborating with UPM, CASA-UCL and TU/e, respectively, in other research initiatives. Finally, INSIGHT will explore the potential of new data sources available from smart technologies. We will take advantage of the data collection and integration work being undertaken by IFISC in the frame of the FP7 EUNOIA project (www.eunoia-project.eu), in which several of the INSIGHT partners are also participating. The EUNOIA data, which will be reused to the extent they are also relevant to INSIGHT, include data from Internet social networks, credit card payments, and mobile phone calls. Other potentially useful data sources, such as e-shopping sites, will also be explored.

Data analysis. The data sets will be mined to analyse urban development patterns in Europe, focusing on the interrelations between retail, housing, and public services, and their evolution during the economic crisis. We will analyse how traditional, cross-sectional data sources (e.g. databases on the geographic location of economic activities) can be blended with new data sources (e.g. electronic transactions) to uncover location and activity patterns at different spatial and temporal scales. We will focus on Madrid, London, Rotterdam and Barcelona, which will allow a comparative analysis of cities with different geographical, political, institutional, socio-economic, and cultural characteristics, helping discern between local and general basic features. To extract knowledge from the data, INSIGHT will make use of exploratory data analysis, spatial statistics and data mining methods, and spatial analysis methods recently developed in the context of network theory (spatial networks). Classical approaches aimed at the analysis of spatial data from a static viewpoint will be combined with techniques for the analysis of the temporal dynamics. Relevant issues are the representativeness of the new data sources, or the development of spatio-temporal data mining methodologies able to uncover mechanisms that operate at different scales. Examples of the questions that will be explored are the clustering between different activities and the coupling between location decisions; the spatio-temporal propagation of the financial crisis across the housing market, the downturn of the real economy, the fiscal crisis and the subsequent cuts in public services, and the feedforward and feedback mechanisms therein; or the analysis of the spatial conditions that created the breeding ground for the emergence of innovation poles in certain locations, e.g. East London Tech City.

Theoretical modelling. Until recently, urban models have been based on thinking of the city as a static system. The emergence of new spatio-temporal data sets and the recent advances in complex systems theory and computational modelling offer a unique opportunity to develop an improved theory of cities that captures the complexity of urban dynamics. The approach adopted by INSIGHT aims at combining data-driven modelling with explanatory theories anchored in complexity science. First, we will build on the results of the data analysis to devise, test and validate behavioural and local interaction rules aimed at improving location models for the retail, housing, utilities and public services sectors and making them more sensitive to the current European urban context. We will model the coupling between the three sectors and incorporate the effects of the financial crisis. In a second step, we will model the interaction between location decisions and daily activity-travel patterns, with a view to develop the theoretical basis for the integration of these sector-specific models into large scale land use transport interaction models.

Urban simulation tools. The new theoretical models will be integrated into comprehensive, state-of-the-art urban simulation tools. INSIGHT will adopt an eclectic approach, aimed at further developing a variety of tools based on different modelling paradigms. We will evolve several simulation tools currently being used and developed by Consortium members, in particular the agent-based models Albatross [Are05, Tim11], developed and implemented for Rotterdam by TU/e, and MATSim (http://www.matsim.org/) and UrbanSim (www.urbansim.org), which are being implemented for Barcelona by Nommon; as well as the more parsimonious models SIMULACRA (http://simulacra.blogs.casa.ucl.ac.uk/), a model of London developed by CASA-UCL, and MARS [Pfa08], a system dynamics model which UPM has implemented for Madrid and is currently coupling with a cellular automata model. Our strategy stems from the conviction that there is not a 'one size fits all' modelling framework for all kind of problems, but a set of modelling approaches with the potential to enrich our understanding or urban systems from different perspectives.

Policy interfaces and visualisation tools. INSIGHT will aim at involving policy makers and other social stakeholders from the initial stages of the project, with the purpose of reinforcing the credibility and usability of the models and fostering their application in policy decision contexts. The consultations and discussions with stakeholders will be used to derive requirements for the development of user-friendly visual interactive interfaces and data representations enabling analytical reasoning and interpretation of the simulation results, and will help construct a methodology for collaborative assessment of urban policies supported by the demonstrative simulation and visualisation tools developed by INSIGHT.

Case studies. The tools developed by INSIGHT will be evaluated, refined, and validated through the case studies of Madrid, London, Rotterdam, and Barcelona. The case studies will encompass a variety of policy decisions related to urban development, such as those involved in land use, transportation, or environmental planning, in order to carry out a comparison of the advantages and disadvantages of different modelling approaches to tackle various types of policy questions. The focus on four rather different cities will display a variety of urban forms, providing a good basis for comparisons elsewhere. Taking advantage of the direct involvement of the City Council, the Barcelona case study will also serve to explore the use of newly developed tools in participatory policy formulation events. Experience of similar stakeholder involvement processes in which CASA-UCL is involved for the GLA in London will be available for comparison.

4.3 Target outcomes and expected impact

Scientific and technological impact

New methods for the collection and analysis of urban data. The project will adopt an eclectic approach, collecting, integrating, fusing, and analysing a broad range of large-scale data sets. Though recent work has begun to explore the use of alternative data sources (e.g. credit card payment, mobile phone calls, Internet social networks) for the characterisation of land use and transport patterns in cities, INSIGHT is one of the first projects that will merge these data sources and will combine them with more conventional, cross-sectional data to study location and activity patterns in cities. New methods for spatio-temporal data mining will be developed, allowing the identification of patterns at multiple spatial and temporal scales.

Improved understanding of location patterns and urban development. INSIGHT will broaden the knowledge of the ultimate causes underlying urban location and activity patterns. In particular, it will provide new insights into the relationship between the different urban activities and the evolution of the urban morphology. INSIGHT will look closely at the positive and negative synergies between different types of services and activities, with a strong focus on the way these patterns are affected by the financial crisis and socio-economic trends such as aging or migration. Location and activity patterns in different cities across Europe will be compared in order to discern between local (city-specific) and universal features. INSIGHT will also develop new sustainability indicators based on the mix of land uses and availability of services, as well as leading and lagging indicators evidencing changes in the urban form, such as the deterioration of an area or the emergence of new economic activities.

Improved urban simulation models. The knowledge obtained from the analysis of the large and varied data sets available to the project and the integration of improved sector-specific models will allow the development of more realistic land use-transport interaction models. The resulting simulation and decision support systems will be able to address questions that are still not well understood today, and will be better suited to tackle the new challenges of sustainable urban development. The modelling of the interactions between the retail, housing and public services sectors and their influence on land use will improve our understanding of the conditions triggering the emergence of different urban patterns and activity clusters, thus helping grasp the more suitable policies to foster sustainable development paths.

Increased take up of open and public data for provision of public services. The models developed within INSIGHT will demonstrate how public data (either in isolation or blended with other public and/or private data sources) can be used to develop improved urban models enabling better policy choices. INSIGHT will also show how these data can be exploited to characterise the demand for public services and optimise their location and dimensioning. We expect that the results of INSIGHT will contribute to prove not only the enormous potential of open and public data for the planning of public policies and services, but also their value for households and private firms, thus unleashing new technological developments aimed to create value-added services.

New visual analytics and visualisation tools. INSIGHT will develop new tools for data exploration and analysis, which will be seamlessly integrated with data mining and simulation to take advantage of the synergies between the three areas. Visual analysis will suggest specific hypotheses that will be tested through data mining techniques; data analysis will inspire new modelling and simulation approaches, whose results will in turn be analysed in an intuitive and graphical way by means of visual analytics tools.

Impact on policy and governance

Integrated, holistic approach to urban development. The approach adopted by INSIGHT, and more specifically the modelling of the interactions between the different sectors, will contribute to advance towards an integrated and cross-sectoral approach to urban planning.

Reduction of the barriers for the use of state-of-the-art simulation models in policy making. The development of an integrated visual ecosystem supporting intuitive user interaction with the new urban simulation and decision support tools will facilitate the interpretation and communication of the results of simulating a specific policy scenario, contributing to overcome the current gap between 'sketch' planning tools (simple, easy to use, visually appealing, but often suffering from the lack of a solid theoretical basis) and state-of-the-art urban simulation tools (highly sophisticated and more suitable to capture the complexity of urban systems, but often difficult to understand and use in policy making contexts). User requirements will be collected through consultations and especially through the participation of the municipal authorities of Barcelona, London, Madrid and Rotterdam as end users.

Better links between modellers and stakeholders, and new methodologies for collaborative policy assessment and multilateral governance processes. INSIGHT will develop new methodologies for science-driven, collaborative, multi-stakeholder policy analysis. Building on state-of-the-art approaches in collaborative policy modelling, as well as on recent practical experiences of multi-stakeholder assessment of urban policies in different European cities, INSIGHT will put in place an interactive learning process between the model developers and the planning practitioners, which will lower the barriers posed by discipline-specific languages and will facilitate the integration of the new simulation and decision support tools into participatory decision making processes. The working sessions carried out in collaboration with the Barcelona City Council, which will bring together modellers, policy makers, and stakeholders related with urban planning, will yield new insights into the problems faced by diverse stakeholders, their needs and expectations, and the most effective means to get them involved in policy modelling and articulate policy deliberation. The working sessions will focus on the conception and demonstration of new methodologies for better integration of scientific knowledge into processes of collaborative analysis of urban policies.

Regeneration of urban areas. The objective of land use policies is not only to develop new areas, but increasingly also to renew and regenerate dysfunctional areas. The success or failure of such policies may be related to how well we can answer the question of what is the most propitious environment for the emergence of a certain mix of economic, cultural or social activities, and how this emergence can be boosted by a certain combination of policies; as well as the question of which activities are most likely to emerge considering the human, social, cultural and economic capital of a particular city. The models developed by INSIGHT will contribute to answering these two fundamental questions.

Increased efficiency in the provision of public services. The enhanced understanding of the evolution of location patterns and their interaction with daily activity-travel behaviour of different social groups will enable a more efficient and balanced dimensioning of public services.

Impact on innovation and competitiveness

Increased profitability of private business. The location models developed by INSIGHT will provide a strong evidence of the productivity gains derived from the association of particular types of activities, and will help private firms identify and quantify potential market opportunities. The access to this information can also have a positive impact on the confidence of new investors, helping overcome their reluctance to invest in certain urban areas particularly affected by the current economic crisis.

Development of innovation poles. Many publicly-driven attempts of creating innovation poles in certain areas have failed, often due to a centralised, top-down planning approach that has ignored the complexity of urban development patterns and the specificities of the local socio-economic and cultural characteristics and human capital. INSIGHT will help understand the proper conditions for the emergence and survival of innovation poles, thus contributing to the design of better strategies, combining top-down and bottom-up perspectives, to stimulate innovation and sustainable economic growth.

Commercial exploitation of the project results. The smart city concept offers a coherent vision for bringing together innovative solutions that address the issues facing the modern city, but there are many challenges still to be faced to define a consistent business model. Notwithstanding, there is a growing consensus among the industry that smart city technologies will offer exciting market opportunities in the decade ahead, as proven by different market forecasts and also by the fact that many of the world's most successful ICT companies, such as IBM (http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview/index.html), are extending their strategy to include the development of products and services for smart cities. Although most current applications address issues like utilities management or traffic control, the focus is now widening to deal with more strategic functions, such as those addressed by INSIGHT.

Impact on society

The different impacts on science and technology, policy and governance, and innovation and competitiveness described above will ultimately revert to society through new products and services, better public policies and new and more efficient public services, contributing to the goal of a achieving a **holistic and integrated model of city development that is economically efficient, socially inclusive and environmentally sustainable**.

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