Current trends in Smart City initiatives: some stylised facts

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Abstract

The concept of Smart City (SC) as a mean of enhancing the quality of life of citizens has gained increasing importance in policy makers' agendas. However, a shared definition of SC is not yet available, and it is hard to identify common global trends. This paper is an attempt to provide a comprehensive understanding of the notion of SC through a taxonomy of pertinent application domains, namely: natural resources and energy, transport and mobility, buildings, living government, and economy and people. It also explores the diffusion of smart initiatives via an empirical study that has the aim of investigating the ratio of domains covered by a city's best practices to the total of the potential domains of smart initiatives. The paper also has the aim of understanding the role that various economic, urban, demographic, and geographical variables could have in influencing planning approaches to create a smarter city. The results have revealed that the evolution patterns of an SC depend to a great extent on its local context factors. Economic development and structural urban variables are in particular likely to influence a city's digital path, the geographical location to affect the SC strategy, and the density of the population, together with the associated congestion problems, might be important components in determining the routes for SC implementation. This work provides policy makers and city managers with useful guidelines to define and drive their SC strategy and planning actions for the most appropriate implementation domains.

Introduction

Current cities are complex systems that are characterised by massive numbers of interconnected citizens, businesses, different modes of transport, communication networks, services and utilities. Population growth and increased urbanization raise a variety of technical, social, economic and organisational problems that tend to jeopardize the economic and environmental sustainability of cities. The rapid growth faced by several cities has generated traffic congestion, pollution and increasing social inequality (Kim and Han, 2012). In this context, a debate has emerged on the way new technology-based solutions, as well as new approaches to urban planning and living, can assure future viability and prosperity in metropolitan areas (Alawadhi et al., 2012; Dirks et al., 2009; Nam and Pardo, 2011; Nijaki and Worrel, 2012). In this discussion, the concept of Smart Cities (SCs) (Hollands, 2008) has been the subject of increasing attention and it now appears as a new paradigm of intelligent urban development and sustainable socio-economic growth, whose origin can be traced back to the Smart Growth Movement of the late '90s (Harrison and Donnelly, 2011). However, despite the rise in SCs in the urban planners' debate on the future of cities, the diffusion of SC initiatives in countries with different needs and contextual conditions (e.g. in either developed or developing nations) makes it difficult to identify shared definitions and common current trends at a global scale. There is still in fact no general consensus on the meaning of the term SC or on what its describing attributes are. However, there is wide agreement about the fact that SCs are characterized by a pervasive use of Information and Communication Technologies (ICT), which, in various urban domains, help cities make better use of their resources. However, ICT-based solutions can be considered as just one of the various input resources for projects and approaches to urban planning and living that have the aim of improving the economic, social and environmental sustainability of a city. This implies that those cities that are more equipped with ICT systems are not necessarily better cities, and that the number of "smart" initiatives launched by a municipality is not an indicator of city performance, but could instead result in an intermediate output that reflects the efforts made to improve the quality of life of the citizens.

As a consequence of the lack of a common view, investigating the diffusion patterns of SC initiatives around the world may help to generate a better understanding of the characteristics and future trends of SCs and contribute to the current debate. The importance of this analysis lies in the awareness that various obstacles tend to slow down the diffusion process of SC initiatives. According to recent evidence (The Economist, 2013), most of the companies on the market for ICT solutions for cities have not met their revenue targets from 2010 to 2013.

Because of the obstacles that slow down ICT diffusion, and the central role of political, economic and cultural contexts in shaping the way cities try to become smarter, it can be expected that there is not just one unique paradigm of SC evolution throughout the world. As a result, the aim of this research activity was to investigate whether, and how, the emerging models of SCs differ from the concept of SC developed by city planners, technology visionaries and academicians.

This work is an attempt to fill the research gap in the diffusion of SCs through an empirical study on the role that SC initiatives play on the functional domains of urban living. The role of economic, urban, demographic, and geographical factors on the planning approach to the building of a smarter city is investigated by analysing the coverage ratio that SC initiatives have in relation to the extent of their application domains. The paper may thus be considered as a support for local policy-makers and city managers as it articulates the value proposition of SCs in a basket of appropriate initiatives and applications.

The remainder of this paper is structured as follows. The key elements that characterise the notion of SC in the literature are examined and integrated in an extended taxonomy of SC application domains. On the basis of this taxonomy, a sample of 70 international cities has been analysed through the lens of a Coverage Index (CI), which takes into account the number of application domains wherein cities have launched their projects. The relationship between the CI and the economic, social, geographic, demographic and environmental characteristics of a city allows one to find common points and differences in the way the SC paradigm is applied throughout the world. The implications of these analyses are discussed in the final part of the paper with the aim of providing policy-makers with recommendations on the levers that are likely to foster SC initiatives. Finally, possible future research directions are discussed.

Literature review on the Smart City notion

This section is aimed at clarifying the meaning of SC by discussing its characterizing features and their application domains. To this end, a categorization of the possible domains of an SC has been proposed to represent the patterns of SC initiatives in the empirical work presented in this paper.

The characterizing attributes of SC

One part of the SC literature stresses the need for citywide planning and control, and the central function of ICT systems as the city digital nervous systems that obtains data from heterogeneous sources (e.g. sewers, parking spaces, security cameras, school thermostats, traffic lights, etc.). Many SCs are thus sophisticated systems that “sense and act” (REF, (Hall, 2000; Marsa-Maestre et al., 2008), and in which a great volume of real-time information is processed and integrated across multiple processes, systems, organisations and value chains to optimise operations and inform authorities on incipient problems. The role that ICT plays in cities is the same one that these technologies have in organizations and that has been largely described in Information Systems literature and organization studies: improving productivity (i.e. output divided input) through automatic routine processes and by powering managers' decision-making, planning and control activities. In cities, ICT is likely to contribute substantially to solve the emerging problems of urban living. For example, a mixture of the right data and of the right policies and interventions can make morning traffic run more smoothly, or spread out the evening peak energy use.

According to this view of SCs, the deployment of ICT should not be identified with the concept of SC, since smart initiatives do not only entail technology changes, but also investments in human capital and changes in urban living practices and conditions. In other words, ICT is a General Purpose Technology (Bresnhan and Traitenberg, 1995), which is complementary to human and organizational capital and whose usage is shaped by political choices and by the urban ecosystem of the citizens, technology vendors and local authorities, depending on the city's needs and habits. As such, the same ICT system can exhibit different patterns of usage across cities to reflect different needs and conditions in their local contexts. This directs interest towards studying the various diffusion patterns of SC initiatives around the world.

Since ICT is unable to transform cities without human capital, another body of studies has focused on the role of human capital in improving city liveability. As such, SC initiatives can also include human capital investments that are aimed at fostering a city's capacity for learning and innovation, by supporting and motivating the local population in education and by improving their own life and attracting and retaining other valuable inputs from outside, i.e.: talented and highly educated figures, investments from innovative enterprises, investors and entrepreneurs with the financial and human capital to start-up new enterprises (Caragliu et al., 2009; Correia and Wünstel, 2011; Giffinger et al., 2007; Hollands, 2008; Rios, 2008; Toppeta, 2010).

Finally, in previous studies, the adjective "smart" also referred to the government of a city and its capacity to generate innovation in the way services and communication are delivered to the local population (Gonzales and Rossi, 2011).

Application domains of the SC

Basically, the various positions in the debate agree on the fact that an SC should be able to optimise the use and exploitation of both tangible (e.g. transport infrastructures, energy distribution networks, natural resources) and intangible assets (e.g. human capital, intellectual capital of companies, and organisational capital in public administration bodies). The various approaches to the definition of SC are mainly related to two different factors, namely the way cities can steer themselves to achieve this goal of optimisation, and the domains that are more critical for a cleverer usage of urban resources. Some planners, who have echoed Le Corbusier's dictum that a "house is a machine for living in", see cities as factories for life, on the basis of a broad use of ICT that enables central planning and an integrated view of the processes that characterize urban operations. Consequently, the emphasis of this approach is on production and the distribution of energy, transportation and logistics, waste management and pollution control, and it looks at the way ICT can harness information processing in these fields.

The other positions instead view the ways of building SCs as being based more on bottom-up approaches in which cities provide access to data and allow citizens to make their own decisions. Consequently, they stress the importance of investments in “soft” urban living domains wherein ICT plays a more limited role in enabling sustainability and handling “transactions”, which is thus related to welfare and social inclusion policies (e.g. the assistance of disabled citizens), culture and education.

This variety of visions and facets about the SC concept is an expression of the multitude of urban living domains to which technology and policy interventions can be applied. Table 1 provides an overview of the domains that are illustrated in various streams of literature, relevant to the topic of urban development. As can be seen in this table, the domains in which urban development policies are applicable can be classified as “hard” or “soft”, in relation to the importance that the ICT systems have as key enabling technologies. Specifically, hard domains refer to office and residential buildings, energy grids, natural resources, energy and water management, waste management, environment, transport, mobility and logistics. In these settings, an improvement in sustainability relies on the deployment of ICT systems, along with the introduction of appropriate policy interventions and urban planning. In other words, hard domains are the city settings in which the vision of a city that senses and acts can be the most applicable, thanks to the use of sensors, wireless technologies and software solutions to handle “big data” (McKinsey Global Institute, 2011; McAfee and Brynjolfsson, 2012).

--- Table 1 around here ---

By contrast, soft domains include areas such as education, culture, policies that foster entrepreneurship, innovation and social inclusion, as well as communication between local public administrations and the citizens (e-government). In these areas, ICT has a more limited role and is not necessarily aimed at processing and integrating real-time information. This is the case of education, where processes are not based to any great extent on handling transactions. In other cases, such as the one of innovation and social inclusion policies, SC initiatives are not characterised by new technology deployment but rather by public interventions aimed at creating the right societal and institutional conditions (e.g. incentives, ad-hoc organizational bodies, etc.). In the case of culture, public involvement could be aimed at improving the exploitation and attractiveness of a city’s cultural heritage. In the case of policies that foster human capital and innovation capabilities, the role of the local policies in creating the right institutional condition could mean, for example, the establishment and support of local incubators for hi-tech start-ups and their connection to global-scaled innovation systems. Fields such as healthcare and public safety can be positioned somewhere in - between hard and soft domains, as SC interventions in these settings can be characterized by the deployment of sensors and wireless technologies (e.g. the use of such technologies to automate the remote assistance of patients outside hospitals) or by the deployment of practices and campaigns aimed at creating social values. For instance, the city of Yokoama, Japan, has created the “Creative City Yokoama Office”, wherein artists and other creative individuals can meet up, and exhibitions, performances, workshops and similar events can take place (Sasaki, 2010). Moreover, Chicago, through the “Empowerment Zone Program”, has improved the quality of the healthcare services delivered to the poorest areas of the city (Oakley and Tsao, 2007).

Conceptual framework

The application domains illustrated in Table 1 have been grouped into six categories, which in turn include some sub fields. Table 2 illustrates this aggregation. The search for a high-level taxonomy instead of a fine-grained classification can be traced back to our intent to develop insights into the international trends in SC initiatives at a macro level. To this end, the CI takes into account the fields of a given domain that have been covered by initiatives launched by municipalities. In other words, a CI index equal to 1 in a given domain means that the city has recently launched at least one smartness intervention in each area that makes up the domain (i.e. the subfields in table 2). An aggregated CI can be computed from the linear combination of the CIs in each of the six domains above.

--- Table 2 around here ---

The number of urban living domains covered by the spectrum of a city's projects reflects the effort made to improve sustainability at various economic, social and environmental levels, and can be interpreted as the consequence of the needs a city has towards that specific direction and the amount of resources that it uses for this purpose. As such, a comprehensive empirical exploration of the antecedents and impact of SC would imply an analysis of the impact of the coverage ratio of SC initiatives on the actual indicators of sustainability and quality of life in the city. Therefore, a CI should be interpreted as an intermediate factor between input and performance variables at a city level. Figure 1 illustrates the meaning of a CI in relation to a more comprehensive analysis framework, and clarifies the focal point of the present analysis .

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Context variables that characterise the development trends of Smart Cities

A variety of factors can influence the way cities choose to develop SC initiatives. In this paper, we choose to focus on four groups of contextual conditions that have key importance on the resources and the needs of investing in SC cities (see figure 1). The following subsections discuss how and why these conditions are expected to be relevant for the development of SC trends around the world.

Structural factors: size and demographic density

City size can be relevant for the development patterns of SC initiatives for a variety of reasons. First, large cities attract more human capital (Elvery, 2010) and can usually rely on a greater implementation of infrastructural resources for electricity, water and telecommunication infrastructures. Large cities also have critical masses of ICT users, and this may favour a more rapid scaling up and breaking-even for new digital services. This, for example, is the case of infomobility services for urban public transportation, such as BusChecker in London (REF), which are commercialized using a software application for smartphones that is sold for around £3.00. Being a niche market (not every citizen has a smartphone or is willing to pay £3.00 for a mobile application), this business is more likely to only have sufficiently high volumes of users in large cities.

However, large size can also be associated with barriers to SC initiatives. For example, small towns might be ideal settings for pilot projects, as they can deal with shorter installation times when projects requiring investments in distributed infrastructures (e.g. street lighting, smart waste) are needed. As such, they can more easily attract technology vendors who are willing to undertake the experimentation of new technologies, and who, in some cases, can even willing to license the technology free of charge in the start-up phase of the initiative.

Large cities often have a high demographic density, which can be another relevant variable in the assessment of SC trends throughout the world. Large and dense cities ease the flow of knowledge and ideas by putting a greater number of people in contact, by facilitating social interactions (Glaeser and Gottlieb, 2006), and by generating ideas and innovation. Furthermore, cities with high a demographic density have traditionally made a greater effort to develop their local public transportation systems (Jun et al., 2013), and, as a consequence, they are now in more favourable conditions for the launching of SC initiatives in these settings. However, over a certain threshold, demographic density and size lead to diseconomies in many settings, such as in transportation, real estate, security, and energy consumption. Thus, these diseconomies make dense cities less smart, but in the same way, they make them potentially more interested in introducing ICT based initiatives aimed at mitigating the congestion problems induced by such diseconomies.

Economic development

A city's GDP and its growth rate may influence the development of SC initiatives for several reasons, related mainly to the local economic conditions and development rate. Cities and countries with a higher GDP growth rate undergo a higher economic expansion, which influences the financial resources that are available for investments in new transportation, utility and telecommunications infrastructures, and in education. Furthermore, cities with a greater economic development appear more attractive to those people who wish to increase their standard of life (Cheshire and Magrini, 2006; Lambiri et al., 2007) and they are thus in a better position to develop their human capital. Human capital is crucial for the enacting of SC initiatives, since citizens with more human capital are more likely to be end-users (or active contributors in the development stage) of new software tools aimed at improving the quality of urban life.

Technology development

Technology development and diffusion follow path-dependant dynamics. This implies that systems and organizations that have started to invest earlier in a technology trajectory are in more favourable conditions to further develop or adopt emerging technologies belonging to the same trajectory. This principle also holds true for the case of cities that adopt the ICT that characterizes the actual trends of SC initiatives. Specifically, the diffusion of Internet access and the use of Internet-based services among the local population represent a relevant proxy of the development of an Information Society (Beniger, 1986) and, as such, they can facilitate the enactment of smart initiatives in many urban settings. On the other hand, a limited diffusion could reflect a digital divide that hinders the achievement of a critical mass of users. This could jeopardize the development of a variety of SC initiatives and restrain their economic and societal value. This can be the case, for example, of car sharing initiatives, participatory sensing (Beniger, 1986), or issue tracking systems (e.g. the case of StreetBump in Boston or Fixmystreet, etc.). Cities with a digital divide are less favourable settings for economic sustainability at the local level of these initiatives.

The budget for R&D investments in both private and public expenditure represents another proxy of technology and human capital development. Moreover, high R&D investments reflect a higher weight of hi-tech and service sectors on their industrial composition. The countries and cities in which these sectors are more developed are more likely to produce or effectively deploy those technologies that enable many SC initiatives.

Environmental-friendly policies

Environmental sustainability represents a fundamental determinant of urban living quality. The availability of green spaces is an important dimension of smartness, as it can generate many types of socio-economic benefits (Del Saz-Salazarand Menéndez, 2007; Jim, 2013). As cities with such attributes can face lower marginal costs for the further development of SC initiatives aimed at improving their environmental sustainability, they can rely on a more developed infrastructure than polluted cities with limited green areas.

Thus, although the costs for more polluted cities to adopt smart initiatives in transportation, energy and urban planning can be higher, their relative advantage, as well as the effort spent by local policy-makers to enact initiatives aimed at mitigating pollution, can be more evident, given their relevance in public opinion and in the political agenda. It is thus worth analysing whether SC development trends that are expected to affect environmental issues involve green cities as well as cities with a more critical level of pollution (Glaeser, 2011; Zheng et al., 2010).

Other country-specific factors

The chances of a city increasing its level of smartness also depends on some country-specific variables that go beyond its economic, technological and environmental development rate. In particular, country-specific factors can capture a complex array of institutional variables (i.e. type of political leadership, types of strategic guidelines in the current political agenda, etc.), cultural variables, morphological and climatic conditions (e.g. that have a weight in determining the needs and the approaches to the development of an SC policy).

As far as political conditions are concerned, centralization in decision-making power at the political level, political risk, and the level of corruption can influence a city's capability of implementing SC projects. For example, in a country with a moderate-high political risk, multinational ICT enterprises may be more reluctant to enter public-private partnerships, due to the higher economic and political uncertainties. These factors certainly play a role in explaining the considerable number of SC initiatives adopted in some large Asian cities (e.g.: Singapore, Seoul and Hong Kong), which have reported a unique combination of favourable conditions for investment in the current SC trends over the last decade: a centralized governance favouring shorter decision-making processes for public investments and more rapid development times for their execution, a high economic development rate, a low political risk, and unique weather conditions that determine particular needs, with special regard to transportation systems (Mahizhnan, 1999).

Country factors can also point out the differences in the political agenda that can influence the way SC policies are designed and planned. For example, the focus on a knowledge society in the European Union's Lisbon political agenda (Johansson et al., 2006) could lead European cities to put greater emphasis on those policies that foster human capital, education and entrepreneurship.

Methodology

Sample characteristics

The empirical analysis was conducted on a sample of 70 cities that have claimed to have developed projects and best practices in one or more of the SC domains listed in Table 2. The analysis adopted to identify these cities and their related best practices was carried out referring to city rankings[1] on the quality of life, awards (e.g. the Intelligent Community of the Year given by the Intelligent Community Forum), research centres (e.g. MIT's Senseable CityLab), technology analysts (i.e. Gartner and Forrester) and the web sites of the main ICT multinational enterprises involved in SC projects (IBM, Siemens, Cisco, ABB, Alcatel-Lucent, Toshiba). Eighteen of these seventy cities are located in North-America, twenty one in Asia, five in South America, twenty five in Europe and one in Africa. Most of the observations are related to cities with less than 3 million citizens.

Measures

Coverage of the Smart City's domains

A value of either 1 or 0 was assigned to each specific domain and sub-category reported in Table 2, depending on whether a city reports best practices in that specific context, or not. In order to avoid subjective judgements, all five authors independently assigned their scores and the resulting score used for the analysis was the most frequent one.

The Coverage Index (CI) was then calculated for each of the six domains listed in table 2. An aggregate CI was then computed as the sum of the six indices calculated at the

[1] The Siemens' Green City Index about environmental aspects; the European Cities and Regions of the Future ranking proposed by the Financial Times; the Ranking of European medium-sized cities report proposed by Vienna University of Technology; Mercer's Quality of Living survey and the Economist's World's Most Liveable Cities.

level of the individual domains. The CI is an expression of the number of domains covered by the best practices of an SC. In other words, the CI is an indication of the ability of an SC to develop projects and consolidate best practices in a smaller or larger spectrum of vertical domains.

The CI is used to study the impacts on the development of SC initiatives in the identified application domains pertaining to the social, geographic, demographic, and environmental variables that describe the reference context of an urban area. To this end, a linear regression analysis was performed assuming CI as the dependent variable. Computations were performed using the SPSS Statistics® software tool.

The antecedents of the coverage of SC initiatives were operationalized through variables collected from public databases (Census, 2010a; International Monetary Fund, 2010; Census, 2010b; Eurostat, 2012; The World Bank, 2012). Table 3 reports these measures and their related sources, along with their descriptive statistics.

--- Table 3 around here ---

Findings

The data analysis had two objectives. First, when the descriptive statistics were analysed, the goal was twofold: i) to identify the fields with the greatest diffusion of SC initiatives throughout the world; ii) to detect commonalities and differences in the patterns of SC trends across continents.

The second step of the empirical study involved a more comprehensive analysis on how the contextual factors discussed in the conceptual model could influence the different dimensions of the CI. This was obtained through a regression analysis on the different layers of the CI.

Coverage indices in the six SC domains

Table 3 reports an exploratory analysis for the CI observed at the level of the six domains identified in Table 2. The domains with the highest CI are Transportation and Mobility and Natural Resources and Energy. Government is the domain in which the cities included in the sample report the lowest number of initiatives.

In order to identify higher-level factors, the coverage indices in each domain were analysed using factor analysis at an exploratory level. The factor analysis highlighted two dimensions that confirmed the separation into hard vs. soft domains discussed in Table 1. Each item showed the greatest weight for only one factor, thereby supporting the discriminant validity of the measures. For example, the first factor identified by the analysis refers to "hard domains", as it encompasses the Natural Resources and Energy, Transportation and Mobility and Buildings domains. The second factor refers to those domains where the support of the technology to the projects is almost absent, or it is more limited and is not aimed at enabling the city's sensing and acting capability. This factor encompasses the following domains: i) Living, ii) Smart Government; iii) Economy. The score for these two dimensions were computed as two variables that consisted of the sum of the items that resulted to be associated to the related factor. It is worth noticing that the variables that express the two dimensions identified by the factor analysis are negatively correlated (Spearman coefficient -0.212; p-value<0.05). The negative correlation highlights that cities that invest in hard domains are also less likely to invest heavily in soft domains, and vice versa. This result can be considered as evidence which supports the idea that there is no dominant worldwide SC model, but there are at least two models: one focused on the technology vision and one that stresses the soft aspects. The lower mean for the variable used to measure the soft dimensions reflects the fact that a smaller percentage of cities in the sample follows this second SC model than the percentage of cities that follow the technology-based approach.

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Diffusion rates of initiatives in the sub-domains

Figure 2 is a further illustration of the diffusion of SC initiatives. About two thirds of the sample reports the development of projects in the field of renewable energies and half of the sample refers to mobility systems, which represent the areas where enabling technologies are more mature. As can be seen in Table 3, the domains with a lower IC are those related to Government, tourism and culture. Among the hard domains, the fields with the lowest diffusion are the ones in which the enabling technologies are in their early stage of commercial development (e.g. public lighting, water management and agriculture), and where there are few best practices to finance their investments through public-private partnerships .

--- Figure 2 around here ---

Cross-continent patterns of SC development trends

ANOVA analyses have shown significant differences across continents, in relation to the coverage indices for Transport and Mobility, Government, and Economy and People. Asian cities have paid particular attention to the Transport and Mobility domain, whereas they report lower CI in the soft Government and Economy and People domains. This result confirms the trends highlighted in recent studies (Ng and Hills, 2003; Tsou and Cheng, 2012; Thynell et al., 2013; Dahiya, 2012) on the patterns of urbanization of large Asian cities. Countries such as India, China, Taiwan, Singapore and Korea have encountered a mix of conditions over the last few decades that favours investments in these settings: i) a high level of pollution, due to the fact they lag behind international markets in terms of environmental standards and regulations; ii) a considerable economic development that has made it critical for large cities to alleviate congestion and reduce pollution through investments in new physical infrastructures. On the other hand , European cities have so far emphasized softer aspects of the SC concept. This trend reflects that EU policies support R&D and human capital investments as a consequence of the so-called Lisbon Agenda, as well as a lower investment capacity due to the current financial and economic crisis. The Lisbon Agenda in fact encourages governments to increase their spending on R&D and education, to support innovation and research and to promote ICTs (Winden et al., 2007).

Finally, both North and South American cities systematically exhibit lower coverage rates of smart initiatives than their European and Asian counterparts. In particular, there is still a substantial lack of environmental regulation in South America (Castello 2011).

--- Figure 3 around here ---

Antecedents of CI

Regression analyses are performed to understand the influence of contextual variables on the CI. The effect of contextual variables on the CI has in particular been analysed at different levels: firstly by considering the coverage of all the SC domains, and then by analysing the coverage of each single domain, as well as their aggregate measures at the the hard and soft domain levels identified in the factor analysis.

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Structural factors

Despite expectations, the city size (with reference to the size of the population) has not been found to be a significant predictor of the CI. This might be due to the above-mentioned existence of contrasting arguments that suggest a possible positive relationship between city size and attitude to SC investments. Urban demographic density instead showed a significant positive effect on the aggregate coverage index (model 1). Demographic density was found to have a significant and positive effect on Hard Domains (model 2), and in particular on the Transport and Mobility and Buildings domains. This result underlines the fact that dense urban agglomerations face more critical needs in order to build new infrastructures to reduce congestion in transportation and energy use in buildings. Such cities usually have large commercial and residential buildings in which the deployment of ICT solutions for the automation, heating and cooling, and facility management of homes leads to a more efficient maintenance and a reduction in the total cost of ownership.

Environmental variables

The regression also shows a negative effect of pollution on the CI related to the aggregate domains (model 1) and on that related to the hard domains. In other words, pollution - measured as carbon emissions – reduces the intention of a municipality to enact smart initiatives in hard domains. This applies in particular to the Transport and Mobility domain (model 5). Although speculative, a probable explanation is that the most polluted cities are located in developing countries in which complete awareness of the SC concept has not yet been established and the capabilities and the financial resources for investments in new physical and ICT infrastructure to support mobility are still limited.

Economic and technology-related variables

The expectation was that cities with more advanced technological and economic development are likely to be more active in launching and implementing SC initiatives. Contrasting evidence has emerged in support of this expectation. On the one hand, it has been found that cities in richer countries (in terms of GDP per capita) are more active in hard domains (model 2), but are less active in projects aimed at fostering their innovation capabilities and human capital (model 6) than cities in countries with a lower economic development. In a similar way, cities in countries with a greater use of Internet services among the local population are more active in launching initiatives in soft domains, and, in particular, in the Government (model 8) and Economy fields (model 9). This confirms the crucial importance of the telecommunication and human capital infrastructure in enacting e-government and e-democracy initiatives based on increased transparency and citizens' empowerment. The growth rates in the GDP result do not show any significant influence on the model specifications, as their effect is probably covered by the geographical localization dummies (and by the fact that Asian cities have a higher economic growth).

On the other hand, the R&D expenditure result shows a negative effect on the aggregate CI and in particular on the number of fields covered in the Natural Resources and Energy domain (model 4). One explanation of this evidence, although speculative, is that under a certain threshold, national investments in R&D in countries with a low R&D attitude could substitute R&D investments at the city level in the physical infrastructure for the SC.

Other country-specific effects

As expected, cities in the American and Asian regions have exhibited a lower coverage of soft domains, related to human capital and government practices, than European cities. This is likely the consequence of the EU policies enacted to meet the Lisbon agenda with regard to improvements in a knowledge-based society and economy. As far as “hard” domains are concerned, namely transportation, buildings, energy and natural resources, no significant geographical differences have emerged, except the negative effect of South American cities, That is, South-American cities are less active in all the hard domains considered in the analysis, thereby showing persistence in their structural weaknesses in relation to their transportation, electricity and telecommunication networks.

Finally, cities in countries with a lower degree of transparency in public administration processes are more likely to sustain e-government initiatives, which shows that SC trends are exploited in some domains to invert their structural attitude.

Discussion

In the era of knowledge economy, urban areas should not only adjust redistribute their local wealth, but also invest in the quality of life of their citizens. In this context, SC is a wide notion that encompasses many different socio-environmental aspects and ICT applications. However, it has so far received limited attention by academic empirical researchers . Despite the recent growing interest in the topic, public administrations still need support to structure the concept of the smartness of a city, to capture its implications, to identify benchmarks at the international level, and to find improvement opportunities.

In this scenario of limited empirical evidence and hype on SCs, this paper can be considered a first attempt to provide a comprehensive definition of the SC concept and an empirical assessment of current trends at the international level. In doing so, the paper proposes a definition of SC that is based on a combination of both academic and the practitioner literature.

From a theoretical perspective, the exploration of taxonomies that are relevant for the definition of an SC and its application domains allows comprehensive knowledge to be acquired of such a notion. This knowledge goes beyond the focus of ICT vendors on digitalization, and also takes into consideration some of the aspects that are related to soft components that have crucial importance on the urban, social and economic development of a city, such as human capital.

As far as its empirical contribution is concerned, the paper essentially highlights three key issues. First, there is no dominant design for SCs, as economic development and structural urban variables are important in influencing the way cities design their digitalization paths. In this context, a path dependency effect can be highlighted, as wealthier cities and those with more "open" democracies exhibit higher investments in fields that are related to the development of innovative capabilities. Furthermore, a negative correlation between the scope of SC interventions in hard and soft domains has been reported: cities that are more active in the domains that are aimed at improving their capacity to "sense and act" through ICT systems are less likely to differentiate the initiatives launched for soft domains related to human capital, cultural heritage, and innovation.

The second key issue concerns the influence of geographical variables. Again, this observation reflects the principle that each country follows its own smartness strategy, due to the importance of its local socio-economic and cultural background. On the basis of this evidence, it is possible to claim that the exportation of best practices may not occur easily.

Finally, the number of city domains covered by smart initiatives does not seem to be correlated to the size of a city, considered in terms of population, but it is significantly correlated to the demographic density. This shows that both large and small cities exhibit some strengths and weaknesses in terms of innovation capabilities. Basically, small cities represent a good “ecosystem” to launch new experimentation at a limited scale and may exhibit less inertia stemming from past investments in ICT infrastructures. On the other hand, large cities usually face more critical needs and problems that entail digitalization endeavours and they can attract technology vendors more easily as they can offer a larger potential market of more educated citizens. However, density is a factor of developing SC initiatives, as it increases problems related to urban congestion at various levels of the physical infrastructure (e.g. transportation, energy distribution, waste and water management, etc.).

Policy implications

Overall, this study provides policy makers and city managers with useful general guidelines and suggests some practical implications. On the one hand, the proposed definition offers a systemic and practical perspective of the SC notion as the CI enables a preliminary assessment to be made in order to direct the SC planning efforts towards the appropriate application domains and initiatives. In other words, the analysis of the relationships between the CI and the selected contextual variables can help identify the main factors that enable the development of projects which could contribute towards increasing the smartness of a city.

Moreover, a practical approach has been proposed to identify the actual efforts that are made to increase the smartness level of a city, to set strategic objectives, and to select effective actions in order to achieve the predetermined targets.

In addition, three further conclusions can be drawn, based on the findings of this work. Firstly, the negative correlation between hard and soft domains is an indicator that many municipalities and their technology vendors mainly focus on technology, and not on people. However, complementarities between ICT systems and the human/relational capital of the local population should be achieved to facilitate the building of a comprehensive approach for the SC evolution.

Secondly, those cities that have planned a broader portfolio of investments in smart initiatives are not necessarily better or more liveable cities. Rather than reaching a good level of democracy and quality of life, these cities could turn into panoptical environments in which the citizens are persistently observed and scrutinized. For example, their vulnerability and resilience could be put at risk as their digital systems could be more easily paralyzed by hackers or bugs. By requiring greater accessibility to real-time information through electronic devices, and by using taxation to entail investments in digital infrastructure, these cities could follow new unintended paths towards social divide. Policy-makers and city planners should therefore take vulnerability, resilience, financial sustainability and social inclusion into consideration in their approaches to build cleverer cities.

Thirdly, the policy makers of cities that show less technological and economic development should find ways of breaking the path dependency on technology adoption in order to reduce the delay in implementing the SC paradigm. To this end, cities should enact “bottom-up” approaches that are not just based on the deployment of complex technological platforms, but rather on harnessing the collective intelligence and creativity of their citizens. For example, smart phones rather than infrastructure sensors could offer an alternative way of collecting mass user-centric real-time data. The way these bottom-up approaches can be developed is still unclear, but possible directions for future research have been pointed out.

Future research could also be directed towards overcoming some limitations inherent to the present study, concerning an extension of the sample and the introduction of life quality indicators to help assess the impact of SC strategies and their consistency with local urban contexts.

Conclusion

This work can be considered a preliminary contribution to the development of empirical research in order to obtain a better understanding of the current phenomena of SCs.

To this end, six main domains and the associated sub-domains of SC deployment have been classified (i.e.: natural resources and energy, transport and mobility, buildings, living, government, as well as economy and people) and a CI has been defined as the ratio of domains covered by a city's best practices to the total of the potential domains or sub-domains. A dataset of contextual variables has been collected and regression analyses have been conducted in order to understand the relationship between various geographical, urban, demographical, human capital, environmental and technology-related variables, and the dependent CI variable.

The results of this study have revealed that there is no unique global definition of SC , and that the current trends and evolution patterns of any individual SC depend to a great extent on the local context factors. City policy makers are therefore urged to try to understand these factors in order to shape appropriate strategies for their SCs. This study is in particular based on a framework that could also be applied to make a better selection of investment opportunities in periods of limited financial resources and to prioritize SC initiatives in the various domains and sub-domains of potential implementation, considering their ability to maximize the benefits associated with the specific competitive characteristics of an SC.

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Prevalence of investments in:	Domain	**Main objectives**	**References**
"Hard" Domains	Energy grids	Automated grids that employ ICT to deliver energy and enable information exchange about consumption between providers and users, with the aim of reducing costs and increasing reliability and transparency of energy supply systems.	Chourabi et al., 2012; Correia and Wünstel, 2011; Mahizhnan, 1999; Steria, 2011
	Public lighting, natural resources, and water management	Managing public lighting and natural resources. Exploiting renewable resources such as heat, solar, cooling, water, and wind power.	Accenture, 2011; Correia and Wünstel, 2011; Dirks et al., 2009; ; Hughes et al., 2013; Nam and Pardo, 2011; The Climate Group et al., 2011; Think, 2011; Toppeta, 2010
	Waste management	Applying innovations in order to effectively manage the waste generated by people, businesses, and city services. It includes waste collection, disposal, recycling, and recovery.	Accenture, 2011; The Climate Group et al., 2011
	Environment	Using technology to protect and better manage environmental resources and related infrastructure, with the ultimate goal of increasing sustainability. It includes pollution control.	Atzori et al., 2010; Caragliu et al., 2009; Chourabi et al., 2012; Inayatullah, 2011; Nam and Pardo, 2011; Tiwari et al., 2011;
	Transport, mobility, and logistics	Optimising logistics and transportation in urban areas by taking into account traffic conditions and energy consumption. Providing users with dynamic and multi-modal information for traffic and transport efficiency. Assuring sustainable public transportation by means of environmental-friendly fuels and innovative propulsion systems.	Atzori et al., 2010; Caragliu et al., 2009; Correia and Wünstel, 2011; Dirks et al., 2009; Giffinger et al., 2007; La Greca et al., 2011; Munizuri et al., 2005; Nam and Pardo, 2011; Steria, 2011; The Climate Group et al., 2011; Think, 2011; Toppeta, 2010; Washburn et al., 2010
	Office and residential buildings	Adopting sustainable building technologies to create living and working environments with reduced resources. Adapting or retrofitting existing structures to gain energy and water efficiency.	Accenture, 2011; Steria, 2011; The Climate Group et al., 2011; Think, 2011; Washburn et al., 2010
	Healthcare	Using ICT and remote assistance to prevent and diagnose diseases, and deliver the healthcare service. Providing all citizens with access to an efficient healthcare system characterised by adequate facilities and services.	Accenture, 2011; Atzori et al., 2010; Correia and Wünstel, 2011; Dirks et al., 2009; Nam and Pardo, 2011; The Climate Group et al., 2011; Washburn et al., 2010
	Public security	Helping public organizations to protect citizens' integrity and their goods. It includes the use of ICTs to feed real-time information to fire and police departments.	Accenture, 2011; Dirks et al., 2009; Nam and Pardo, 2011; Washburn et al., 2010
Soft domains	Education and culture	Capitalising system education policy, creating more opportunities for students and teachers using ICT tools. Promoting cultural events and motivating people participation. Managing entertainment, tourism, and hospitality.	Accenture, 2011; Dirks et al., 2009; Mahizhnan, 1999; Nam and Pardo, 2011; Washburn et al., 2010
	Social inclusion and welfare	Making tools available to reduce barriers in social learning and participation, improving the quality of life, especially for the elder and	Atzori et al., 2010; Bakıcı et al., 2013; Caragliu et al., 2009; Chourabi et al.,

	disabled. Implementing social policies to attract and retain talented people.	2012; Correia and Wünstel, 2011; Giffinger et al., 2007; Mahizhnan, 1999; Toppeta, 2010
Public administration and (e-) government	Promoting digitised public administration, e-ballots and ICT-based transparency of government activities in order to enhance citizens empowerment and involvement in public management.	Accenture, 2011; Bakıcı et al., 2013; Caragliu et al., 2009; Chourabi et al., 2012; Correia and Wünstel, 2011; Dirks et al., 2009; Giffinger et al., 2007; Odendaal, 2003; Steria, 2011; Think, 2011; Toppeta, 2010; Washburn et al., 2010
Economy	Facilitating innovation, entrepreneurship and integrating the city in national and global markets.	Bakıcı et al., 2013; Caragliu et al., 2009; Chourabi et al., 2012; Correia and Wünstel, 2011; Giffinger et al., 2007; Mahizhnan, 1999; Toppeta, 2010

Table 1. Classified literature on the domains of a Smart City

Domain	Sub-domain	Description
Natural resources and energy	Smart grids	Electricity networks able to take into account the behaviours of all the connected users in order to efficiently deliver sustainable, economic, and secure electricity supplies. Smart grids should be self-healing and resilient to system anomalies.
	Public lighting	Illumination of public spaces with street lamps that offer different functions, such as air pollution control and Wi-Fi connectivity. Centralised management systems that directly communicate with the lampposts can allow reducing maintenance and operating costs, analysing real-time information about weather conditions, and consequently regulating the intensity of light by means of LED technology.
	Green/renewable energies	Exploiting natural resources that are regenerative or inexhaustible, such as heat, water, and wind power.
	Waste management	Collecting, recycling, and disposing waste in ways that prevent the negative effects of an incorrect waste management on both people and the environment.
	Water management	Analysing and managing the quantity and quality of water throughout the phases of the hydrological cycle and in particular when water is used for agricultural, municipal, and industrial purposes.
	Food and agriculture	Wireless sensor networks to manage crop cultivation and know the conditions in which plants are growing. By combining humidity, temperature, and light sensors the risk of frost can be reduced and possible plant diseases or watering requirements based on soil humidity can be detected.
Transport and mobility	City logistics	Improving logistics flows in cities by effectively integrating business needs with traffic conditions, geographical, and environmental issues.
	Info-mobility	Distributing and using selected dynamic and multi-modal information, both pre-trip and, more importantly, on-trip, with the aim of improving traffic and transport efficiency as well as assuring a high quality travel experience.
	People mobility	Innovative and sustainable ways to provide the transport of people in cities, such as the development of public transport modes and vehicles based on environmental-friendly fuels and propulsion systems, supported by advanced technologies and proactive citizens' behaviours.
Buildings	Facility management	Cleaning, maintenance, property, leasing, technology, and operating modes associated with facilities in urban areas.
	Building services	Various systems existing in a building such as electric networks, elevators, fire safety, telecommunication, data processing, and water supply systems. Computer-based systems to control the electrical and mechanical equipment of a building.
	Housing quality	Aspects related to the quality of life in a residential building such as comfort, lighting, and Heating, Ventilation and Air Conditioning (HVAC). It includes all that concerns the

		level of satisfaction of people living in a house.
Living	Entertainment	Ways of stimulating tourism and providing information about entertainment events and proposals for free time and night life.
	Hospitality	Ability of a city to accommodate foreign students, tourists, and other non-resident people by offering appropriate solutions to their needs.
	Pollution control	Controlling emissions and effluents by using different kinds of devices. Stimulating decisions to improve the quality of air, water, and the environment in general.
	Public safety	Protecting citizens and their possessions through the active involvement of local public organisations, the police force, and the citizens themselves. Collecting and monitoring information for crime prevention.
	Healthcare	Prevention, diagnosis, and treatment of disease supported by ICT. Assuring efficient facilities and services in the healthcare system.
	Welfare and social inclusion	Improving the quality of life by stimulating social learning and participation, with particular reference to specific categories of citizens such as the elder and disabled.
	Culture	Facilitating the diffusion of information about cultural activities and motivating people to be involved in them.
	Public spaces management	Care, maintenance, and active management of public spaces to improve the attractiveness of a city. Solutions to provide information about the main places to visit in a city.
Government	E-government	Digitizing the public administration by managing documents and procedures through ICT tools in order to optimise work and offer fast and new services to citizens.
	E-democracy	Using innovative ICT systems to support ballots.
	Procurement	Allowing the public sector improving procurement procedures and the associated contract management, with the purpose of assuring best value for money without decreasing quality.
	Transparency	Enabling every citizen to access official documents in a simple way and to take part in the decision processes of a municipality. Decreasing the possibility for authorities of abusing the system for their own interests or hiding relevant information.
Economy and people	Innovation and entrepreneurship	Measures to foster the innovation systems and entrepreneurship in the urban ecosystem (e.g. presence of local incubators).
	Cultural heritage management	The use of ICT systems (e.g. augmented reality technologies) for delivering new customer experience in enjoying the city's cultural heritage. Use of asset management information systems to handle the maintenance of historical buildings,
	Digital Education	Extensive Use of modern ICT tools (e.g. interactive whiteboards, e-learning systems) in public schools
	Human capital management	Policies to improve human capital investments and attract and retain new talents,

	avoiding human capital flight (brain drain).

Table 2. Classification of Smart City domains and sub-domains

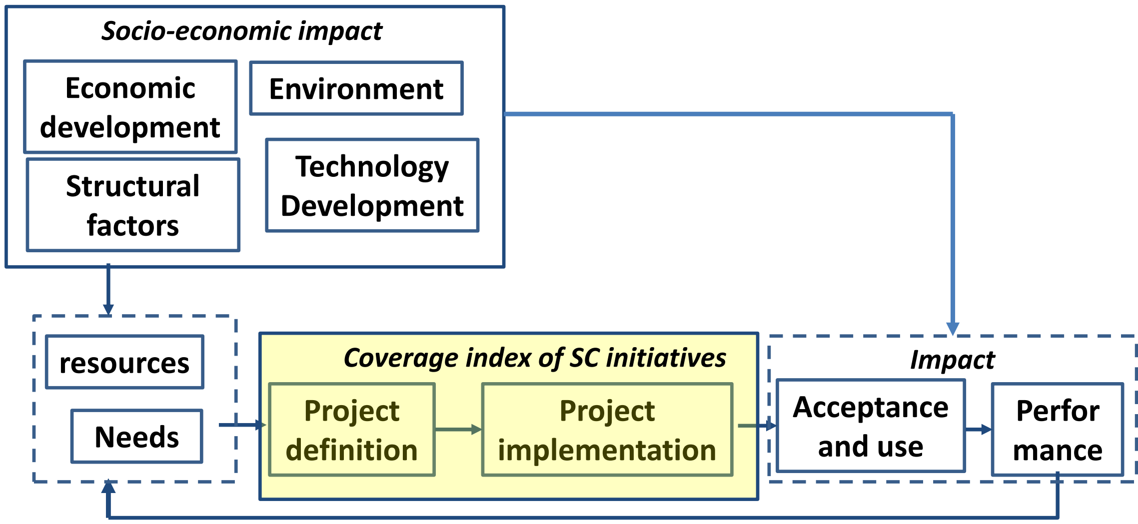


Figure 1. Conceptual framework.

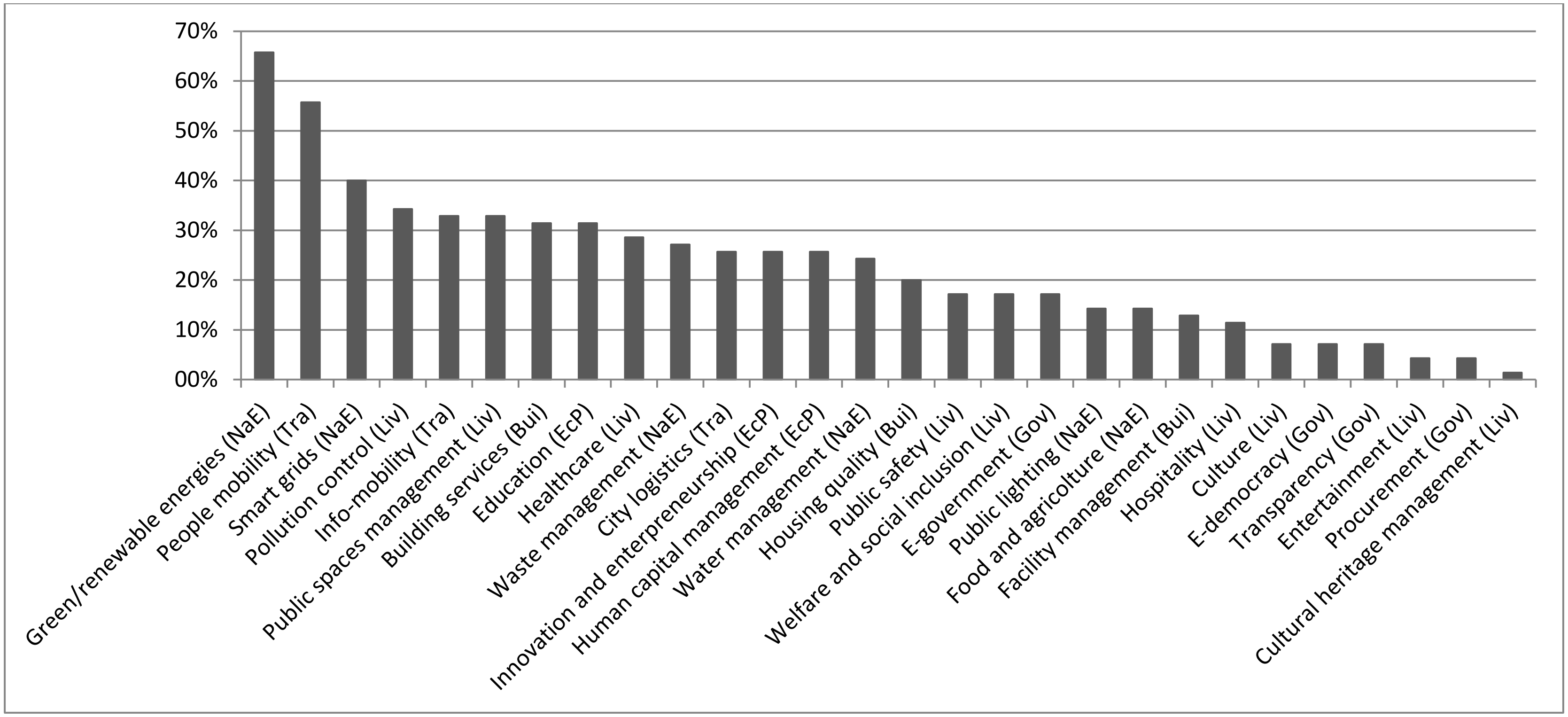
Broken lines refers to constructs of the framework not analyzed in this work

Context variable	Unit	Mean	StDev	Coeff. of Variation	Min	Max	Source
Structural factors							
Population	# inhabitants	2,334,386	3,049,843	1.31	52,497	13,185,502	Census, 2010 [3]; Eurostat [4]
City area	Squared Km	617	970	1.57	18	6,598	Census, 2010 [3]; Eurostat [4]
Demographic Density	# inhabitants/ Km^2	5,447	6,394	1.17	436	42,363	Census, 2010 [3]; Eurostat [4]
Development of Environment protection policies							
Carbon emissions per capita	ton/inhabitant	7.16	4.54	0.63	0.70	22.20	Economist Intelligence Unit, 2009-2011
Economic development							
GDP per capita	$/inhabitant	35,926	18,079	0.50	2,800	70,927	Economist Intelligence Unit, 2009-2011
Unemployment rate	%	7.51	3.61	0.48	2.00	21.00	Eurostat [4]
Country GDP per capita	$/inhabitant	35,204	17,076	0.49	1,160	59,400	International Monetary Fund, 2010 [2]
Country GDP growth	%	4.01	3.08	0.77	-4.00	15.00	World Bank [6]
Technological development							
Households with Internet access	%	60.33	23.15	0.38	8.00	99.00	Eurostat [4]; Intelligent Community Forum, 2009-2012 [5]
Country R&D expenditure	% GDP	2.15	0.97	0.45	0.10	3.72	World Bank [6]
Country-specific variables							
Corruption Perceptions Index (CPI)	Score measuring level of corruption in the public sector as perceived by a	6.63	2.13	0.32	2.40	9.30	Transparency International [7]

the informed view of a panel of experts and analysts

Table 3. Variables describing the urban context variables included in the conceptual framework:

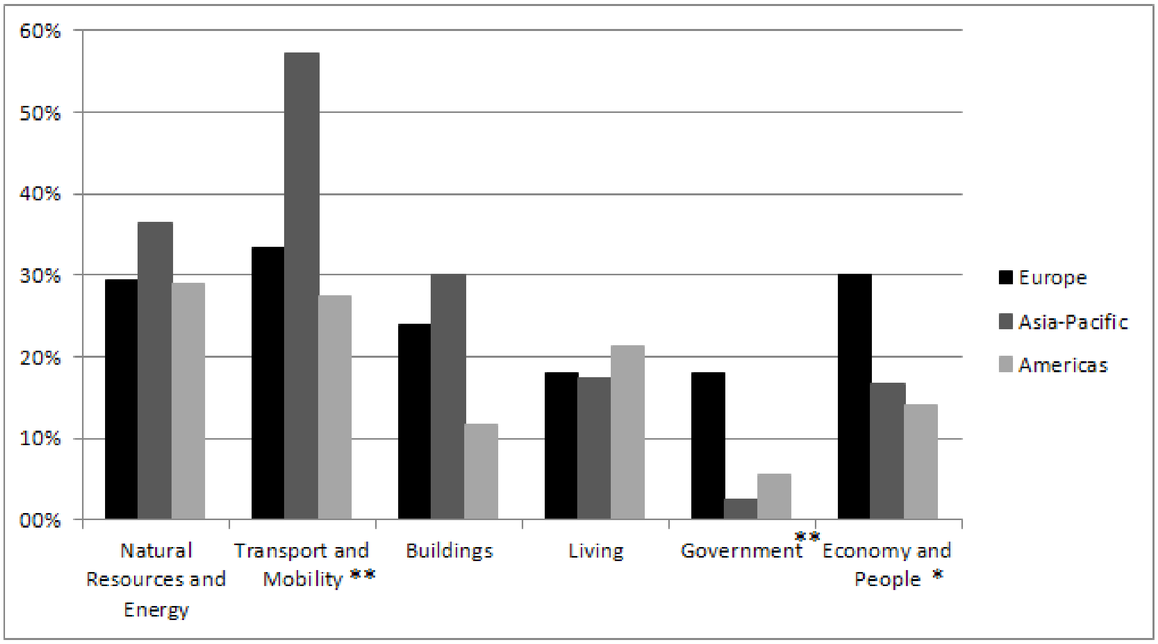
descriptive statistics and sources employed



Legend:

- NaE = Natural Resources and Energy
- Tra = Transport and Mobility
- Bui = Buildings
- Liv = Living
- Gov = Government
- EcP = Economy and People

Figure 2. Coverage Index by sub-domains



** = p-value < 0.01 in the ANOVA
* = p-value < 0.05 in the ANOVA

Figure 3. Coverage Index by region

Variable	CI	HD	SD	Nat.Res&En.	Trasp.&Mob.	Buildings	Living	Government	Economy
Dummy N_America	-0.311	-0276	-0.035	0.036	-0.174	-0.138	0.016	-0.005	-0.001
Dummy S_America	-0.489*	-0.903***	0.413***	-0.219*	-0.379**	-0.304**	0.218***	0.209***	-0.014
Dummy Europe	0.043	-0.333	0.377**	-0.078	-0.192	-0.063	0.0311	0.161**	0.184*
GDP per capita (e^-6)	4.000	1.030**	6.28[x]	6.870***	1.620	1.780	-18.700	-2.070	-4.020[x]
GDP growth	0.025	0.025	0.001	0.012	-0.001	0.136	-0.007	0.003	0.003
GDP (e^-6)	3.780	2.490	1.290	-830.300	53.700	3.860	-1.570	6.650[x]	-3.790
CO_2 emissions	-0.027[x]	-0.025*	-0.001	-0.055	-0.015*	-0.047	-0.001	0.003	-0.004
Internet diffusion	0.037	-0.002	0.005**	-0.002	0.001	0.001	-0.001	0.002**	0.003**
Transparency	0.013	-0.002	0.014	0.017	0.004	-0.239	0.009	-0.047[x]	0.005**
R&D Expenditure	-0.222*	-0.138	-0.084	-0.071*	-0.031	-0.353	-0.004	-0.045	-0.035
Population	0.006	-0.148	0.021	0.012	0.002	-0.302	0.011	0.014	-0.004
LN Density	0.216***	0.220**	-0.004	0.028	0.097**	0.094*	-0.006	-0.016	0.185
Constant	-0.374	-0.393	0.188	-0.141	-0.199	-0.053	0.134	0.026	-0.141
R-Squared	0.338	0.420	0.273	0.277	0.308	0.199	0.170	0.356	0.263

Table 5. Coefficients of the Regression Analysis

* 0.05<p-value<0.1
** 0.01<p-value<0.05
*** p-value<0.01