**Toward a Global Systems Science of Urbanization**

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**Introduction**

This white paper is a first attempt to design a research program that conceives urban dynamics and urbanization as part of the changing global system. It is based on the first two of a series of workshops held by the GSDP program in collaboration with Arizona State University.

The first of these workshops was held in Tempe on November 1 and 2, 2012 under the title "Urban Networks, Sustainability, and Resilience", and brought together participants from ASU, the Santa Fe Institute, Yale University, University College London, the MIT Media and Senseable City Labs, Michigan State University, UNC-Charlotte and others.

The second workshop consisted of three sessions on urban dynamics at the GSDP second annual Open Science of Global Systems meeting, in Brussels on November 8-10, 2012. It brought together scientists and practitioners from UC London (CASA), Veolia Environnement, the University of Paris I, the Santa Fe Institute, CSIC (Spain), Virginia Tech University, the Global Climate Forum, La Sapienza University, and others.

This white paper is based on the discussions held at these two workshops, but does not pretend to be a report on them. Instead, it is an attempt to set a first step towards a GSS research program on cities and urbanization. It will be refined as a result of other workshops still to be held in Brussels (by EUNOIA, February 13-14 2013) and Phoenix (by ASU, February 24-28, 2013 on Global Systems Science, and April 15-19 on 'Innovation and Urban Sustainability').

**Context**

Of the roughly 7 billion people on Earth, 3,5 billion (50%) live in cities, and within the current century, this is expected to rise to 80% (some 6,5 billion of the 8-9 billion people expected). The development and growth of urban systems is the most constant dynamic in human societies since about 6000 years ago, and in recent years individual cities have reached proportions that were not imaginable even fifty years ago. In effect, since the earliest towns emerged, urban systems have multiplied and grown thousandfold. Recent research attributes this to the fact that most innovations emerge in cities, so that they act as drivers for the surrounding rural society. Yet individual cities are the least sustainable and most vulnerable institutions in our societies. They are centers of wealth disparity and social insecurity, loci for sanitation and waste problems, sensitive to epidemics and other health issues; they are energy-intensive and high infrastructure maintenance, they are often noisy and polluted, etc.

Cities innovate and change rapidly, but the trajectories they take are difficult to predict or to impact. They consist of many tightly entangled interactive networks of cables and tubes, streets and avenues, businesses and social groups. The huge investments in their creation and maintenance, as well as their tight integration make them high-risk systems, prone to external and internal perturbations. They are highly multi-scalar in space and time; the interaction between ‘bottom up’ and ‘top down’ is nowhere as pregnant as in cities. Hence, in recent years, urban systems have become a major topic of interest to scientists and to politicians, decision-makers of all kinds, and the general public.

Though the research is done in trans–disciplinary teams, it remains essentially sectorial (focusing on water, energy, pollution, metabolism, etc.). We must change this by making an encompassing investment in Complex (Adaptive) Systems modeling of urban dynamics, aiming todeliver a coherent set of portable models of urban dynamics. To understand urban dynamics, and to effectively make decisions about cities and urban systems, such a complex systems approach is essential. But we must do more; we must view the dynamics of urban systems as part of the wider dynamics of the Earth as a complex system (hence the inclusion of this theme in a research agenda on Global Systems Science, see Dum 2012). Doing that will transform our understanding of urbanization in many different ways, among which the following are important:

1. Focus on urban systems instead of individual cities (cf. Pumain 1992). Work in Europe on Europe, the US, India and S. Africa shows that one gets a much better perspective on the long-term urban dynamics when one does not look at individual cities, but at the systems of cities (from large to small) that interact in urban systems. At the top level, the world urban system, in which Singapore, Hong Kong and other major trading cities (Shanghai, New York, London, etc.) are linked seems to be the appropriate level of urban analysis to determine the sustainability and resilience of these cities. At a level below, essentially that of continents, the same can be said for places like Paris, Berlin etc. in Europe, Philadelphia, Boston, L.A., but also Phoenix. The research shows that the resilience or sustainability of cities is to an important extent determined by competition between them at such levels, and that spatial, legal, demographic, resource and innovation differences play an important role.

2. Apply complex systems concepts and approaches. Recent research (e.g. Bettencourt & West 2010) has shown the power of conceiving urban systems as complex systems, in which dynamics among actors at many different levels interact to create the patterns observed. Most of the dynamics are driven bottom-up, and can be modeled in multi-level models that use agent-based modeling, network analysis and other complex adaptive systems techniques. At issue here is that urban systems combine hierarchical and market dynamics, and that the analysis therefore needs to be able to combine both. One possible approach is to decompose the urban dynamics into intersecting subsets based on the temporal dimension of their dynamics, such as has been proposed by Allen (Allen & Hoekstra 1993) and by Gunderson & Holling (2002).

3. Combining different modeling techniques. The complexity of urban dynamics makes it essential to model these to improve understanding. Many different modeling techniques are available. In creating a CAS perspective on the dynamics of the whole as well as the individual parts, we could for example combine various Agent Based Models (reflecting the ‘bottom-up’ component of behavior (individuals, families, companies, etc.) with Network Models reflecting the various urban infrastructure networks and the social networks processing information in the city. Differential-equation models could reflect the ‘top-down’ component of behavior (rules, institutions, external conditions), etc. The (multi-scale) spatial structure could be included as a set of GIS layers with transition matrices that set the conditions for changes in spatial structure.

Studies of the current sustainability predicament indicate that recent and future developments in information technology will (have to) play an essential (and growing) role in extricating our societies from that predicament. As this research agenda is to be part of the EU's Information and Communication Technology Directorate, *we have paid particular attention to the future role of information technology in both the research on urban dynamics and in developing tools that will enable us to implement the results of that research in both policy-making and day-to-day adaptive management of cities.*

In the following pages, we have therefore divided the issues into three categories:

1. Questions to which an answer is necessary to understand fundamental urban dynamics and therefore to impact on such dynamics in the future
2. Questions relating to the potential impacts of ICT on the global urban system
3. Questions regarding ways to improve the sustainable management of the global urban system through enhanced use of ICT

**1. Questions to be answered to understand fundamental urban dynamics and to impact on such dynamics in the future**

**Cities are doing well - or are they?**

Superficially speaking, cities seem to be doing extremely well. They constitute the most persistent characteristic of societies since about 6000 years ago. In the last few centuries they have grown to encompass an increasing proportion of the world population; all over the world rural populations have for centuries flocked to cities in an attempt to improve their material conditions, and in some parts of the world (e.g. China) government views them as a solution to many challenges and goes out of its way to build them. Recently, urban life has become the dominant mode of life worldwide, and in many countries. It sometimes seems as if urbanization cannot be stopped.

On the other hand, cities are a major source of challenges in many domains. They require major investments in infrastructure that all but the wealthiest of nations cannot afford. They promote social inequality, economic misery and illnesses of various kinds. Though they may add to overall productivity, that has a high social cost. Although taken singly they may in some cases appear to be energy-efficient in the sense that living in dense cities requires less energy (mainly for transportation) than living in the countryside, we should not forget that our urban society uses about 100 times as much energy as is needed to maintain each individual alive. Altogether, cities are in effect a highly vulnerable part of our global system.

**Drivers of urban dynamics**

The apparent contradiction between the ubiquity of urban life and the challenges that it poses leads us to formulate a first research question: *"What is (are) the driver(s) that continue(s) to push for aggregation in cities notwithstanding these challenges?"* Although at a proximate level there are of course many of these, and different ones in different situation, at a more general level there appear to be only two candidates: accumulation of energy and matter or accumulation of knowledge and information. For a long time the energy perspective dominated, and in certain sense it still does when we cite future shortages of energy as the major reason why our society might disintegrate (e.g. Patzek & Tainter, 2011). Recent work, some of it initiated as part of the ICT directorate's ISCOM research project, seems however to indicate that the accumulation of knowledge is the ultimate driver of urbanization (Bettencourt et al. 2007; Florida 2005). This, then, raises the next major research questions: *"Will a (potential) lack of energy spell the end of urbanization (and thus our current way of life) as we know it?"* and *"If that is not the case, what will (need to) change in the structure of our civilization to maintain its continuity, yet deal with a substantive reduction in available energy?"*

Of course energy is but one of the resources upon which our current mode of life depends, although it is the one that is currently most discussed. Water and food are two other ones that spring to mind. One must therefore also ask the above two questions for resources such as these (and others).

Approaching the challenge from the other side, looking at the current mode of information gathering and processing, its consequences for our current mode of life, and how the future of ICT might affect urbanization (if society does not collapse due to lack of energy), we come up with different, but related, questions. First of all *"Is there a relationship between the accumulation of knowledge in urban centers and the increasing disparities in wealth, knowledge, culture and material circumstances that one observes in cities?"* Then: *"If that is the case, will urban growth ultimately lead to such important disequilibria (and potentially ruptures) in the coherence of our societies that this might result in chaos?"* and its corollary: *"What would need to change in the way we currently process information to ensure that that does not happen?"*

**Inside the Global Urban System**

Although we have written the last paragraphs with a clear focus on the urban part of our current global system, their significance went beyond the urban system itself, and included the whole of all of our current societies. In this section, we want to move a level down, and ask questions pertaining to the urban systems themselves. Here, again, there is currently no overarching perspective that is widely accepted as being able to explain and predict a wide range of aspects of urban dynamics and phenomena. Indeed, there seem to be two dominant approaches that complement each other - the metabolism approach and the network approach. The former looks at the material and energetic in- and outputs of cities, while the latter pays attention to the various kinds of relationships that 'weave the city together' - and is thus more involved with the structure of urban relations. For the moment, neither has made much headway in asking the fundamental question: *"What constitutes a sustainable city or system of cities?"* But maybe a combination of the two approaches might help us here, prompting us to ask: *"What is the structure of the various networks that constitute the urban framework, and what kinds of flows are transmitted through them?"* and the subsidiary questions: *"How do the dynamics of the various networks impact on each other?"* and *"How do the network dynamics impact on* *and are impacted by, the urban metabolism?"* The flows in question concern all resources - energy, water, food, materials, but also ideas and people - and all sources (the whole of the world trade network). Urban network science is in its early stages, and there is a lot to be done in this domain. It will be important to deal with all the various aspect of these flows, such as their nature, volume, value, frequency, local importance and effects, etc.

And in particular, it will be important to get a good sense of the structure of the networks. For the resource networks, one expects a dendritic structure (assembling resources from many places and distributing them to many other ones), whereas information networks combine elements of both hierarchical and market (distributed or heterarchical) organization in different ways that affect the resilience, and thus the sustainability, of the system. For example, Huberman & Hogg (1988) have shown that with time, the complexity of hierarchical self-organizing systems is reduced, as are their rate of evolution and their adaptability. On the other hand, it seems that very large distributed systems also have difficulty adapting due to the persistence of non-optimal strategies (Ceccato & Huberman 1988). However, the introduction of globally controlled (hierarchical) communications in market systems causes them to lose their penchant for retaining non-optimal strategies, whereas the existence of untied (heterarchical) connections in a hierarchical system increases its adaptability. Inevitably, a hybrid structure will develop which is a 'best fit' in the particular context involved.

The crucial questions here refer to the balance between these two aspects: *"What determines the balance between the hierarchical and the heterarchical characteristics of an urban system's organization?"* and *"How does this balance impact on the urban system's adaptability, resilience and sustainability?"*

**Macro-regional urban dynamics**

At this level, we must consider some of the differences between the very large regions that make up the current socioeconomic world, such as North America, Europe, Australia, China, India, South America, Africa, and the ways in which these differences impact the global urban system. But it should be noted that some of these regions are made up of smaller units that are only recently growing together, intensifying their interactions and their symbiosis. This is easiest seen in Europe, where over the last sixty years the various national urban systems have begun to meld into one overarching European urban system. The very concept of 'region' is thus subject to change in scale, and the urban dynamics are evolving as part of that process. That poses the questions*: "How are the national urban systems, which were for a long time being kept apart by borders, being integrated into the supra-national system?", "What drives that process, and what are the variables that affect it, and are affected by it?"*

The dynamics at this level are the result of the articulation between the urban system dynamics and overall trends in each area such as their demography, the nature of their economy, wealth disparities, resource availability, climate and so forth, as well as the dynamics of (political, social and cultural) institutions, etc. *It is fundamental to our understanding of the current and future trajectories of these macro-regional systems that we understand the interaction between this complex set of regional trends and the urban dynamics in the area.*

To an important extent, relative differences between these trends in different places are affecting the trajectory of the urban systems at the macro-regional scale. One would therefore need to ask: *"How do these relative differences actually affect, and are affected by, the urban dynamics in these areas?"* For example: *"With population growth in China exceeding that in the US, and even more that in Europe:* *how do demographic differences affect the urban systems of these three macro-regions, and the interactions between them?" "How do differences in climate, landscape, spatial and economic structure, productivity, wealth level, resource availability, etc. affect the dynamics of the region's urban systems compared to other such systems?"* It is essential that in these comparisons the evolutionary state of the systems is taken into account, but equally that such comparisons not be limited to economics in the traditional, macroeconomic sense, but also include a wide range of other parameters (such as, for example, energy efficiency, innovativeness, productivity, income differentials, etc.). Once a relatively detailed picture of such macro-regional differences and dynamics has been gained, one can then move onto the next lowest level, that of the local urban dynamics.

In particular, at this level, we will therefore make an effort to better understand the relationship between territorial and functional patterns as a key problem for the emerging science of global systems along the following lines:

* Territorial patterns: centre-periphery structures, energy and information gradients in nation states and empires
* Functional patterns: division of labor, industries and producer markets, system of professions, social and professional networks
* Renewables and global energy/matter flows: geopolitics and regional innovation in the global economy, the role of trade, policy and finance
* Computing and global information flows: the interactive nature of computing, hierarchical and non-hierarchical networks, money flows as information flows

**Local urban dynamics**

At the level of local urban dynamics, there is an immense literature that deals with virtually every aspect of urban organization, function and evolution from any imaginable perspective. It is at this level, therefore, that the articulation between the Global Systems Science perspective and extant work is at once the most poignant and interesting, and the most difficult and necessary. It is where the rubber hits the road. *"Can a Global Systems Science perspective improve our understanding of what happens in individual cities?"*

We think that it can. What happens at this level is the articulation between the global urban system's dynamics in its macro-regional form and the local circumstances (spatial organization, resources, past history) of the particular city that one is studying, and this articulation is determinant for the success and sustainability of that city. Hence, in our opinion, articulating between a coherent approach to the global urban system and the regional and local circumstances is the only way to arrive at explanations of what happens in individual cities that allows comparisons between the latter.

*This requires assembling a coherent model of urban dynamics.* Lack of a coherent and widely accepted theory of urban dynamics has thus far hampered any efforts to create such a model. We would argue that such a model should bring together the network and the metabolism approach. Bettencourt (in press) has argued cogently that the state, structure and extent of the transport network determines many aspects of the city's dynamic. If one were to extend that approach to the communication and energy/matter flow networks, including such domains as distribution etc., as well as the social networks in the city, one would in effect be able to model the very 'urbanness' of cities - that which accounts for the close spatial proximity and entwined nature of many societal functions. Comparing urban dynamics between different cities in this light would thus have major advantages over current approaches, as it would allow us to assess the role of different forms of 'urbanness' in structuring local societies and in shaping the recurrent 'hairy' problems that occur in all cities.

**2.** **Questions relating to the potential impacts of ICT on the global urban system**

By removing the material basis of information transmission, the ICT revolution will potentially also fundamentally change the actual urban dynamics at all levels from the global to the local. As outlined earlier, urbanization requires both increasing information-processing capacity so as to maintain a high level of invention and innovation and a sufficient matter and energy flow to meet the needs of the individuals and the infrastructure in the city. In the pattern of urbanization that emerged over time, hub-and-spoke systems of larger and smaller cities connected by roads and transport networks between them channeled all three flows – matter, energy and information – and urban growth patterns as well as the geography of urbanism were thus determined by these flows.

In the last thirty years, ICT has fundamentally changed this. Information flows are now no longer constrained by transport networks, and therefore do no longer follow the hub-and-spoke pattern that generated the urban landscape. As this process advances (it is currently only at the beginning), we might therefore see a very different urban geography. The differences will in part be determined by the geography of energy, and therefore the future of energy.

If we assume that for the next couple of hundred years our societies remain dependent on fossil fuel, this will on the one hand maintain the current spatial configuration in the western countries, which is determined by current pipelines, grids and road transportation networks for solid and liquid fossil fuel. But on the other hand, global warming will lead to important rises in sea level, and thus the disappearance of many coastal cities, requiring us to deal with the migration patterns that are inherent in that change, as well as the changes in trade patterns.

If, on the other hand, we assume that alternative fuels will indeed become a more important source of energy, this may change the urban geography because it would enable many cities to become independent of the existing energy networks, generating enough solar and wind energy locally to avoid the major investments needed in the creation and upkeep of those networks. We have seen a similar change in telecommunication networks, where radio, television, web and cellphone are taking over from landline-based communication. In such continents as Africa, this is increasingly enabling changes in other domains, such as removing the need for branch offices of many companies, which thus far constituted an important component of cities. Were we to invent means to transmit energy via electromagnetic waves rather than cables, a similar change is conceivable in energy-related domains.

Matter transport is less far advanced, but we are beginning to see signs of delocalisation there, too. Amazon and eBay are early examples of this, as they reduce the need of the customer to go any particular place to acquire the goods that facilitate daily life. Web ordering of household goods contributes to this as well. If one were to develop a material culture that is adapted to the increased use of 3-D printing, this development could become more and more important - even though the distribution of basic raw materials will remain dependent on the transport network.

We conclude from these examples that a number of the constraints that have led to the concentration of population in cities are likely to be relaxed in the coming century, which might in theory enable the re-dispersal of people in the countryside. This is where other environmental factors come into play. The increasing stress on those surfaces that serve currently to provide food is likely to lead to important increases in the relative price of meat and fish (which require inordinately more energy to produce), thus pushing our food systems to become more and more geared towards vegetarian diets. That in turn could easily enable an increased use of local production in many parts of the world, further reducing the need for bulk transport (of foodstuffs).

It will be the task of Global Systems Science to begin to posit and answer the many questions that trends like those outlined will generate. From among those, we only mention a handful:

* These developments seem to indicate a shift to a more heterarchical social system, in which it is more difficult to control information flows. Such control is essential in order to maintain the coherence of societies, which is based on the alignedness of individuals around concepts, ideas and culture. This alignedness has thousands of years partially been assured by geographic constraints, but these constraints are weakening. *How can ICT help us to find an alternative balance between individual diversity and societal coherence?*
* *Will there be other constraints that come instead of those that are weakening*? No doubt. As I have argued elsewhere (van der Leeuw 2012), solutions lead to challenges, lead to solutions, lead to challenges, and so forth. Part of the task of Global Systems Science will be to look at those challenges and devise perspectives that enable us to anticipate them. One important example is the future distribution of employment. Much urban immigration is driven by the expectation of urban employment, and the above trends seem to point to delocalization of such employment. *How will these two trends articulate?*
* *How will these trends affect the pattern and speed of innovation that is necessary to maintain people interested in our societies?* Recent research closely relates innovative capacity to spatial proximity of large numbers of the 'creative class' working in institutions such as businesses that are co-located in cities. One may distinguish cities in which truly original innovation emerge from cities that specialize in recombination of existing technologies, and from cities that focus on elaboration of technologies. The spatial relationship between these cities is co-determined by the role each plays in the fabric of society. *How might that change in a distributed world?*

**3. Questions regarding ways to improve the sustainable management of the global urban system through enhanced use of ICT**

To pose the third set of questions, it is important to point to another, very different, trend: the use of Big Data to enable much closer fine-tuning of the management and organization of our current social systems and institutions, including the health and behavior of individuals. Here we will be moving from what I'd call a 'statistical approach' to a 'personalized approach'. Currently, management of societal processes essentially depends on a statistical approach to understanding and managing them, in which common denominators are identified in perception, behavior and interaction, and these lead to the creation of adaptive institutions that channel them. The precision of this approach, and hence its effectiveness, was limited by the information available, based on censuses, opinion polls and other social science tools. In the medical field information acquisition was achieved (and limited) by other tools, but the effect was the same: treatments and drugs developed to have a statistical success rate, rather than an assured individual one.

Big Data offers the possibility to acquire such data in incredible detail and in real time. Currently, certain companies in the US have data about each household according to more than 500 criteria, Sophisticated analytical methods allow pollsters to address each family with a detailed copy of their 'mental map' in mind. This capacity was one of the factors that played out in the last presidential elections in the country. Tools currently being developed that are able to simultaneously identify very large numbers of health risk factors very early will no doubt help reduce health costs in the future and may also lengthen life expectancy. These are but two examples of this general trend. Although this is only the beginning of this trend, the volume "*The Human Face of Big Data*" (Smolan & Erwitt, 2012) gives many examples of how the collection of massive, and very precise, data will affect our lives - whether for better or for worse depends on one's personal attitudes, but as humans are known for their adaptive capacities, ultimately these developments seem inevitable.

**Smart cities**

In the domain of urbanization, this trend has recently led to the concept of the 'Smart City'. For instance, Scientific American ran a special issue on smart cities (September 2011). Industry players such as IBM and Siemens have specific programs and practices dedicated to advancing the cause of building smart cities. Despite its intuitive appeal, we have limited knowledge within the design, planning, policy, sustainability or ICT fields about the dimensions of the concept of smart cities, and limited practical experience regarding the barriers and potential opportunities. Tentatively, one could use the following definition (DeSouza 2012): *A smart city is livable, resilient, sustainable, and designed through open and collaborative governance.*

De Souza (ibid) argues further that a smart city:

* is resilient, i.e. possesses the capacity, desire, and opportunity for sensing, responding to, recovering, and learning from natural and man-made disasters.
* takes a sustainable approach to the management of its economic, social, and ecological resources to ensure that they have vitality going into the future.
* infuses information for automated and human, individual and collective, decision making on optimal allocation of resources, design of systems and processes, and citizen engagement.
* enables intelligent decision making through leveraging information via technology, platforms, processes, and policies across its environments, infrastructures, systems, resources, and citizens.
* operates as a seamlessly integrated platform where information links the various infrastructures, systems, organizations, and citizens' goals and values.
* engages citizens in planning and design of public spaces and governs use of public resources through open and collaborative governance platforms supported by information technologies that generate, and leverage, the collective intelligence of its residents.

These goals are achieved by infusing novel information flows into the city that gather information about citizen and infrastructure behavior and disseminate information to the citizens. Smart cities use a wide assortment of information pipelines and platforms to integrate the – often disparate – physical and human sub-systems, infrastructures, and processes. By building viable connections, information flows between the various parts of the city seamlessly so as to enable real-time intelligent decision-making. Leveraging information technologies is central to the goal of developing smart cities. Technologies, especially computational and communicational systems, are vital for optimal processing of information in real time and facilitating both automated and human decision making. Hence smart cities are laden with information generation sensors, automated systems that aggregate and store data, and even tools that enable data to be transported across administrative systems. On the other hand, and maybe less evident to the ICT community, is the fact that smart cities also use information technology to involve their citizens in the decision-making and implementation of policies and other measures. This is necessary to ensure that very large cities avoid major social ruptures and political traumas. They do so by extensively using participatory platforms.

Five essential domains of development of ICT for smart cities are relevant here:

1. ***Smart planning*** requires us to *think of cities as ecosystems*. Planners will be faced with the challenge of designing a new ecosystem (when faced with the challenge of creating a new city) or modifying an existing ecosystem (when retrofitting an existing city). Such infrastructure projects insert new actors, dependencies, or interactions, and require that participants renegotiate their place in the ecosystem. Many projects strand because the different stakeholders communities have not sufficiently been involved in the planning.

Successful planning for smart cities also requires *looking broadly at the impact of the infrastructure on the dynamics of the economy and the geography of the region.* Failure to think of such projects holistically as complex systems will result in isolation of critical stakeholders, flawed plans, and, ultimately, in poorly executed or failed projects. An excellent example of a very good plan is the model designed by Revi (20XX) for the city of Goa (India). He decomposed the economy of the environment and the infrastructure of the current city, and rebuilt them with an interesting twist: rather than work from the city center outwards, he worked from the surrounding countryside and its resources inward, thus creating a much less energy-intensive and highly functional city plan.

Finally, smart planning is *planning and designing for change*. Planning should look beyond immediate completion into the life stages of planned infrastructure, based on an informed understanding of the future of the city in order to build projects that fulfill the needs of the city that will be, not the city that was. Smart planning aims to build plans and infrastructures that are adaptable and flexible, and that have the capacity to be repurposed as conditions change.

1. ***Collective Smarts.*** Smart cities take advantage of the talent and education that is locally available *by creating and maintaining effective platforms for citizen participation in the construction of the city*, encouraging their citizens to contribute constructive ideas and innovations. This is achieved by means of ICT platforms that enable co-construction of ideas among citizens. Such co-construction can happen in meetings that are organized at looking at different scenarios of the future, but could ultimately also entirely happen on-line.

Another effective tool in this domain is *crowd-sourcing both 'what lives in the city' and ideas that might indeed, realistically, contribute to a smarter city*. Regularly monitoring of the ideas that are being discussed on the web, in social networks, etc. , enables the city government to be better in touch with what actually goes on in the city. By selecting the best from among the many ideas contributed by the urban citizenry, one could achieve a kind of "Emergence by Design" of urban innovations that respond effectively to the city's needs. In the process, transparency is much improved.

1. ***Smart Infrastructures.*** *Sensors are to be present in the physical infrastructure of a city* from intelligent traffic lights to metering technologies that regulate parking spaces. Buildings in a city also act as information sensors, tracking details such as personnel movements, energy consumption, and the flow of goods and services. In addition, citizens have multiple devices through which they interact and exchange information on their activities and whereabouts. These tools enable city managers to understand the behavior of individual citizens, and thus help move management from the 'statistical' to the 'personalized' state. This has many advantages for individual citizens as well as the urban society as a whole. And it allows the city to gain efficiencies in many domains, from resource use to transportation. Robust, nimble, and agile: smart infrastructure is the new vision of infrastructure.
2. ***Smart Operations.*** While information is present in the many facets of a city, this *information needs to be cohesively managed.* Managing information across subsystems, systems, infrastructures, and organizations is critical to realizing the goals of resiliency and sustainability and to creating smart cities. The underlying structure and foundation of smart cities will be built upon the policies and design guides used by government, planners, and architects. The benefits of solid, smart city regulations will be a healthier and more fruitful life for the increasing numbers of urban dwellers. *This concept of "social sustainability" also will impact those living in the cities through the presence of green spaces, walking paths, etc.* For example, through the design of smart transportation systems one might be able to not only reduce the emissions for vehicle traffic, but also increase the health and well-being of citizens by promoting healthier habits like bicycling or walking to work. Economic sustainability should be present, as the city will create jobs and inform job-creation activities using information smartly.
3. ***Smart Governance.*** Cities are administered by a collection of agencies and governing bodies, mixed and matched in singular ways depending on the local laws and cultures. *Smart agencies are a vital part of the smart city fabric.* These agencies leverage the power of information to conduct their operations in an optimal manner. Smart cities must be adept at multi-objective optimizing, able to pursue multiple goals, negotiating among possibly conflicting constituencies. In order to achieve this level of efficiency and responsiveness, public agencies must revolutionize their operations. Smart institutions will embrace information technologies to achieve their goals in a sustainable manner. Today we have sophisticated computing technologies, access to data of all kinds from geographic to economic with even finer granularities, and we have visualization and mapping tools that can leverage information for better decision making around megacities.

Cities also represent critical economic hubs between nation-states. As such, increasing the sophistication with which information is processed to enable smart decision-making will contribute positively to national stability and growth. Cities are resource-constrained and need to resolve multiple, and conflicting, goals of various stakeholders who own, or have access to, these resources. Hence, there must be a movement toward information-driven, collaborative, and inclusive decision making. The fact that there is a greater chance that these spaces can recover from internal and external shocks through effective resource allocation and infrastructure management during times of distress adds to urban and national resilience. But such smart governance calls for optimal collaboration between the various stakeholders involved in addressing complex challenges around the design and planning of urban spaces.

**Conclusion**

In this contribution to the Global Systems Science project, I have deliberately focused on questions and issues, rather than on the specifics of the many ways in which ICT is going to change urban systems, and our understanding of them. The impact of ICT is going to change so rapidly, and in so many unpredictable ways, that it seems to make little sense to outline our current vision on these in this programmatic paper. Rather, the paper aims to outline a major field of action, in which - over the coming ten years - things will change very rapidly, and out best efforts will be required to steer these changes in a constructive way.

In that process, there is a distinct role for academic research, which is to look further ahead than industry, business and politics can, and in particular to look critically at potential unintended consequences of solutions that are about to be implemented, so as to avoid that our path-dependency drives us into traps that we will have a difficult time to come out of.