Global Systems Science and Urban Development

March 2013
Executive summary

The rapid urbanisation of world population and the increasing interconnection of cities across the world create new opportunities for urban development, but also introduce challenges that require new policies and measures. Global System Science (GSS) intends to address these challenges and opportunities from an integrated and holistic perspective, making use of methods and tools from data science and systems thinking, as well as new ICT tools to engage collective action. In order to define a research agenda in the area of GSS and urban development, at the end of 2012 the European Commission DG CONNECT and the FP7 project EUNOIA launched a number of consultations, including a workshop held on 13-14 February 2013 in Brussels that brought together a group of about 25 researchers, practitioners and policy makers. This report is the outcome of the reflection process.

The report first presents the concept of Global Systems Science. Then the implications of globalisation and of the pervasiveness of ICT for urban dynamics are discussed, and an overview of the challenges and competing forces associated to urban development in the 21st century is presented, both from an intraurban and an interurban perspective. These challenges include managing demographic changes and new societal trends, combining competitiveness in the global economy with urban diversity, ensuring the sustainability of urban ecosystems, adapting to the transition from the centralised systems of the industrial age to the distributed systems of the information age, exploiting the opportunities offered by ICT while avoiding a new alienating coupling between machines and society, or developing new governance structures and empowering citizens to achieve a better matching between global/societal needs and individual needs.

The two main paradigms included within the concept of Global Systems Science, policy informatics and societal informatics, are also addressed. The report outlines the different roles of models, from scientific explanatory models to predictive models for policy design (policy informatics). It then discusses the use of models for participatory planning and governance, and discusses the new opportunities opened by ICT for citizens’ engagement (societal informatics), including new trends like participatory sensing, gamification and social computation activities.

Building on the identified challenges for urban development and the potential of GSS to contribute to addressing these challenges, we identify a number of research threads related with data integration and analysis, modelling and simulation, social computing and collective awareness, and policy making and participatory governance, presenting some relevant research questions within each of these four areas. The report concludes with a discussion of the expected impacts of a research programme on GSS and urban development, and some practical considerations about the implementation strategy for such a programme.
Contributors

This report was compiled by the EUNOIA Consortium. We would like to thank all the contributors providing inputs and feedback either as participants in the workshop organised in 13-14 February 2013 in Brussels by EUNOIA and/or through written comments.

Rudiger Ahrend  OCDE - Regional Economics and Governance
Lisa Amini  IBM Research
Ricardo Baeza-Yates  Yahoo! Labs
Pedro Ballesteros  European Commission - DG ENERGY
Marc Barthélemy  CEA-IPhT
Michael Batty  University College London - Centre for Advanced Spatial Analysis
Ralph Dum  European Commission - DG CONNECT
Oliva García-Cantú  Nommon Solutions and Technologies
Sylvain Haon  POLIS
Colin Harrison  IBM
Christian Heimgartner  City of Zurich
Ricardo Herranz  Nommon Solutions and Technologies
José Lobo  Arizona State University
Vittorio Loreto  Sapienza University of Rome and ISI Foundation
Antonio Lucio  Independent Consultant
Peter Nijkamp  Vrije Universiteit Amsterdam
Denise Pumain  CNRS
José Ramasco  IFISC (CSIC- University Balearic Islands)
Maxi San Miguel  IFISC (CSIC- University Balearic Islands)
Alex Serret  City of Barcelona
Frédéric Sgard  OECD - Global Science Forum
David Simmonds  David Simmonds Consultancy
Folke Snickars  KTH Royal Institute of Technology
Christian Svanfeldt  European Commission - DG REGIO
Joan David Tábara  Autonomous University of Barcelona & Global Systems Dynamics and Policy
Luis Willumsen  University College London & Luis Willumsen Consultancy
Table of contents

1. PURPOSE, SCOPE AND OBJECTIVES .................................................................................. 1

2. URBAN DEVELOPMENT CHALLENGES ........................................................................... 2
   2.1 GLOBALISATION AND URBANISATION ....................................................................... 2
   2.2 CHALLENGES FOR URBAN DEVELOPMENT IN THE 21ST CENTURY ......................... 3

3. CONCEPTS AND METHODS ............................................................................................. 6
   3.1 POLICY INFORMATICS: MODELS AND DATA ............................................................... 6
   3.2 SOCIETAL INFORMATICS ............................................................................................ 9
   3.3 COMPLEMENTARITY BETWEEN SOCIETAL AND POLICY INFORMATICS ...................... 10

4. RESEARCH CHALLENGES AND OPPORTUNITIES ......................................................... 11
   4.1 DATA INTEGRATION AND ANALYSIS .......................................................................... 11
   4.2 MODELLING AND SIMULATION ................................................................................. 12
   4.3 SOCIAL COMPUTING AND COLLECTIVE AWARENESS .............................................. 15
   4.4 POLICY MAKING AND PARTICIPATORY GOVERNANCE ............................................. 15

5. EXPECTED IMPACT AND IMPLEMENTATION STRATEGY ............................................... 17
   5.1 EXPECTED IMPACT ....................................................................................................... 17
   5.2 IMPLEMENTATION STRATEGY ...................................................................................... 17
1. Purpose, scope and objectives

Globalisation and the resulting increase in interconnectedness and interdependence of people and nations create new opportunities, but also new challenges that require policies and measures at a holistic level. Global System Science (GSS) intends to address in an integrated manner the increasingly global and interconnected nature of challenges facing humanity, with the aim to provide scientific evidence in support of policy options. Pertinent elements of GSS in this context are:

- the capacity to gather, integrate and correlate large amounts of 'Big Data';
- the modelling and simulation of large socio-technical systems;
- the interaction with policy makers and society at large;
- the use of modern ICT to engage collective action.

GSS will focus on a few selected areas, urban dynamics being one of them. The term ‘global urban systems’ means considering urban problems at an integrated scale taking into account many aspects of urban life and urban knowledge, with particular focus on the impact of ICT on cities and their dynamics.

To address these questions, the European Commission DG CONNECT and the FP7 project EUNOIA launched a number of consultations, including a workshop held on 13-14 February 2013 in Brussels that brought together a group of about 25 researchers, practitioners and policy makers. This report is the outcome of that reflection process. The objectives of this report are:

- to analyse the major scientific challenges associated to urban development from a GSS perspective;
- to identify the role that ICT could play in such context in order to develop policy modelling tools and bridge the gap between modellers, policy makers and societal actors;
- to contribute to the creation of an interdisciplinary research community at the intersection of urban planning, ICT and complex systems science, able to formulate innovative approaches to the challenges facing urban development in the 21st century;
- to provide inputs for the European Commission to develop a research agenda in the field of 'Urban Development and Global Systems Science', with a view to include this thread in the future Horizon 2020 work programme. The results of the workshop will be reflected into an Orientation Paper for GSS research in Horizon 2020.
2. Urban development challenges

2.1 Globalisation and urbanisation

It is now estimated that over 50% of world population is living in urban areas, with a yearly growth rate of about 2%. By 2100, the world’s population will be almost entirely urban and will have probably peaked at around 9-10 billion persons. There will be more people, unevenly distributed across the world, and migration will become the predominant mode of population change.

Cities and global challenges

The global challenges of economic recovery, poverty eradication, environmental sustainability, climate change, or sustainable and secure energy, are all intimately and intricately linked to cities. The implementation of solutions to these challenges will, to a very large extent, be implemented in cities around the world. The issue of sustainability, which is now on top of the political and societal agenda, has a strong urban dimension, increasingly important as the world becomes more urban. Urbanisation is unfolding, and wealth is being concomitantly created, but urbanisation might not be occurring in a sustainable and resilient way. There is a need for an integrative analytical framework that can facilitate the design of policies promoting resilient and sustainable urban development.

The pervasiveness of ICT: impact on spatial dynamics

The pervasiveness of ICT and the coupling of the real world with the virtual (digital) world are having an impact on spatial dynamics, e.g. changing microspatial dynamics, which is having a profound impact on location and activity patterns in cities.

ICT and globalisation: world cities

In the coming years, most cities will be somehow locked into the global economy if only through the fact that their populations will engage in accessing information which is non-place related and somewhere in the cloud. In this sense, all cities will be world cities, which will have strong implications in terms of their economies, trade, specialisation, or polarisation of communities. There will be a new kind of urban dynamics through access to ICT and through new migration streams. Cities’ global connections raise an entirely new set of issues. What this will do to cities and urban planning is largely unknown, but the need to think globally in space and time will be essential.

Smart cities

Most smart cities work is what we call intra-urban rather than inter-urban, except of course that the larger and the more global the city, the more likely it is to be involved in new ICT. Cities can be studied from many different vantage points with respect to ICT, such as embedding ICT into cities, big data and real time sensing, urban services optimisation, longer term transportation and land use modelling and forecasting, or digital participation. The list is endless. Particularly interesting are new kinds of short term dynamics which come out of real-time big data, sensing, and integrated databases and that are likely to provide new kinds of longer term data about cities in due course.
The economy of cities

New kinds of economic data and the new ways in which economies operate in a global world have a major impact on cities, particularly through markets. A new push for an economy of cities is needed in terms of understanding how markets are being structured using real time and online data. Capital markets are a key issue here, as well as the flow of global capital into different places.

2.2 Challenges for urban development in the 21st century

In the short and medium term, cities are facing the major challenge of overcoming the current financial and economic crisis and emerging stronger from it. As a result of the financial crisis of 2008 and the subsequent economic recession, 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. In the long term, cities are also facing other structural challenges, such as globalisation, climate change, pressure on resources, migrations, and demographic change. Some challenges are shared by cities from developed and developing countries across the world, but there are also specific factors depending on geographical, structural, political, institutional, socio-economic, or cultural differences at different scales (city, country, region, etc.) that must be taken into account. The main challenges for urban development in the 21st century derive from contradictory trends and forces that are difficult to reconcile.

Managing demographic changes

Cities will have to manage an increasing longevity and declining fertility in developed countries, and fast demographic growth in developing countries. Cities will have to adapt to changing family structures and migration, and be able to exploit the potential of socio-economic, cultural and generational diversity (e.g. the economic and social value of the activities of the elderly) as a source of innovation and progress.

Converting quantitative growth to qualitative improvements

Developing countries will have to manage rapid economic urban growth. Developed countries must face shrinking demography and lowering rate of economic development: the links between economic growth, employment and social progress are weakening, the cuts in public budget are having a strong impact on the welfare state, and 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. Both in developed and developing countries, there is a need to find more effective solutions to ensure the provision of essential services and to face rising urban rents and land prices while avoiding social polarisation and segregation.

Combining competitiveness in the global economy with geographical diversity

Cities will have to reconcile competitiveness in a globalised world with sustainable local economies by developing key competences and resources. The challenge is to improve the quality of urban life and urban environment by sharing emerging solutions at worldwide level, while preserving the geographical diversity of urban systems (in terms of size, economic specialisation, architecture, culture, etc.), which is essential to maintain and develop urban dynamics.
Ensuring the sustainability of urban ecosystems

There is overwhelming evidence that the current organisation of our economies and societies is seriously damaging biological ecosystems and human living conditions in the very short term, with potentially catastrophic effects in the long term. In addition to the challenges posed by energy scarcity and climate change, cities shall be able to organise urban sprawl while mitigating growing pressures on local ecosystems. 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. 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 developed countries, and increasingly since the advent of the economic crisis, many urban planners are advocating a shift in the 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.

Transition from industrial age centralisation to the distributed systems of the information age

The core principles of the industrial age were the concentration of the means of production; defined products and services based on historical demand; the distribution of these products and services to an anonymous group of consumers; and the combination of these capabilities by consumers to best meet their needs. Though there were good reasons in the past for employing this model, a key shortcoming is the disconnection between the design and production of the capability and the actual needs of the consumers. In the age of information we have new ways of providing complex capabilities, new levels of education, and new methods of capital allocations. Across many domains, e.g. media, electrical utilities, and manufacturing, the industrial model is breaking down: broadcast media give way to self-selection; electrical utilities realise the need to understand and influence consumer behaviour, while consumers implement distributed generation for sustainability and resilience; and 3D printing enables individuals and small companies to design and produce complex mechanical devices. Perhaps the greatest failure of the industrial model has been in transportation, where the private car has largely displaced public transportation. In the coming decades there will be significant changes that we may not be fully prepared to face, e.g. the change in the nature of car ownership, with the advent of autonomous driving vehicles procured, rather than owned, via organisations like ZipCar, weakening our emotional attachment to driving and raising new questions such as the role for public transport. Cities will need to be more agile as they are confronted by global challenges, which will make it necessary for both public and private institutions to develop new forms of governance and management thinking.

Managing new ICT-driven forms of spatial organisation

The emergence of new social media and electronic communications are providing more and more access to distant information and replacing sense of place and proximity by sense of connectivity, leading to profound social and behavioural changes and modifying location and activity patterns in cities (more distributed work, new sense of communities, etc.).
Exploiting the opportunities offered by ICT while avoiding a new alienating coupling between machines and society

Exploiting new sources of big data will change the way we plan and monitor cities. ICT systems will improve information processing at citizen level and enable new forms of planning and governance, but they can also orient towards more control. The challenge is to make best use of this opportunity while avoiding risks such as threats on confidentiality and privacy, addiction, or dehumanisation through machine use, especially in public urban space.

Adapting governance structures and empowering citizens to achieve a better matching between global/societal needs and individual needs

There is a tension between existing and future needs and demand from the city users and inhabitants and emerging constraints (physical, environmental, social, economic, etc.). For instance, city dwellers request more space in and around their housing (hence sprawling), while transport or energy constraints push towards more compact cities. A lot can and must be done from the technological and policy making perspective, but it is only when people become fully aware of their actual environmental conditions and their future consequences that the much needed change of behaviour will truly happen, which requires adapting governance structures for the empowerment of urban areas and facilitating widespread citizen participation.
3. Concepts and methods

GSS combines two different, yet complementary paradigms:

- the provision of scientific evidence for public action: ‘policy informatics’; and
- the use of ICT to communicate these scientific evidences and facilitate stakeholders’ engagement: ‘societal informatics’.

3.1 Policy informatics: models and data

When studying entities as complex as cities, we face three fundamental, intermingled problems:

- 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. Cities can be seen as very large sets of interactions over many layers, including the topography of the city; the fixed resources within the region (arable land, minerals, aquifers); the renewable resources (air, water, soil, vegetable and animal life); the built environment (major infrastructure, housing, workplaces); the public and private capabilities (government, public safety, healthcare, utilities, education, transportation, industry, commerce, entertainment); and the living systems by which each inhabitant or visitor conducts his or her own life, thereby creating the social and economic systems. The spatial scales for these layers range from one meter to several kilometres, and the timescales range from a few seconds to several decades;
- the limited understanding of urban dynamics makes it difficult to anticipate the impact and unintended consequences of policy action. The interdependencies within each layer and between layers, in many cases not yet fully understood, may have crucial bearing on the sustainability and resilience of the city;
- 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 and/or contradictory objectives.

The role of modelling

Urban models are mathematical representations of the ‘real world’ that describe, explain, and forecast the behaviour of and interactions between different elements of the urban system. Models serve various functions, which can help address the three abovementioned fundamental problems:

- in a scientific explanatory role, models allow a better understanding of urban dynamics;
- in a predictive and policy design role, they enable virtual experimentation, providing evidence of the impact of new policies;
- in a narrative and deliberative role, 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.

Each of these three purposes probably requires different types of models, but at the same time different types of modelling approaches can mutually inform and enrich each other. We believe that GSS should adopt an integrative and pluralistic approach, encompassing the three purposes of models described above. Recent advances in areas such as network theory, and more generally the intrinsically holistic and eclectic approach advocated by complexity science, appear as a suitable
theoretical 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.

**Scientific explanatory models**

There is a general recognition that cities, regardless of their size, geography, time or culture, share many underlying organisational, social and economic characteristics, and play similar functional roles. A citizen of New York City will quickly understand how Tokyo works. Arriving in Tenochtitlan (today’s Mexico City) in 1519 as part of Cortes’ invading army, Bernal Diaz del Castillo famously described the city as spectacular for its scale (about 200,000 people, one of the largest cities of the time) and wealth. But perhaps the true surprise should have been — given its independent development from old world cites — how familiar it all was, in terms of its roads and canals, its public buildings and neighbourhood organisation, and its markets and social life. The same could be said of many travellers, emissaries and historians encountering (to them) new cities in (to them) strange locations. There is a sense in which human settlements of ancient Mesopotamia and of modern nations share enough features that the term ‘cities’ can be used to meaningfully refer to entities separated by thousands of years of cultural, social and technological development. All of this suggests (but only suggests) that the functional role of cities in human societies, as well as some of the general aspects of their internal organization may be ‘universal’: they may be expected to develop and evolve independently, and display similar dynamics regardless of socio-temporal and locational specificities. The endeavour to discover broadly general empirical regularities of urban life is relatively new but increasingly possible given the growing availability of more and better data, and a growing interest in developing a truly multidisciplinary and scientific understanding of urbanisation.

One approach to building a theory of cities and urbanisation takes the self-similarity of cities as its starting point: the hypothesis of urban scaling. In its strongest form it states that essential properties of cities in terms of their infrastructure and economy are functions of their population size in a way that is scale invariant and that these scale transformations are common to all urban systems and over time. Any urban system is ultimately rooted in material resources derived from food, energy and other basic materials but it is the connection of these many (smaller) settlements with larger cities that drives the system as a whole to greater resource and economic efficiency and productivity, and permits increasing returns to the population scale of large cities in terms of innovation and wealth creation. These are ultimately the reasons why cities exist and can continue to grow. Yet we still don’t have simple, out-of-equilibrium models that describe satisfactorily the evolution of a city and extract generic features and stylised facts.

Another line of progress in academic modelling has been the move from simpler aggregate equilibrium models to highly disaggregated models. 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. Transport models, for example, have moved from aggregate trip based models to disaggregate discrete choice models and more recently to activity-based microsimulation models, utilising the exceptional flexibility of microsimulation frameworks and the increasing availability and affordability of computing power.
Predictive models

Decision makers need reliable facts to take decisions. In many situations in which decisions cannot be taken upon experiences with similar applications in other places, modelling can be a useful instrument to forecast the impact of different policy alternatives. However, despite the significant progress made on the scientific track, our forecasting ability has not improved much. Many researchers in systems science contest whether people can be modelled in a meaningful way. If we aspire to relevance in the real world, we must assume that our models will be imperfect in many ways, which will require caution and specific expertise in how we interpret our results. Forecasting is in many aspects different from explanatory modelling. Where is the limit of modelling for practical forecasting purposes? Was Alonso right that simpler models can be as good as or even better than very detailed and disaggregated models for the purpose of forecasting? It is surprising how little evidence has been gathered to answer this question.

One of the key elements is the accuracy of the input data, which often implies estimates about the future. If the future is going to be very different from the past, then this future “data” is likely to be much less accurate than current expectations. On the other hand, the emergence of big data is opening new avenues. In the frame 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. In contrast with hard science, historically we have been heavily restricted in the experiments we could undertake on cities, and have had to rely on models based on very small samples complemented with partial theories of behaviour and assumptions about the permanence of behavioural traits over time. Tomorrow, we will be able to micro-track the effect of spontaneous experiments — fare adjustments, strikes, infrastructure closures, flooding, etc. — and achieve deeper learning from interactions with volunteers. With very large samples at nearly no collection cost (processing and analysis is another matter) we will have, for the first time, detailed longitudinal data. The first uses of this rich database are likely to adapt it to the needs of current models, including agent-based models. However, the type of models that make the best use of this fertile data source could be different from the current trends, at least for short and medium term and for pragmatic forecasting purposes.

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. The (sometimes contentious) relationship between theorising and empiricism, between model building and data collection, between explanatory and predictive modelling, has long animated discussions among epistemologists, philosophers of science and scientists themselves. We see an abundance of data as a necessary but by no means sufficient condition for developing a thorough understanding of a phenomenon, and advocate an integrative approach based on a fruitful interaction between data analysis and theoretical modelling. But it remains to be seen whether the explosion of available data and new forms of data analysis will inform the development of better urban theories or the scientific and forecasting modelling streams will not only not converge, but diverge further.
Models for participatory planning and governance

Cities will only be truly smart if the 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 many other areas, like land use planning, the potential of urban models is still largely unexploited. Particularly relevant is the issue of participatory planning and governance: while contemporary trends in urban planning — such as transactive planning, advocacy planning, bargaining or communicative planning — aim at integrating a plurality of interests and an active public engagement, it is a fact that there is not much use of models in participative mode (except in some enlightened examples), and in many cases, the potential users do not have the skills to use such models or are not convinced of the benefits.

The use of models in collaborative planning needs a fresh way of thinking. The development of the models needs to be based on a continuous dialogue between modellers and policy makers. New forms of information visualisation and visual analytics, which can make model results more accessible, can help lower these barriers. Finally, ICT enables new ways of citizens’ engagement, by capturing 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 multi-stakeholder policy assessment and collaborative decision making processes in which societal actors collaborate with experts in the generation and analysis of urban policies, bringing together and exploiting the synergies between policy informatics and societal informatics.

3.2 Societal informatics

ICT opens the door to the development of new ways of citizens’ engagement in the design and planning of their cities. New scenarios are now possible in which active citizens can help gathering sensible data through participatory sensing and social computation activities, with the twofold purpose of: (i) stimulating individual and collective awareness and learning; and (ii) providing relevant inputs for data analysis, modelling and decision making.

ICT for participatory sensing

ICT can support informed action at the hyperlocal scale, providing capabilities for environmental monitoring, data aggregation, and information presentation. The goal is to enhance knowledge, understanding and social awareness about urban habitats through the use of ICT tools deployed to gather user-generated and user-mediated information from web-based and mobile sensing devices. The possibility to collect digital fingerprints of individuals is opening tremendous avenues for an unprecedented monitoring at a microscopic level of collective phenomena involving human beings. We are thus moving very fast towards a sort of a tomography of our societies, with a key contribution of people acting as data gathering ‘sensors’.

Web-gaming, social computing and internet-mediated collaboration

In the last few years the web has progressively acquired the status of an infrastructure for social computing that allows researchers to coordinate the cognitive abilities of users in online communities and steer the collective action towards pre-defined goals. This trend is also triggering
the adoption of web-games as a laboratory to run experiments in the social sciences and whenever the peculiar human computation abilities are crucially required. Potential areas of interest include:

- Spatial games (related to traffic, mobility, coordination, etc.). These games/experiments are aimed at investigating how people explore geographical spaces and use geographical information in a way that is meaningful and culturally appropriate for them. Specific tasks can include coordination, exploration, cooperation, and annotation. At the same time these games/experiments allow the collection of information about how people perceive their environment, which can be organised in layers (e.g. traffic or pollution in urban environments, social interest, landmarks, etc.) and made available through interactive visualisation tools in order to facilitate informed decision-making.

- Citizen games. Interesting activities here include the development of new tools for the sustainable management of natural resources (in particular for marginalised communities) and good practices for recycling, food management, mobility, energy consumption, etc.

**Collective awareness and decision-making**

The access to both personal and community data collected by users, processed with suitable analysis tools and represented in an appropriate format, has the potential of triggering an improvement of collective social strategies. By providing personally and locally relevant information to citizens, i.e., related to their immediate locality rather than to the city or region in which they live, one can induce changes in individual behaviour and pressure on policy makers. The key idea here is that fostering awareness will stimulate fundamental shifts in public opinion, contributing to more sustainable behaviour, and will stimulate bottom-up participation, by collecting public opinions and perceptions in a trusted way and orienting the democratic processes of decision making.

**Learning**

Learning is at the basis of our ability to construct models of our reality and take decisions. The societal challenges of our highly interconnected and rapidly changing world call for an increase of the number of people that are educated and capable of using the technologies that will sustain large human societies safely and prosperously. ICT tools can be used to generate new concepts and innovative learning schemes through which this much needed breakthrough can be obtained.

**3.3 Complementarity between societal and policy informatics**

In social phenomena, behavioural and cognitive aspects, as well as the way humans take decisions, are key ingredients that have to be taken into account in order to make sensible predictions. It is thus crucial to deepen our understanding of the causal link between the level of the individual and the emergent collective phenomena. In order to do this, one has to parallel the monitoring of emergent phenomena in social dynamics with the investigation of the behavioural and cognitive foundations of such dynamics. The possibility to collect relevant and capillary data about human urban activities can stimulate the development of data-driven modelling schemes integrated in ICT-based infrastructures for an empirical, computational and theoretical approach to social dynamics processes.
4. Research challenges and opportunities

Globalisation raises a set of issues, both at intracity and intercity level, which are in many respects different from those faced in the past decades. These issues require new models and tools, as well as more integrated approaches to urban development. At the same time, this need for adaptation is an opportunity for new emerging technologies to deliver their full potential and contribute to the more liveable, resilient and sustainable cities. We discuss hereafter the main challenges and opportunities associated to the different research threads relevant to GSS, organised in four research areas:

- data integration and analysis,
- modelling and simulation,
- social computing and collective awareness, and
- policy making and participatory governance.

4.1 Data integration and analysis

Data availability and quality

The calibration and validation of urban models require abundant and high quality data. However, data requirements are not always met, and modellers usually have to operate in a data-poor environment, despite the wealth of information now available. The proprietary nature of certain information about urban services (e.g. on water or energy consumption) limits access to data. There are also potentially useful data belonging to other types of companies, e.g. phone companies, banks, or online social networks, which need to be engaged in the study of cities and in the benefits derived from granting access to their data. 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 that need to be further explored. An open data policy, and in general a simpler access to data, can boost urban research and enable innovative ideas.

Relevant issues related to data collection are:

- The way data collection means and system interfaces bias the data we collect.
- Privacy issues. The resolution of many data sources can go down to the single individual. Most of the time, this resolution is not needed for the question under investigation, so data can be anonymised and aggregated retaining only those aspects that are important.
- Coherence and harmonisation. The format of data also varies across jurisdictions and operational domains, and many indicators relevant to urban systems have yet to be agreed upon and established at a system-wide level.

Data filtering and integration

For many problems we don't need big data, but the right data. This means that, before big data, we need the ‘big picture’. In many cases, data acquisition is being done indiscriminately without paying attention to the real needs. The data can also be noisy and may depend on local particularities; a consistent representation of cities is needed, allowing the extrapolation from one city to another and the identification of general trends. Local coordination, redundant information and data filtering are key issues here.
Once filtered, 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. Crossing data from different databases can help to develop synthetic data, the so called contextual information or procedural data, which can complete missing information in the databases or extrapolate known data to unexplored geographical regions.

**Spatio-temporal data analysis**

In the present situation, the concept of smart cities is well established and the proliferation of sensors provides a humongous amount of information. We are moving from “data hungry” research to data abundance, but we still don’t know much about how to make sense of this abundance of data from a behavioural perspective. We need to develop data analysis tools, including filters to reduce noise levels and tools to extract system information out of a sea of data. Relevant issues are the representativeness of the new data sources (e.g. the representativeness of credit card or social media users as a source of survey sample), or the development of spatio-temporal data mining methodologies able to uncover mechanisms that operate at different scales.

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 has stimulated a great interest in spatio-temporal data mining, which still remains, however, a largely unexplored territory.

### 4.2 Modelling and simulation

While some models of urban systems and processes are intended as tools to improve scientific understanding, other models are specifically developed to assist decision making. As already discussed, both trends can mutually enrich each other, so we believe that the GSS research programme should have room for both types of research efforts. But it must also be acknowledged that they have different purposes, which suggests different practices in the commissioning of models, the process of their development, and their application. We discuss hereafter a number of research challenges related to modelling and simulation. Some of these challenges are more relevant either to scientific explanatory models or to models for decision/planning support, while other challenges are relevant for both.

**A science of cities**

A first, fundamental questions is whether there can be a science of cities, i.e., whether a quantitative, predictive and falsifiable theory of cities is conceivable.

In relation to this fundamental question, several other questions arise:

- How well do we currently understand urban phenomena? What do we robustly know and what are major lacunae in our understanding?
- To what extent such theory would be based on generic underlying principles that transcend history, geography and culture? How temporal and context-dependent are cities?
- Interconnection is not a new element, but why things are connected and why some things are more connected than other? Is Tobler’s first law of geography true?
What should a science of cities be able to accomplish? Examples of relevant targets are to explain general empirical relations concerning infrastructural and socio-economic characteristics, the reasons why cities arose in the first place, or the mechanisms behind socio-economic development and decay.

What are we missing in terms of data and theoretical developments?

How to do it? We believe such an effort would necessarily involve an interdisciplinary effort, bringing together researchers from areas like anthropology, urban planning, sociology, economics, environmental sciences, ICT, complexity, or political science, among others.

Would such theory offer practical solutions for the management and planning of cities?

Theoretical challenges

As indicated in section 3, further progress is needed to develop out-of-equilibrium models able to describe urban dynamics. Examples of relevant research areas of which we still have a limited understanding and that required more theoretical work are:

- Behavioural drivers and social determinants of the observed trends.
- Systematic approach for human modelling, including modelling of partial rationality and emotional behavior.
- Coupling between slow and fast dynamics.
- Coupling between intercity and intracity interactions: impact of global trends or urban dynamics, and cities contribution to global challenges.
- Path dependence and evolutionary urban theory (integration of the past into the present).
- Identification of critical parameters (key variables), and analysis of tipping points and critical transitions.
- Analysis of urban resilience, disturbances and vulnerability.
- Impact of the overabundance (and exchange of) of information on urban dynamics.
- Model calibration and validation, including the analysis of how errors and accuracy are affected by the level of disaggregation of our models and data.

Adaptation of models to the current socio-economic landscape and new global challenges

The current generation of urban models was developed in an era when urban growth and sprawl was in the ascendancy. 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, migration flows, and the overlay between climate change, cities and economy. Particularly relevant is the restructuring of the local economies to embrace new varieties of ICT-based services: in the past, people used to accommodate in cities according to economic drivers, but this is to some extent changing with ICT penetration, leading to a disconnection between information and physical layers that could challenge the urban theories developed along the past decades. Urban simulation models need to be refashioned to deal with these and other emerging trends, which are in turn being reflected in changes in transport and spatial interactions.
New tools for planning and decision support

The availability of new data and the theoretical advances in urban modelling should be exploited to develop new tools for urban planning and decision support, both in terms of real-time city management and strategic planning tools. Relevant issues are:

- Development of new and more meaningful performance indicators.
- Development of ‘city dashboards’ monitoring the critical parameters that drive the dynamics of the city.
- Improvement of travel demand models.
- Improvement of land use transport interaction models.
- Coupling between different models.
- Development of early warning and risk management systems.

Coordination of the efforts of different urban modellers and model integration

In many situations decision makers need models that are really ‘global’ and integrate engineering solutions and scenarios from social, economic and geographical situations. Despite major improvements in urban data collection and modelling accomplished in the recent years, there remains a huge gap between technical models (for instance transportation models) and physical models (for instance about environmental risks), and current models present a series of limitations derived from the lack of integration. Many models are aggregation of pre-existing methods and packages loosely integrated and adapted for particular situations, rather than being holistic tools applied generically as a standard set of integrated methods. More generic models (usually developed privately) often present limitations in their capacities of integrating complex set of data.

Further work is needed to couple different models that differ in their methodology and scale, including the development of built-in validation mechanisms to ensure the robustness and coherence of the coupling algorithms. Relevant examples are the coupling of GIS-based models of property and demographics with models of energy consumption, or the integration of sectoral models, such as models of housing choice, retail or public services location, into land use transport integrated frameworks.

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. In a recent paper, 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.
4.3 Social computing and collective awareness

The dynamics of cooperation and human computation

Here the problem concerns how to sustain over time collaborative behaviour in intelligent tasks, which is fundamental both for the understanding of social dynamics and for the design of effective forms of web-mediated collaboration. Research is needed to enhance our understanding of the role of motivations, incentives and mechanism design together with other factors such as social ties, culture and the cognitive framing of problems, in order to effectively use ICT as means for mediating behavioural change and introducing self-awareness of the citizens within the urban environment.

Special care must be taken about certain feedback loops. One example is that of satellite navigators for cars with information about traffic. If a zone of the city is congested, the navigator may try to redirect the user through a less transited route. But if all the navigators act in the same way, the new route will become collapsed. Game theoretical considerations can be useful to address this sort of problems.

Societal informatics gives us the opportunity to pioneer a new type of experimental science, by using the web as a laboratory for the social sciences. The challenge here is to develop the means for integrating different perspectives to test the limits and potentials of collective knowledge production.

4.4 Policy making and participatory governance

Integration of urban models into multi-stakeholder policy making processes

Policy assessment and participatory planning are still largely based on qualitative considerations, and there is a sense among practitioners that urban models are immature with respect to institutional integration and operational use. Interaction between model users and model makers during model development remains rare, which often creates a gap between model providers and user needs.

Potential users include a broad diversity of stakeholders (usually non-experts), which constitute a major issue influencing the effectiveness of models in application and their capacity to influence understanding and decision making. Typically, model users now include:

- technocrats (employed within government or consulting companies) who interface with the models and the community at large;
- policy and operations decision makers (elected government officials or advisors to government, such as private sector planners and designers);
- the general public (communities with interest in specific issues or places);
- the technical and scientific community (other modellers and urban specialists).

Model users often identify an issue about which they want to be better informed, but may not know what they are looking for or what models actually do. They possess a very valuable implicit knowledge about the issue under investigation, but do not always understand the limits of models, or how data availability influences them. Conversely, modellers make assumptions about how models should be applied and may lack the skills to interact effectively in the socio-cultural and political domains in which models are used. In addition, they may not have the training (or time) to produce models of complex interactions that are comprehensible to non-experts.
The challenge here is to integrate state-of-the-art with multi-stakeholder decision making process, bridging the gap between implicit and explicit knowledge. The development of models and decision support 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. We need to exploit the potential of models to act as a catalyst for integration, interdepartmental collaboration, collaboration between authorities and stakeholder involvement.

**Transparency and ease of use**

As already discussed, urban development policies imply highly distributed decision processes and influence a variety of stakeholders. The policies under study often being controversial, models will not gain the necessary credibility 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 shall be built according to the question to be addressed, and people need to understand what the models are intended for.

Models must also achieve a threshold of usability that makes it possible for model users to use the model without excessive support. In particular, models must be consistent with the level of competence of the relevant (local) authority. 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.

**User-model interaction - Information visualisation and visual analytics**

To bridge the gap between modellers and model users and facilitate user-model interaction, new forms of information visualisation and visual analytics have a particularly important role to play. Several research challenges can be identified here:

- Development of more intuitive, user-specific interfaces addressing the needs and requirements of different communities and enabling a better integration of quantitative and qualitative information.
- Real-time interaction and analysis. Big data production rate is growing faster and faster. Real-time interaction and analysis have to be addressed carefully in order to reduce latency, so that the analysis capabilities keep the pace in terms of effectiveness and efficiency. Scalability and computational efficiency are key issues here.
- Integration between visualisation and analytical functionalities. Visualisation is a fast growing area, but there is still little integration with data analysis functionalities. Progress is needed in terms of combining data mining tools with iterative visualisation on top of specific geographical representations.

**Societal informatics for participatory urbanism**

Participatory urbanism, which promotes new styles and methods for individual citizens to become proactive in their involvement with their city, neighbourhood, and urban self-reflexivity, also implies a different approach to urban models and new research areas at the crossroads between policy informatics and societal informatics. Relevant issues are the collection of user-generated and user-mediated content which can feed in and update models, which will in turn require more flexible modelling tools; and the development of tools for more active involvement of citizens in the evolution of urban systems.
5. Expected impact and implementation strategy

5.1 Expected impact

A research programme on GSS and urban development would have positive impacts of different nature:

**Scientific and technological impact**

The programme will contribute to making progress in the integration and analysis of spatio-temporal databases; the understanding of urban location and activity patterns, and the interaction between globalisation and urban development; the development of improved urban simulation models; or the increased take up of new data sources for urban research.

**Impact on policy and governance**

GSS can contribute to a more integrated approach to urban development; lower the barriers for the use of state-of-the-art simulation models in policy making; develop better links between modellers and stakeholders, and new methodologies for collaborative policy assessment and multilateral governance processes; and help design better policies and more efficient provision of public services.

**Impact on innovation and competitiveness**

There is a growing consensus among the industry that smart city technologies will offer exciting market opportunities in the decade ahead. The smart city market being a worldwide market, a global approach to cities and an enhanced understanding of global and local urban issues will help Europe to be a leader in this market.

**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 achieving a holistic and integrated model of urban development that is economically efficient, socially inclusive and environmentally sustainable.

5.2 Implementation strategy

Different instruments can be applied to ensure the efficiency and effectiveness of a research programme on GSS and urban development. We highlight hereafter a number of aspects to which particular attention should be paid.

**Stakeholder engagement**

Urban research and innovation can significantly contribute to solve the challenges of the future, but only if research results are adopted by policy makers, industry, and society. Linkages established between researchers and stakeholders during the research process can contribute to end use, because useful channels for information exchange are established.

EU funded research in the field of urban and regional development is first of all taking place in large interdisciplinary networks representing several countries and cultures. Besides, different research institutions and stakeholders are often involved in the urban-oriented research projects in one way or another.
or another, however sometimes at a late stage of the research process, implying limited value added. For applied research, stakeholders possess important knowledge, so extensive stakeholder involvement is particularly relevant to achieve meaningful and useful results. Representatives from society, public administration, business and NGOs should be involved in the research application from the very beginning.

Further dialogue throughout the research process is in many cases indispensable. However, some research may be opposed by stakeholders if it does not serve their interests. Furthermore, research should always have the potential for surprise, so the assessment criteria must reward novelty and accept that the potential impacts will not be known a priori.

**Flexibility and adaptation**

In projects of significant policy content, increased flexibility on deliverables is highly desirable. As the time that elapses between project contract negotiations and the end of the project is usually significant, sometimes a procedure to update what needs to be done is necessary.

**Dissemination**

Needless to say, further to connections between researchers and end users, publication of research results or other forms of dissemination is a precondition for use. More attention should be given to local dissemination networks as a multiplier of the messages. Also social media provide for innovative engagement of end users in urban research. Observatories set up under the universities and publicly financed laboratories with joint participation of regions, metropolitan areas, local councils, entrepreneurial associations and trade unions could help bridge the gap between research and end users.
The research leading to these results has received funding from the European Community’s Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 318367.