A Unified Smart City Model (USCM) for Smart City conceptualization and benchmarking

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A Unified Smart City Model (USCM) for smart city Conceptualization and Benchmarking

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ABSTRACT

Smart cities have attracted an extensive and emerging interest from both science and industry with an increasing number of international examples emerging from all over the world. However, despite the significant role that smart cities can play to deal with recent urban challenges, the concept has been being criticized for not being able to realize its potential and for being a vendor hype. This paper reviews different conceptualization, benchmarks and evaluations of the smart city concept. Eight different classes of smart city conceptualization models have been discovered, which structure the unified conceptualization model and concern smart city *facilities* (i.e., energy, water, IoT etc.), *services* (i.e., health, education etc.), *governance*, *planning and management*, *architecture*, *data* and *people*. Benchmarking though is still ambiguous and different perspectives are followed by the researchers that measure -and recently monitor- various factors, which somehow exceed typical technological or urban characteristics. This can be attributed to the broadness of the smart city concept. This paper sheds light to parameters that can be measured and controlled in an attempt to improve smart city potential and leaves space for corresponding future research. More specifically, *smart city progress, local capacity*, *vulnerabilities for resilience* and *policy impact* are only some of the variants that scholars pay attention to measure and control.

Keywords

Smart city; e-government; measurement; benchmarking; modeling; frameworks; architectures.

1. INTRODUCTION

Smart cities have been research for over a decade and there are many ways of looking at Smart Cities. Recently Smart Cities are viewed as ecosystems which are generally defined as communities of interacting organisms and their environments, and are typically described as complex networks formed because of resource interdependencies (Gretzel et al., 2015). Similarly, an ecosystem can be seen as "an interdependent social system of actors, organizations, material infrastructures, and symbolic resources" (Maheshwari and Janssen, 2014). Ecosystems, like other kinds of systems, are comprised of elements, interconnections and a function/purpose, but are special types of systems in that their elements are intelligent, autonomous, adaptive agents that often form communities and also because of the way they adapt to elements being added or removed. According to this definition, four critical elements exist in ecosystems: (1) interaction/engagement; (2) balance; (3) loosely coupled actors with shared goals; and, (4) self-organization (Gretzel et al., 2015). This term has been adopted by businesses, where an "ecosystem" describes the relationships between economic entities (i.e., producers, distributors, intermediaries, consumers etc.). Moreover, information and communication technologies (ICT) industry uses the term of digital ecosystems, which are focused on interactions among technological agents (devices, databases, programs, etc.) and respective information flows and form the infrastructure for digital business ecosystems.

Smart cities have been realized as intelligent digital ecosystems installed in the urban space (Neirotti et al., 2014; Piro et al., 2014; Desouza and Flanery, 2013; Wey and Hsu, 2014; Lee et al., 2014; Giffinger et al., 2007; Churabi et al., 2012). However, smart cities have not been limited to ICT and they shifted to '*smart people*' and their corresponding creativity. From this point of view, they are focused on enhancing urban life regarding six dimensions: people, government, economy, mobility, environment and living (Giffinger et al., 2007). Angelidou (2014) approached smart city using a civil engineering and urban architecture lens and classified smart cities as new versus existing cities, and corresponding smart city projects to "soft" versus "hard" implementations. More than 150 smart city cases can be observed around the world, which can be classified in (a) from-scratch city cases; (b) hard ICT infrastructure focused cases; and (c) soft ICT infrastructures in the urban space (Anthopoulos et al., 2016). Since there is no clear smart city approach yet, there have been several attempts by international organizations to standardize smart city solutions, such as for smart water, energy, transportation, buildings etc.

Recently, scholars have started criticizing the use of smart city concept and potential (see for example Söderström et al., 2014, Nam and Pardo, 2011; Brown, 2014). Some scholars argue that smart city is mostly the outcome of vendors' marketing campaigns (Söderström et al., 2014), others say that smart cities reflect little more than usual urban innovations (Nam and Pardo, 2011), while Brown (2014) criticizes the whole concept of smart city by questioning their effectiveness. Moreover, many scholars argue about technological adjectives to the "city". For instance, Allwinkle and Cruickshank (2011) argue about the "self-congratulating" efforts that city leaders follow when they claim to be "smart" and in this regard they differentiate "smart city" (the city that holds the computational power to perform tasks) from "intelligent city" (the city that utilizes the results from the application of innovation within the urban space). Churabi et al. (2012) compare the alternative technological adjectives to the smart city, while Anthopoulos and Fitsilis (2013) define a roadmapping tool for smart city technological adjective adoption.

To shed light on the smart cities concepts, various models for understanding and conceptualizing smart cities have been developed, which aim to define their scope, objectives and architectures. Also benchmarking methods for comparing smart city initiatives with each other have been developed. The aim of this paper is to analyze the existing smart city conceptualization modeling and benchmarking methods. Such a presentation is of extreme interest to the smart city domain, due to the continuous public spending in this domain, for which no agreed framework has been defined to evaluate the achievements regarding the initially grounded expectations.

The remainder of this paper is structured as follows: section 2 provides an overview of the research approach, followed by an analysis of existing smart city modeling and benchmarking approaches and concluding with a brief discussion on the most appropriate to apply for the purposes of this paper. The following section discusses findings, while section 5 contains some conclusions and future thoughts.

2. RESEARCH APPROACH

To attain the objective literature was reviews using the following sources: international standards organizations for smart city documents; and SCOPUS, with searches only in journals that publish smart city articles (Anthopoulos, 2015), with the combination of terms "smart city", "model" and "assessment or evaluation or benchmarking". Article search was performed within the period of 1997 (appearance of smart city concepts in literature) to early 2016. More than 4,800 articles were returned from this crawl, where screening was used to leave out irrelevant publications like editorial, measurements on individual smart solutions (i.e., smart water; smart transportation etc.) as well as articles discussing issues mostly focused on city growth (like "urban growth assessment") or modeling and benchmarking in general. Screening examined citations that leave space for further exploration resulted in 48 publications as shown in Table 1.

Search terms	SCOPUS	GOOGLE SCHOLAR	Articles After Screening	Citations
"smart city" & "model" & "assessment"	49	4,830	48	Albino and Dangelico (2015); Anthopoulos (2015); Anthopoulos and Fitsilis (2013); Bakici et al. (2013); Baron (2012); Batty et al. (2012); Bellini et al. (2014); Calvillo et al. (2016); Caragliu et al. (2011); da Cruz and Marques (2014); De Marco et al. (2015); Desouza and Flanery (2013); Duarte et al. (2014); Edvinsson (2016); Fan et al. (2016); Fei. (2012); Giffinger et al. (2007); Glebova et al. (2014); Hancke et al. (2013); Kii et al. (2014); Kourtit et al. (2014); Hollands (2008); ISO (2014); ITU (2014); Lazaroiu and Roscia (2012); Liu et al. (2014); Lee et al. (2013); Lee et al. (2014); Leydesdorff and Deakin (2011); Lombardi et

				al. (2012); Malek (2010); Marsal-Llacuna et al. (2015); Mori and Christodoulou (2012); Naphade et al. (2011); Neirotti et al. (2014); Pires et al. (2014); Shapiro (2006); Shwayri (2013); Singhal et al. (2013); Söderström et al. (2014); Strategic Energy Technologies Information System (SETIS) (2012); Thite (2011); Tsolakis and Anthopoulos (2015); United Nations (2014); UN Habitat (2014); Winters (2011); Yovanof and Hazapis (2009); Zygiaris (2012)

3. FINDINGS

3.1 Smart city conceptualization models

Many scholars and several organizations try to conceptualize smart city and understand its synthesis with alternative models (Table 1). This conceptualization has been performed from different perspectives and in this respect, some aggregation is necessary. The first class of models that comes up from this aggregation addresses smart city *architecture* and corresponding component definition. In this respect, Anthopoulos (2015) compared eight (8) models and concluded to a seven-axe modeling tool, which confirms the previously mentioned 6 dimensions of smart city (Giffinger et al., 2007) and extends them with *coherency* in terms of social equity and engagement, while Neirotti et al. (2014) extend it with the incorporation of *smart building*. Glebova et al. (2014) conceptualize smart city with 5 key elements (intellectual transport system, public security, energy consumption management and control, environmental protection and ICT) and they define indexes to measure ICT component in Russian cities. Hollands (2008) discusses about smart city structure in terms of instrumentation (based on data collection), interconnection (enable data flow) and smart (utilize data to improve urban living). Hancke et al. (2013) define the sensing areas in smart city and develop a corresponding architecture. IBM (Söderström et al., 2014) uses a nine pillar system and an equation that combines instrumentation, interconnection and intelligence. Naphade et al. (2011) suggested an alternative smart city model that consists of alternative 7 key elements: government services, transportation, energy and water, healthcare, education, public safety and other core ICT systems. Yovanof and Hazapis (2009) define an architectural framework for smart service delivery, which consists of infrastructure, service and policy. Finally, Zygiaris (2012) introduced a smart city reference model, which consists of six layers (innovation, applications, integration, instrumentation, interconnection, environment and city), each consisting of several components and entities for smart city formulation.

The second class of models analyzes smart city with a focus to its *governance*. From this point of view, Albino and Dangelico (2015) compare alternative smart city definitions, theories and approaches and summarize them to four dimensions (networked infrastructute; urban growth; social inclusion and environment). On the other hand, Baron (2012) uses a 3-level model to conceptualize intelligence for urban resilience. The International Standards Organization (ISO, 2014b) uses a table to define city characteristics, where smartness is pursued. The International Telecommunications Union (ITU, 2014a) in its attempt to define smart city conceptualized it with 4 core themes and 4 attributes. Lee et al. (2014) presented a framework, which focuses on the integration technological and institutional perspectives in attempting to understand the process of building a smart city and consists of 6 ”stylized facts”: urban openness; service innovation; partnership formation; urban proactiveness; infrastructure integration; and governance. Additionally, Leydesdorff and Deakin (2011) argue that community concerns a key component of the city innovation system. Their approach utilizes the triple-helix model, which studies networks of university, industry and government and generates knowledge and innovation under a disciplined manner. Among their findings, the application of the triple-helix model in two cities (Montreal and Edinburgh) shows that cultural development within a city is not a spontaneous product of market economics, but a product of the policies which need to be carefully constructed by a governing authority. In general, cities can be considered as densities in networks among three relevant dynamics: the intellectual capital of universities, the industry of wealth creation, and their participation in the democratic government which forms the rule of law in civil society. Similarly, Lombardi et al. (2012) focus on the triple helix model again, which they extend with a civil society indicator group, in order to measure smart city components performance. Lombardi et al. (2012) adopted Giffinger et al. (2007) model, but they exclude smart mobility from their model. Furthermore, Liu et al. (2014) defined a value chain assessment model, which was inspired by Porter (1985) business value chain analysis (primary activities: inbound logistics, operations, outbound logistics, marketing and sales, and service; supportive activities: firm infrastructure, human resources, technology development and procurement). This value chain structure was aligned to Giffinger et al. (2007) and Naphade et al. (2011) smart city models. According to Liu et al. (2014), 33 elements concern smart city primary activities, while another 27 address the supportive activities. Finally, United Nations Habitat (United Nations, 2014) defined five dimensions for city prosperity, which have been adopted by standardization bodies in their benchmarking systems. International Standards Organization (2014) proposed a standard for city services and quality of life, as a means to measure smart city sustainable development.

The third model class defines tools for smart city *management*. In this respect, Lee et al. (2013) utilized Technology Roadmapping in an attempt to predict technology development in smart city. More specifically, they applied Quality Function Development (QFD) and defined interconnections between services and devices, and between devices and technologies in smart city. Technology roadmapping was capitalized by Anthopoulos and Fitsilis (2013) too, as a means to define patterns for smart city technological evolution and they showed that cities evolved from one technological form to another, while eco-city is the most preferred among the others.

The next class emphasizes *data*, where Batty et al. (2012) adopted IBM (Söderström et al., 2014) and Giffinger et al. (2007) approach and defined a framework for smart city programme definition, which consists of three components: data analysis, infrastructure and management. Bellini et al. (2014) defined a knowledge model (ontology) for smart city big and open data harvesting and analysis, named KM4City, which consists of major smart city key elements – data sources: (public) administration; street-guide (with regard to street facilities); point-of interest (services and activities of interest); local public transport; sensors (ambient, weather, traffic flow, pollution etc.); temporal (time intervals that associate a timeline to the events); and metadata (associated with the datasets and their status conditions). Similarly, Edvinsson (2016) seeks for knowledge production sources and network and considers the city as a knowledge tool.

The next two classes try to design smart city with an emphasis on *facilies* -i.e., *energy* (Calvillo et al., 2016), *water, buildings* etc.- and *services* -i.e., *health* (Fan et al., 2016), *education, tourism, safety* etc.- respectively, while the seventh class prioritizes *people* in smart city in terms of employment growth source definition (Shapiro, 2006) and human capital attractiveness (Thite, 2011). The last eighth class addresses *environment* and more specifically new modes of ecological urban living and corresponding socio-political relations (Shwayri, 2013). In this same regard, Tsolakis and Anthopoulos (2015) capitalized system dynamics in an attempt to determine the structure of an eco-city and define a model that can support decision makers in optimal planning and future predictions. Their model contains 5 interconnected components/subsystems: (i) population, (ii) housing, (iii) business, (iv) energy and (v) environmental pollution. Simulations with the use of this model with date from the city of Tianjin generated arguments with regard to eco-city's efficiency to succeed in urban sustainability.

The overview of the models show approaches emerge progressively since 2014, when standardization is being performed to deal with the heterogeneity of the smart city concept. Some of the models have hardly any overlapping factors, whereas most models capture a large number of aspects. The broadness of these aspects results to the unclarity of the concept. Yet there are 6 dimensions that are part of most models; people, government, economy, mobility, environment and living and can be seen as the most generic conceptual approach to smart city, which generate corresponding architectures. Nevertheless, conceptualization becomes more complicated when scholars try to focus on particular urban issues like energy and health and questions whether such focused models respect the more generic ones.

Table 1. Smart city conceptualization models

	Model	**Description**
Architecture		
Anthopoulos (2015)	Smart city dimensions	Resource, Transportation, Urban infrastructure, Living, Government, Economy, Coherency
Giffinger et al. (2007)	Smart city components	Smart Economy, Smart Governance, Smart People, Smart Mobility, Smart Living, Smart Environment
Glebova et al. (2014)	Smart city conceptual elements	Intellectual transport system, public security, energy consumption management and control, environmental protection and ICT
Hancke et al. (2013)	Sensor areas in smart city	Smart Infrastructure, Smart Surveillance, Smart Electricity and Water distribution, Smart Buildings, Smart Healthcare, Smart Services and Smart Transportation
Hollands (2008)	Smart City Model	Instrumented (based on data collection) Interconnected (enable data flow) Smart (utilize data to improve urban living)
IBM (Söderström et al., 2014)	Nine Pillar Models Smarter City Equation	Planning and Management Services Infrastructure Services Human Services Instrumentation (*the transformation of urban phenomena into data*) + Interconnection (*of data*) + Intelligence

		(*brought by software*)
Naphade et al. (2011)	Smart city model	Government services, transportation, energy and water, healthcare, education, public safety and other core ICT systems
Neirotti et al. (2014)	Smart City domains	Natural resources and energy, Transport and mobility, Buildings, Living, Government, Economy and people
Yovanof and Hazapis (2009)	Digital City Architectural Framework for Smart Service Provision	Infrastructure (communications); Mobilized Services (capability to mobilize data, applications and users); Policy (legal framework to foster innovation)
Zygiaris (2012)	Smart City reference model	Multi-tier smart city model with several components and entities
Governance		
Albino and Dangelico (2015)	Smart City Dimensions	- city's networked infrastructure that enables political efficiency and social and cultural development - emphasis on business-led urban development and creative activities for the promotion of urban growth - social inclusion of various urban residents and social capital in urban development - the natural environment as a strategic component for the future.
Baron (2012)	Three level-model for city intelligence for resilience conceptualization	First level of city smartness: led by example Second level of city smartness: govern the private urban actors Third level of city smartness: integrated approach (hi/medium/no resilience)
ISO (2014b)	A table of city characteristics where smartness is applied	Environmental Context City History and Characteristics Societal Context City Governance City Subsystems (actors, activities, facilities and buildings, hard infrastructure, soft infrastructure, technical systems, city functions, scale)
ITU (2014a)	Attributes and Core themes	Attributes: sustainability; quality of life; urban aspects; intelligence or smartness Core themes: society; economy; environment; governance
Lee et al. (2014)	Framework for smart city analysis	Urban Openness, Service Innovation, Partnerships Formation, Urban Proactiveness, Smart city infrastructure integration, Smart city governance
Leydesdorff and Deakin (2011)	Triple-Helix Model of Smart Cities	Networks of universities, industry and government
Liu et al. (2014)	Smart city value chain (SCVC) model	Primary Activities: smart inbound logistics; smart operations; smart outbound logistics; smart marketing; smart services Supportive Activities: smart government; smart infrastructure; smart procurement; smart technology
Lombardi et al. (2012)	Triple helix model for smart city analysis and performance measurement	A table with rows: University, Government, Civil Society, Industry and columns: smart governance, smart economy, smart people, living, environment
United Nations Habitat (United Nations, 2014)	Dimensions of City Prosperity	Productivity and the Prosperity of Cities, Urban Infrastructure: Bedrock of Prosperity, Quality of Life and Urban Prosperity, Equity and the Prosperity of Cities, Environmental

		Sustainability and the Prosperity of Cities
Planning and Management		
Anthopoulos and Fitsilis (2013)	Technology Roadmapping for Smart City development	Patterns for smart city technological evolution
Lee et al. (2013)	Technology Roadmapping for Smart City development	Interconnections between services and devices, and between devices and technologies
Data and knowledge		
Batty et al. (2012)	Structure of FuturICTs smart city programme	Data Analysis and Modelling: Mobility and Transport Behavior; Urban Land Use Transport; Urban Market Transactions; Urban Supply Chains Infrastructure: Sensing & Networks, New Social Media; Integrated Databases Management: Decision Support and Participation; City Governance
Bellini et al. (2014)	Knowledge Model for Smart City data (KM4City ontology)	Administration; street-guide; point-of interest; local public transport; sensors; temporal; and metadata
Edvinsson (2006)	City as a knowledge tool model	Knowledge key driver definition and interrelation discovery (ICT and multimedia; University; Society and Entrepreneurship; Knowledge Cafes/Cathedrals; Diversity; Strange Attractors)
Facilities		
Calvillo et al. (2016)	Smart City Energy Interventions and Energy System Design Model	Energy interventions areas: Generation, Storage, Infrastructure, Facilities and Transport Energy System Design Model: (i) System Input (resources, costs, geolocation, energy prices, regulation, demand) (ii) System Output (capacity, total production, costs, environmental benefits, viability)
Services		
Fan et al. (2016)	Smart health organization model	Multi-tier architecture for smart health service production in smart city
People		
Shapiro (2006)	Neoclassical city growth model	Employment growth sources: productivity, quality of life
Thite (2011)	Urban factors for human capital attractiveness	*Magnets* (a healthy and well-educated workforce, clean environment, vibrant business climate, and a solid social and cultural infrastructure) and *glue* (city infrastructure, flexible regulation system)
Environment		
Shwayri (2013)	u-eco-city model	City as a range of ubiquitous services (including u-health, u-education, u-transport and u-government)
Tsolakis and Anthopoulos (2015)	Eco-city System Dynamics Model	A system of 5 interconnected components/subsystems: (i) population, (ii) housing, (iii) business, (iv) energy and (v) environmental pollution

3.2 Smart city benchmarking

Smart city benchmarking should have the purpose to compare them with each other based on various constructs and factors. However, existing literature regarding smart city benchmarking returns different types of measurement, which evaluate alternative city factors. Table 2 provides the results of this analysis and benchmarking methods have been aggregated again in an attempt to clarify what and how it is being measured. More specifically, five (5) classes have been extracted, two of which measure smart city performance, while the next two assess either city performance or urban sustainability and resilience -hence the results are used for smart city estimations-. A final class evaluate policy making with estimations on their expected outcomes.

The first class concerns *smart city progress measurement*, basically in terms of the six dimensions that have been conceptualized earlier. In this regard, Albino and Dangelico (2015) compared various smart city benchmarking indexes (Lombardi et al., 2012); Lazaroiu and Roscia, 2012); Giffinger et al., 2007); Global Power City Index that is based on various stakeholders' perceptions and it was created by the Japanese Institute for Urban Strategies; the Smarter Cities Ranking introduced by the Natural Resources Defense Council that measures environmental-related criteria; Forbes smart city ranking regarding urban economic performance) and concluded to a 72 measurement model. Caragliu et al. (2011) analyzed data from the Urban Audit dataset produced by the European Statistical Office (Eurostat), with regard to European smart cities. From the 250 available indicators in this dataset, which are measured across several domains in cities (demography; social aspects; economic aspects; civic involvement; training and education; environment; travel and transport; information society; culture and recreation) they focused on 6 of them (Per Capita Gross Domestic Product (GDP) in Purchasing Power Standards (PPS); Employment in the Entertainment (Creative) Industry; Multimodal Accessibility; Length of Public Transport Network; e-Government; and Human Capital). In their paper they performed several statistical analysis methods and they discovered a positive association between urban wealth and the presence of a vast number of creative professionals; a high score in a multimodal accessibility indicator; the quality of urban transportation networks; the diffusion of ICTs (most noticeably in the e-government industry); and, finally, the quality of human capital. Some studies (Duarte et al., 2014; Glebova et al., 2014) focus on ICT and define corresponding assessment frameworks (connectivity, accessibility and communicability). With regard to the 6 dimensions of smart city, (Lazaroiu and Roscia, 2012) defined a model with corresponding indices in an attempt to assess urban intelligence or in other words, how "good" or "bad" a city is in achieving its smartness (Vanolo, 2014) or its level of progress (Fei, 2012). Moreover, in their attempt to develop their smart city roadmapping framework, Lee et al. (2013) defined a set of indexes that can measure smart city components: service performance, corresponding devices for service access and technology. Indexes regarding smart service assessment concerns service measurement, service anticipation, space type, infrastructure components and formal type and were grouped in sub categories, while they were calculated with time scales. On the other hand, device assessment concerns their importance, performance level (maturity, use and productivity) and anticipation. Finally, technology was classified in 5 categories (sensing, processing, network, interface and security) and is being evaluated with regard to its importance, performance level (applications availability, future evolution potential, maturity, substitute existence at national level, most advanced nation in this technology) and anticipation. Finally, Lombardi et al. (2012) identify several quantitative indexes in their model presented earlier (Table 1) and they follow the analytic network process (ANP) in their attempt not only to measure specific city elements, but also to identify and measure the relationships between model's components.

The second class, addresses real-time *smart city monitoring*. In this respect, Malek (2010) studied the suitability of the Informative Global Community Development Index (IGC), for monitoring the Smart Cities initiative. IGC refers to a creative and innovative community which can develop its own technology. In his work he assumed that the process of developing an intelligent city has to maximize community's interest in terms of ICT, but his findings from Subang Jaya smart city in Malaysia did not justify this claim. Similarly, Marsal-Llacuna et al. (2015) performed a study on urban monitoring contribution to smart city measurement. Their work compared indicators that address city's sustainability and livability or sustainable and livable cities respectively. Corresponding groups of indicators are opposite with the first group measuring urban environment and local economy with long term data and data from big cities, while the second group measuring quality of life with real time conditions with data even from mid-sized cities. Moreover, their work accounted standardization efforts (i.e., ISO Global City Indicators for City Services and Quality of Life) and suggest a Smart City monitoring synthetic indices Smart City real-time monitoring index.

The next class, measures *city capacity* in various terms, ranging from size and global city performance (Kourtit et al., 2014), to its potential or good urban governance (UN Habitat, 2014) and urban competitiveness (Singhal et al., 2013). Kourtit et al. (2012) wanted to measure the innovation potential of smart cities and in this respect, they performed a principal component analysis (PCA) in European cities. Their study identified the most relevant variables with the highest loading factors, in regard to advanced business and socio-cultural attractiveness (ADBA), presence of a broad (public and private) labour force and public facilities (PBLFPF) and presence and use of sophisticated e-services (PUSS) of smart cities. De Marco et al. (2015) propose several safety measurement indicators, which provide decision makers with a significant tool to develop corresponding policies. Their study developed a three-level index named *global safety indicator*, which is analyzed in road safety and personal safety (second level). Road safety uses parameters that measure corresponding mobility threats (surface quality, traffic, construction sites, accidents and parking spaces) and personal threats (noise, distress and rallies and events). Similarly, Winters (2011) defined a benchmarking model that measures city population growth. More specifically he defines variables and formulas to calculate inhabitants' input and output flows and to measure agglomeration changes within the urban ecosystem. His study showed that in-migration occurs for education purposes and it is mainly based on people from the same state, while many of the immigrants select to remain within the smart city, which results to corresponding population growth.

The fourth class emphasizes on *sustainability* -both economic and environmental- (Pires et al., 2014; Mori and Christodoulou, 2012; ITU, 2015), local government effectiveness (da Cruz and Marques, 2014) and *resilience* (Desouza and Flanery, 2013). Such a measurement is not a simple process and involves alternative values, while the adoption of a synthesized index, a composite index or a single indicator should be avoided. It is appropriate to compare environmental, economic and social aspects respectively among cities at least, because the aspects are complex complement or trade-off relationships and because a composite index often implies weak measurement (Mori and Christodoulou, 2012). Moreover, the European Initiative on Smart Cities or more specifically the Strategic Energy Technologies Information System (SETIS) focused on smart energy and defined a set of key performance indicators that are able to measure carbon emission reduction in Europe: For energy networks, these include: meeting 50% of heat and cooling demand from renewable energy sources (RES); launching at least 20 exemplars by 2015 for "smart grids" coupled with "smart building" equipment, and measuring energy consumption with "smart meters".

The final class, addresses *policy* making in cities, which can be also evaluated with regard to its potential impact (Kii et al., 2014) even with a focus on particular decisions (i.e., energy consuming impact (Gouveia et al., 2016)). Beyond the above scientific studies, several market analyses can be located that evaluate city performance from alternative perspectives. For instance, with regard to city attractiveness for investments, top four factors concern easy access to markets, customers and clients (instead to the availability of quality staff); quality of telecommunications; transport links with other cities and internationally; and current local economic climate (Cushman and Wakefield, 2009).

Given the broadness of this field it is not surprisingly that there are many benchmarking approaches developed. In a similar vein to the modelling overview, the benchmarking comparisons also show the diversity of dimensions that are taken into account. The benchmarks look sometimes at completely different aspects, which hampers comparison. This makes it hard or even impossible to compare the benchmarking outcomes with each other. In one benchmark, a city might be doing well, whereas the same city might be performing lower in another benchmark. In general, it appears that scholars do not follow exiting modeling when they introduce their benchmarking methods.

Table 2. Smart city benchmarking tools

	Benchmarking Tool	**Description**
Smart city progress		
Albino and Dangelico (2015)	72 Smart City Indexes' set	60 indexes from Lobardi et al. (2012) and 12 indexes from Lazaroiu and Roscia (2012)
Caragliu et al. (2011)	6 Smart City Indicators (data analysis from Urban Audit Dataset)	Per Capita Gross Domestic Product (GDP) in Purchasing Power Standards (PPS) Employment in the Entertainment Industry Multimodal Accessibility Length of Public Transport Network e-Government Human Capital
Fei (2012)	Level of smart city progress	3 level Analytical Hierarchy Process: Level 1: Target level (the smarter development level); Intermediate Level 2: development level of informatization; innovation capability; comprehensive resource utilization; Indicator Level 3: informatization development; ICT; proportion of employment in ICT; R&D expenditure; proportion of employment in R&D; new product development; industrial solid waste; products from waste gas
Duarte et al. (2014)	Digital City Assessment Framework	Connectivity, Accessibility, and Communicability
Glebova et al. (2014)	Indexes for ICT element evaluation	New urban technologies; ICT in education; ICT in public health care; e-government

Lazaroiu and Roscia (2012)	Model for computing "the smart city" indices	Economy, Mobility, Environment, People, Living, Governance
Lee et al. (2013)	Smart Service Assessment Indexes Smart Device Assessment Indexes Technology Assessment Indexes	Service Assessment: service measurement, service anticipation, space type, infrastructure components and formal type Device Assessment: importance, level and anticipation Technology Assessment: importance, level and anticipation
Liu et al. (2014)	Smart city value chain (SCVC) assessment model	Indexes for Primary and Supportive Activities
Lombardi et al. (2012)	Triple helix model for smart city analysis and performance measurement	A table with rows: University, Government, Civil Society, Industry and columns: smart governance, smart economy, smart people, living, environment
Smart city monitoring		
Malek (2010)	Smart city monitoring index	Informative Global Community Development Index (IGC)
Marsal-Llacuna et al. (2015)	Smart city monitoring indexes	Smart City monitoring synthetic indices Smart City real-time monitoring index
City capacity		
Kourtit et al. (2012)	City Innovation Potential Measurement	A set of quantitative indexes that measure local economic and business environment, labor market, city infrastructure, governmental economic performance, tourism and cultural heritage and leisure.
Kourtit et al. (2014)	Global City Performance Measurement Indexes	Economy, Research and Development, Cultural Interaction, Livability, Environment, Accessibility
De Marco et al. (2015)	Safety measurement indexes	Global safety indicator (mobility safety and personal safety measurement indexes)
Singhal et al. (2013)	Competitiveness parameters	Physical Environment, Social Capital, Finance, Development, Investment, User Potential
UN Habitat (2014)	Good Urban Governance indicators	Effectiveness, Equity, Participation, Accountability, Security
Winters (2011)	Formulas for smart city growth measurement	Migration rate measurement (in and out) and corresponding source definition
Sustainability and resilience		
Desouza and Flanery (2013)	Resilience City Evaluation and Implementation Framework	City components: Resources and Processes (Physical) People, Institutions, Activities (Social)
da Cruz and Marques (2014)	Sustainable Local Government Scorecard	Social, Economic, Environmental and Government *criteria*
ISO (2014a)	ISO 37120 Sustainable development of Communities Indicators for city services and quality of life	Economy, Education, Energy, Environment, Finance, Fire and Emergency Response, Governance, Health, Recreation, Safety, Shelter, Solid Waste, Telecommunication and Innovation, Transportation, Urban Planning, Waste water, water and sanitation
ITU (2014b)	Smart Sustainable City Key Performance Indicators (KPIs)	Environmental Sustainability, Productivity, Quality of Life, Equity and Social Inclusion, Infrastructure development
Mori and Christodoulou (2012)	City Sustainability Indexes	Various indexes that measure environmental, social and economic performance (Ecological Footprint (EF), Environmental Sustainability Index (ESI), Dashboard of Sustainability (DS), Welfare Index, Genuine Progress Indicator (GPI), Index of Sustainable Economic Welfare,

		City Development Index, emergy/exergy, Human Development Index (HDI), Environmental Vulnerability Index (EVI), Environmental Policy Index (EPI), Living Planet Index (LPI), Environmentally-adjusted Domestic Product (EDP), Genuine Saving (GS))
Pires et al. (2014)	Local Sustainable Development Indicators	21 ECOXXI Indicators, grouped in the following sectors: Sustainable, Development Education, Marine and Coastal Environment Institutions, Nature Conservation and Biodiversity, Forest Planning, Air, Water, Waste, Energy, Transport, Noise, Agriculture, Tourism
Strategic Energy Technologies Information System (SETIS)	Smart energy efficiency's KPIs	50% of heat and cooling demand produced from RES 20 corresponding exemplars' launch by 2015
Policy evaluation		
Kii et al. (2014)	Land-use-transport (LUT) model for policy evaluation in smart city	Parameter groups: employed household; unemployed household; shopping place substitution; firm; developer; landowner; road link cost function
Gouveia et al. (2016)	General framework concept for an Integrative Energy City Plannin	Residential sector: buildings and businesses Transport sector: private and public fleet Other energy consuming sectors: water/sewage/waste systems, public lighting, daily activities (i.e., schools etc.)

4. UNIFIED SMART CITY MODEL

In recent years, there have been many approaches to conceptualize and benchmark smart cities. Conceptualization is a necessary process for smart city definition, which has been recently completed by standardization bodies. Our literature findings show that the ISO (2014), the ITU (2014), the UK Standards (BSI, 2014) and the US National Institute of Standards and Technology (NIST, 2014) are in the process or they have defined smart city: innovation -not necessarily but mainly based on the ICT-, which aims to enhance urban life in terms of people, economy, government, mobility, living and environment. Indeed, standardization respects the 6 dimensions (people, governance, mobility, economy, environment and living) that are recognized for enhancement and are agreed by all scholars, even with small variations. Furthermore, existing standards mainly focus on urban sustainability and resilience, which demonstrate that smart city efforts are, or will be placed mainly on these directions, while scholars go deeper and try to conceptualize smart city in terms that serve particular sectors (i.e., energy, health etc.), without necessary to respect existing modeling.

On the other hand, researchers have tried to evaluate smart city from different lenses: smart city progress; city performance and competitiveness; sustainability and resilience; and even policy making impact. Only Lazaroiou and Roscia (2012) benchmarking framework respects the 6 smart city dimensions, which leave space for the further improvement of smart city measurement. Furthermore, only 3 works (Fei, 2012; Duarte et al., 2014; Glebova et al., 2014) try to evaluate ICT and smart solutions directly, which again leave a space for corresponding optimization.

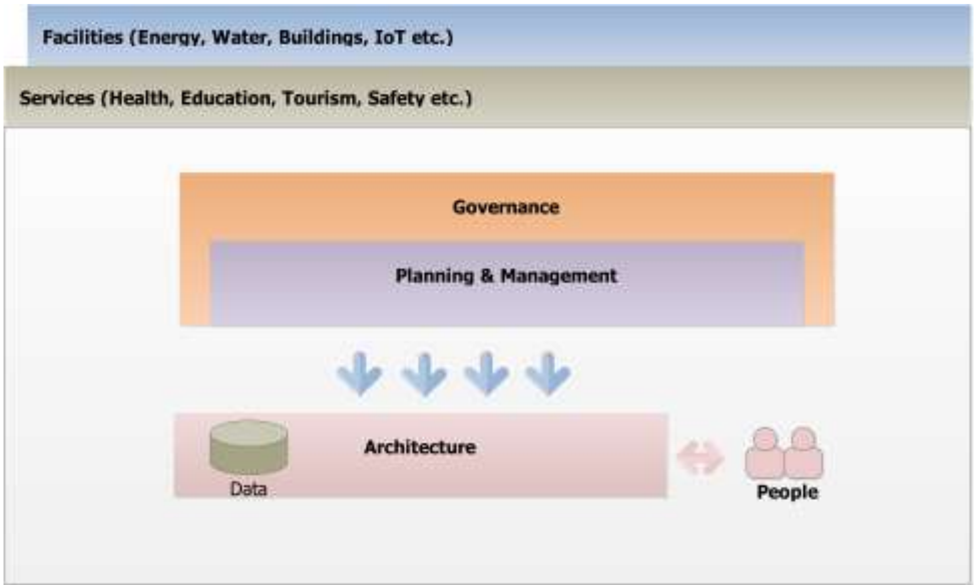

Fig. 1: the unified smart city conceptual model (USCM)

Finally, the above analysis returns an initial taxonomy of smart city modeling and benchmarking. More specifically, 8 classes of conceptual models have been discovered, that address smart city *architecture*, *governance, planning and management*, *data and knowledge, energy, health, people* and *environment* viewpoints. These 8 classes compose a unified smart city model (UFCM), which is depicted on (Fig. 1) and summarize existing smart city conceptualization approaches. Additionally, 6 classes of benchmarking tools have been identified and address *smart city progress, smart city monitoring, city capacity, city sustainability and resilience*, and *policy impact*. Both these classes could evolve further when there's a need to approach specific domains, but they should respect the six smart city dimensions.

5. CONCLUSIONS

This paper reviewed existing smart city conceptualization and benchmarking methods and synthesized them into a unified smart city model. A systematic overview of the main smart city structure was performed and 6 common components have been discovered to be agreed by scholars. The overview confirmed the diversity of factors taken into account and different views that can be taken for smart city understanding, which can become complicated when they go deeper to serve particular sectors (i.e., energy and health). To this end, the paper focused on models and assessment frameworks, which are either still being developed by prestigious organizations or are being tested by scholars and an initial taxonomy of conceptual modeling and benchmarking has been extracted.

The smart city field has come to a uniform definition, which deals with innovation (not necessarily but mainly ICT-based) in the urban space that aims to enhance the 6 city dimensions (people, economy, government, mobility, living and environment). This is a very broad definition to cover the many and variety of initiatives in this field, but it can be respected when further analysis is necessary. As such smart cities are an umbrella term for all sorts of innovations in the urban environment.

Moreover, standards –such as the ones introduced by (ISO, 2014; ITU, 2014; BSI, 2014; NIST, 2014)- are under development or review for smart cities and corresponding solution definitions are being delivered, which illustrate that vendors and organizations with commercial vested interest may aim to dominate this evolving market. With regard to smart city assessment, scholars mainly evaluate the impact of innovation on urban performance, the urban capacity itself, rather than the direct smart solution or the entire smart city system's performance. Instead, some monitoring frameworks have been introduced. Both these findings show that the smart city domain is still embryonic and promises important future results for governments, academia and industry. As future research, we recommend the draft of sector-driven conceptual models that respect the 6 smart city dimensions, together with benchmarking models that again respect these dimensions but, which measure smart city performance.

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