Evaluating and modelling smart city performance

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Smart cities have attracted an increasing and extensive interest of science, industry and governments. There are various attempts to define and conceptualize smart cities, but common understanding on what smart city is still lacks. This paper aims to present the different and heterogeneous definitions and concepts of smart cities. The possible measurement methods are also critically reviewed, analyzing the methodological problems and limits of few existing evaluation methods.

1. Introduction

The phrase of smart city is not new. It may have origins in the 80s and 90s, when a new way of thinking about examining the role of new technologies in the operation, structure and planning of cities emerged. The theory of information society was formed, with the availability, presence and quality of information and communication technologies (ICTs) in the centre of it.
In the 2000s a new concept came to fore emphasizing not only the technology itself, but its role in human, social capital and the usage of these technologies. In recent years the concept of smart cities drew the attention of many researchers dealing with urban development and competitiveness, experts of urban planning and management and leaders of big multinational IT companies.

2. Smart city concept

Smart city concept appeared, not only in academic researches, but in public government choices and projects. In spite of the very broad usage of the notion of smart city, shared and sound definition of the concept is still lacks. Although there is no general consensus on the concept, the idea of smart cities is rooted in the creation and connection of human capital, social capital and ICT infrastructure to generate greater and more sustainable economic development, and a better quality of life ("Doing more with less."). The usage and content mainly depends on the context, background and interest of different stakeholders using the smart city definition.
According to the origin of elaboration, the smart city concept can be:

- academic
- industrial or corporate
- governmental
- term of the media (Mosannenzadeh,- Vettorato, 2014).

In academic research papers and documents we can find a very broad range of smart city definitions and concepts covering very different terms and phenomena. Despite of the variety of definitions, it is obvious that technological and social innovation are basic components of the smart city concept. One of the earliest explanations of what smart city means is coming from Hall (2000): "A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rail/subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security

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aspects while maximizing services to its citizens". One of the most influencing term in this field can be found at Giffinger et al. (2007): "A Smart City is a city well performing in a forward-looking way in six characteristics. It is built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens." Others try to connect smart city to other notions and terms: "The Smart Cities concept is connected to notions of global competiveness, sustainability, empowerment and quality of life, enabled by broadband networks and modern ICTs (Komninos et al. 2011). Caragliu, Del Bo and Nijkamp (2011) give a holistic definition of smart cities: "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory government."

In the past years, cities are increasingly aware of the concept of "smart city" and actively developing strategies towards the goal of becoming "smart", managing city resources more efficiently and addressing development and inclusion challenges. The growth of smart cities is helping the increase of government use of ICTs to improve political participation, the implementation of public policies or the provision of public sector services. A smart city from the governmental aspect can be seen as an urban strategy aiming at improving quality of life in the city, safeguarding the environment and reaching economic development at the same time.

The industrial interpretation of smart cities supplements the term with several practical elements. Big multinational companies like IBM, CISCO, Siemens elaborated their own smart city concepts and smart city solutions and applications. The smart city concept for IT companies means the elaboration, installation and application of complex information systems aiming at integrated operation of cities' infrastructure and services. The blurred boundaries between a policy concept and a business model that is focused on profit maximization, can give rise to semantic confusion and, more relevantly, to ethical issues.

According to the main topic of smart city articles and researches we can differentiate the following concepts:

- ICT oriented. With information and communication technologies in its center, enabling cities to fulfil their future objectives. (Joss 2013, Mitchell et al. 2013). Smart cities combine smart technologies with a new holistic way of thinking, leading to positive changes in cities' behavior, helping to overcome challenges of rapid urbanization (Hill-Watts-Buscher 2011).
- Sustainability oriented. Most of the smart city articles are focusing on sustainability as main topic. In this approach smart city is working in a built environment as an effective integration of physical, digital and human systems, helping to achieve a sustainable, prosperous and inclusive future for the inhabitants of the city (Cavada-Hunt-Rogers 2014).
- Mobility oriented.
- Innovation oriented.

In the numerous definitions of Smart City, which vary according to the origin of the concept, the point of view and the stakeholders the common aspects are the following:

- social and environmental sustainability as strategic priority,
- importance of network infrastructure,
- entrepreneurship as a crucial force of development that needs to be accompanied by other such forces,
- maximizing access of citizens to public services, improving social inclusion,
- crucial role of creative industries,
- the role of social and relational capital in smart city projects (Manitiu-Pedrini 2015).

3. Smart city evaluation

Various evaluation methods, models for understanding and conceptualizing smart cities have been developed to explain smart city concepts, which aim to define their scope, objectives and architectures. The multidimensionality of smartness coupled with cities' complexity, calls for specific assessments able to distinguish between different dimensions of smartness.
Evaluation helps:

- to explore the current status and position of settlements as smart cities,
- to present the relative position of cities to each other
- to explore the development or "movement" of cities towards becoming smart cities,
- to provide information and model future actions,
- to prepare, establish decisions and to determine development trends.

There are many different ways of assessing the smartness of settlements. The first way of evaluation of city smartness is the usage of indicators, elaboration of indexes and city rankings. Indicators and indexes are useful tools of preparation of location choices for enterprises or investments. They are also aiming at positioning cities according to their competitiveness, strength and weaknesses. Indicators are helping to elaborate strategic priorities and development possibilities. There are many advantages of using indicators and indexes for the evaluation of city smartness. City rankings attract lot of attention in both scientific and public life. They generate discussion and debate on smartness, competitiveness, quality of life, helping to rethink formerly elaborated strategies and development priorities. They also allow to position cities, can be marketing tools in city promotion and contribute to the success of city leaders (Giffinger-Gudrun 2010). The usage of indicators is relatively simple, clear, easily interpretable, easy to understand, visualize, compare and reproducible in time and space.
Still, from the review of different smart city rankings and indexes some limits and problems can be derived:

- The problems of data collection. To conduct a successful smart city ranking, very well defined and available settlement level indicators are needed. The settlement level data are missing in most cases or not updated year by year. Using regional or national data is blurring the differences among cities. Most of the data arisen at city level are not collected and processed as there is no interest in them. Huge data sources owned by private enterprises are not available for research or analysis. To conduct a successful smart city assessment not only "big data", but "right data" is needed. An additional important issue concerns the essential data set for measuring smartness effectively. For this reason it is necessary to implement, develop and improve the existing data bases transforming their contents and information in "smart" way. This situation can involve the need to also change the statistical data production process itself, by moving towards more integrated standardised and industrialised systems (De Santis et al. 2014).
- Lack of checking procedures on the statistical reliability and suitability of chosen indicators.
- The weighing and aggregation of indicators will greatly influence the final results.
- The problems of transparency. Although the methods behind the indexes and rankings are complex, the used methods and the selected indicators are greatly influencing the results, the methodology of data collection and processing are usually not transparent.
- The correlation among indicators and different fields of analysis are quite strong.
- The problems of comparison. As the content of the indicators and the methods of data processing are not transparent and heterogeneous, there is a huge obstacle to enhance comparison. There are several studies based on indexes related to smart cities that are repeated annually (e.g. Smart cities in the world by Boyd Cohen), but even these cannot be compared to each other, as the indicators and methodology used to conduct them are changed every year.

- The lack of dynamic analysis. Indexes reflect the static state of a settlement's "smartness" and livability at a specific time. Little knowledge can be obtained about how the development or behavior of a city is changing, how it reacts to certain situations or critical events. However this might be the true essence of smartness (reduced reaction time, rapid adaptation to abrupt changes). A city cannot be studied separately from its surrounding environment; its operation influences the neighboring areas and settlements that are also asserting a dynamic influence on each other. Using dynamic approach also allows you to provide a more appropriate definition of smartness. As well known, the physical space and the "place" are not equivalent (Giovanella 2013)
- The lack of individual aspects. There are people living in the city who are striving to utilize the resources of their city in an optimal way to achieve a higher quality of life. They have their own motivations, expectations, needs, their own lifestyles. When we only consider indexes, the study will lack this bottom up dimension. Several studies have experimented with including the individual dimensions into the analyses of smart cities. For example there are studies that try to research and present the emotional state of a given settlement from the quality and quantity of posts related to city. Utilizing text processor and analyzer software solutions, these studies measure the emotional state of the people living in or talking about the city. Emotions can be studied in the temporal dimension helping researchers to clarify how the emotional state of the city follows the emotional state of its individual citizens.
- Last but not least there is a problem related to how much effort it presents to build qualitative factors into the indicator system (e.g. quality of services).

Another possible evaluation method is the factor analysis followed by clustering. With factor analysis we can eliminate the problem of having strong correlations between indicators and find the factors that have the closest relation to the "smartness" of the city.

With the help of clustering the data arrays available can be categorized into homogenous groups. These can help us to discover and analyze the spatial structure of cities. Clustering can help us visualize the complex information behind the operation of a cities in a simplified way. It can also help us to eliminate the need for comparison from establishing a ranking of such information. There are many existing methods of clustering. The most well known and most used one to study the spatial organizational patterns of cities is the K-means cluster. During K-means clustering we assign all elements to the cluster with closest center point to that specific element.

An emerging method that has not seen much use in social studies yet is the Self organizing map (SOM). The SOM algorithm grew out of early neural network models, especially models of associative memory and adaptive learning (Kohonen 1984). A new incentive was to explain the spatial organization of the brain's functions, as observed especially in the cerebral cortex. With the help of SOM a problem space with many dimensions can be reduced to a space with less dimensions, mostly to a two-dimensional discrete space. Meanwhile we can visualize the most important aspects of the vector space of many dimensions in the topology of a two-dimensional space. This way we can simultaneously reduce the dimension of the inputs used and sort the elements into groups.

The third group of evaluation methods consists of different models and modeling techniques that enable us to predict future events from existing information and allow us to run a better simulation of complex city systems. One such model is a modified version of the triple helix model, relating the multiple and reciprocal relationships between the three main agencies in the process of knowledge creation and capitalization: universities, industry and government. To the previous three main agencies of knowledge creation, the authors added the civil society (determining a "four helices model"), and for each of the four different drivers of innovations, they indicated the possible indicators of a smart city (Lombardi et al., 2012). Another possible modeling approach can be the analytic network process. The ANP model consists of clusters (i.e. groups of homogeneous

elements of a decision problem), elements (i.e. nodes of the network), interrelationship between clusters, and interrelationship between elements. It allows interactions and feedback within and between clusters and provides a process to derive ratio scales priorities from the elements (Lombardi et al, 2012) The spatial autoregressive models are also possible modelling methods for evaluating smartness of cities.
The analysis of smart city projects and initiatives is an other possible way of evaluation of smart city performance. Manitiu and Pedrini (2015) in their research defined a set of smartness and sustainability indicators applicable to European cities and to assess their outcome in an ex-ante perspective with regard to the implementation of Europe 2020 strategy.
Finally there are surveys on quality of life and different attempts to measure "happiness" of cities. These are qualitative researches surveying citizens of different settlements. In this case smartness is interpreted as a kind of well-being, satisfaction, happiness. They measure the effect of habitat on quality of life. In previous works the research was conducted by quantifying objective factors (Mercer Quality of Living ranking, CSR Hungary Livable City ranking), but there is an increasing demand for including subjective factors into the evaluation. For this reason citizens are asked to fill questionnaires where they have to evaluate their medical status, well-being, satisfaction and happiness. The cities that excel in objective studies are not necessarily the ones where people are most satisfied with their lives (Ballas 2013). This kind of approach is strongly connected to the "science of happiness" and draws attention that adding geographical dimension to happiness analysis is strongly needed.

3. Conclusion

This paper attempted to clarify the meaning of a concept that is getting increasingly popular—that of the smart city, and to explore the possible evaluation methods of cities' smartness. The overview is systematic but can not be complete. The definition of smart city is multi-faced. The usage of ICT, sustainability and better quality of life for people are common elements in the concept.
The paper showed that the assessment of smart city performance is complicated. The aim of this paper was not to define one exclusive way of measurement. The evaluated cities are greatly differing in infrastructural, cultural and governmental terms, so there is no one, universal evaluation model for smart cities. The local facilities, capabilities and limits are determining the road to becoming smart city. A meaningful smart city assessment method should be able to measure individual well-being and satisfaction in the city in a comparable and dynamic way which is a very complex goal. Methodological limits, practical and economical obstacles of data collection at settlement level are also affecting the elaboration of better evaluation system. More specific, focusing on city's vision, strength and weaknesses, using bottom-up approach assessment methods are needed. To elaborate a well-performing smart city assessment tool an interdisciplinary research approach is essential drawing expertise from computer science, statistic, sociology, psychology and economics.

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