Ontological Review of Smart City Research

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Abstract

The meaning of the word "city" has evolved since the first urban civilization was labeled as such more than 5,000 years ago. The concept of Smartness in Cities appeared initially because of the advancements in information technology; now cities are working diligently towards being considered "Smart". However, the term Smart City is still conceptually vague and sometimes biased towards the use of information technology, and not on the city. This article a) presents an ontological framework of Smart City which is logically constructed but grounded in the literature of Smart Cities, and b) maps 373 journal articles—published in 2016 on the topic "smart city"—onto the framework. The mapping reveals that Smart City research in 2016 mainly focuses on the Smart part of the framework, specifically the structural elements, while the City part remains largely unexplored.

Keywords

Smart Cities, eGovernment, Ontology, Framework.

Introduction

Cities play a key role in the development of the world being responsible for more than 80% of global GDP. This importance will be even more significant in the future because cities are growing at an accelerated rate; the World Bank estimates that by 2045 the number of people living in cities will increase by 1.5 times to 6 billion (Cohen 2006; United Nations 2016; World Bank 2016). In this context, the International Electrotechnical Commission (IEC) estimates that the infrastructure development for the next 35 years will surpass the one built over the last 4,000 years (IEC 2014). This rapid urban development may bring multiple risks which may surpass the cities' ability to provide adequate services for their inhabitants (Neirotti et al. 2014). Nonetheless, if cities are adequately managed there could be enormous benefits as a result of the economies of scale by sharing amenities such as transportation, sport and entertainment facilities, business services, broadband access, etc. (Swinney 2014). Then, cities need to become what has been called "smart" in order to fulfill the expectations of their stakeholders and produce the desired outcomes for them. Liotine et al. (2016) call this an anthropomorphism (attribution of human characteristics to the city) that is based on the ability of a city to sense and respond using natural and artificial intelligence embedded in the city's information systems. Researchers and practitioners have not been completely successful in unraveling this intricate concept although the term is widely used and intuitive to understand (Akhras 2000; Caragliu et al. 2011).

At the beginning, the term Smart City was mainly focused on the smartness provided by the advancement of information technology (IT) and its potential to improve city services (Bakıcı et al. 2013; Coe et al. 2001; Eger 2009; Harrison et al. 2010; Lazaroiu and Roscia 2012; Lombardi et al. 2012; Mulligan and Olsson 2013; Nam and Pardo 2011; Townsend 2013; Washburn et al. 2010). In this context, the technology industry has used the concept since 2004 for the application of complex information systems to integrate city's infrastructure and services (Harrison and Donnelly 2011; IBM 2009; Malik 2005; Siemens 2004). As a result of this association, the attention of city governments and researchers has been primarily on the IT part of the term "Smart City", with less attention to other important elements embedded in the concept (Murgante and Borruso 2015). Lately, some studies, have widened their scope to include the final results of the smartness such as sustainability, quality of life, and services to the citizens (Ahvenniemi et al. 2017; Aloi et al. 2014; Anthopoulos 2015; Bifulco et al. 2016; Hara et al. 2016; Herrschel 2013; Huston et al. 2015; Lee et al. 2016; Lee and Lee 2014; Marsal-Llacuna 2016; Shapiro 2006).

There are still significant gaps in the Smart City research due to the selective focus. In this paper, we logically deconstruct the Smart City construct to define it using an ontological framework that can be extended, scaled, and refined/coarsened as necessary (Cameron et al. 2017; Ramaprasad and Syn 2015) and map the Smart City research published in the year 2016 onto it.

Smart Cities

The term Smart City is relatively recent. The case of Singapore in 1999 was the first research article that introduces the term (Mahizhnan 1999). Since that time, researchers who are interested in the scope of the term have systematically reviewed the Smart City literature searching for the best definition of the term (Albino et al. 2015; Anthopoulos et al. 2016; Chourabi et al. 2012; Giffinger et al. 2007; Marsal-Llacuna et al. 2015; Nam and Pardo 2011; Zubizarreta et al. 2015).

Researchers, city policy-makers, and international organizations have conceived frameworks, rankings, and technical standards to assess the level of smartness of cities around the world. Nevertheless, a complete picture of the field has been difficult to agree on, in part due to the multidisciplinary nature of the field and the difficulties associated with the integration of disciplines as diverse as urban design, information technology, public policy, and social sciences.

Many of the existing frameworks agree on some of the relevant factors that need to be considered. Elements mentioned include networked infrastructure, business-led urban development, focus on achieving the social inclusion, attention to the role of social and relational capital in urban development, and social and environmental sustainability (Albino et al. 2015; Caragliu et al. 2011). Brandt et al. (2016) propose a framework that combines the resource-based and ecosystem views to provide a comprehensive representation of the Smart City. They discuss the types of resources a Smart City can rely on such as built capital, human capital, natural capital, and information technology infrastructure. Chourabi et al. (2012) attempt to incorporate sustainability and livability issues, as well as internal and external factors affecting smart cities. They propose a framework with eight factors that include management and organization, technology, governance, policy, people and communities, the economy, built infrastructure, and the natural environment. The same spirit of providing a more integrated perspective of smart cities prevails in the study by Neirotti et al. (2014) which presents a taxonomy of domains grouping the key elements into six categories: natural resources and energy, transport and mobility, buildings, living, government, economy, and people. Anthopoulos et al. (2016) carry out a literature analysis identifying eight classes of smart city conceptualization models: smart city facilities, services, governance, planning and management, architecture, data, and people. In general, most frameworks analyzed focus on technology and infrastructure as their main components, and only some include people's wellbeing.

Benchmarking models or rankings have also been created by researchers, governments, and international organizations. Those rankings consider variables like economy, infrastructure, innovation, quality of life, resilience, transportation, urban development, etc. (Brandt et al. 2016; Giffinger et al. 2007; Giffinger and Gudrun 2010; IESE 2016; Lombardi et al. 2012). An aggregated analysis of this rankings is presented by Anthopoulos et al. (2016) who classify all smart city benchmarking models into those associated with smart city progress, smart city monitoring, city capacity, sustainability and resilience, and policy evaluation.

International organizations like the International Organization for Standardization (ISO) and The Telecommunication Standardization Sector in International Telecommunication Union (ITU) have also proposed norms and technical standards for Smart Cities. Those standards and norms are mostly related to IT, infrastructure, and sustainability (ITU 2016; Lazarte 2015).

We propose a high-level ontological framework of Smart City based on an extensive literature review which identifies more than thirty-six different definitions from disciplines as diverse as urban studies, computers and information technology, sociology, and public health (Albino et al. 2015; Chourabi et al. 2012; Marsal-Llacuna et al. 2015; Nam and Pardo 2011; Zubizarreta et al. 2015).

An Ontological Framework of Smart City

There is no standard definition of ontology across disciplines. It ranges from the philosophers' definition as the 'logic of being' as opposed to epistemology which is defined as the 'logic of knowing', to the computer scientists' definition as a triple of subject, object, and predicate. Organizational researchers' and social scientists' definitions are more formal than the philosophers' and less than the computer scientists'. We sidestep the debate about the definition of an ontology by using the adjectival form and calling ours an ontological framework. By doing so we simply assert its similarity to an ontology without defending it as one. Its label is less important than the framework's structure and content. It could simply be called a structured natural language framework or a linguistic framework. It is in many ways a logical extension of the 2x2 frameworks (the simplest of the genre) that are ubiquitous in the social sciences and organizational research—with more dimensions and more categories in each dimension. The adjectival label—ontological—will not affect the method and the consequent insights.

Our definition of a Smart City is shown in Figure 1 and described below. It is presented as a high-level ontological framework as described in prior studies (Cameron et al. 2017; La Paz et al. 2015; Ramaprasad and Syn 2015).

Smart								**City**		
Structure		**Functions**		**Focus**		**Semiotics**		**Stakeholders**		**Outcomes**
Architecture	[to]	Sense	[+]	Cultural	[+]	Data	[by/from/to]	Citizens	[for]	Sustainability
Infrastructure		Monitor		Economic		Information		Professionals		QoL
Systems		Process		Demographic		Knowledge		Communities		Equity
Services		Translate		Environmental				Institutions		Livability
Policies		Communicate		Political				Businesses		Resilience
Processes				Social				Governments		
Personnel				Technological						
				Infrastructural						

Figure 1 Ontological Framework of Smart City

The detailed description of the ontological framework of Smart City is presented in an earlier work (Ramaprasad et al. 2017). Here we will briefly describe it. A Smart City is a compound construct with two major parts–Smart and City–each of which is a complex construct. (Note: Words referring to terms in the framework are capitalized in the text.) The City is defined (for this paper) by its Stakeholders and the Outcomes. The desirable outcomes of a Smart City include its Sustainability, Quality of Life (QoL), Equity, Livability, and Resilience. The Stakeholders in a city include its Citizens, Professionals, Communities, Institutions, Businesses, and Governments. Thus, the effects on 'citizens' QoL', 'communities' equity', 'businesses' resilience', and 27 (6*5–3) other possible combinations of Stakeholder and Outcome, defines the smartness of a city.

Semiotics—the iterative process of generating and applying intelligence—forms the core of smartness. The focus of smartness may be many aspects of interest to the stakeholders to obtain the desired outcomes. It depends on the structure and functions of the systems for semiotics. In the iterative Semiotics process, Data are converted into Information, Information to Knowledge, and the Knowledge is then translated into smart actions. The focus of Semiotics may be Cultural, Economic, Demographic, Environmental, Political, Social, Technological, and Infrastructural. The semiotics of each focus will affect the corresponding smartness of the city, its stakeholders, and the corresponding outcomes. The Structure and Functions of its Semiotics (Data, Information, Knowledge) management system will determine the smartness of a city. The Functions include Sensing, Monitoring, Processing, Translating, and Communicating (Debnath et al. 2014). The Structure includes the Architecture, Infrastructure, Systems, Services, Policies, Processes, and Personnel.

Concatenating the four left dimensions, the smartness of city will be a function of its 'architecture to sense cultural data', 'policies to communicate environmental knowledge', and 838 (7*5*8*3–2) other combinations in 'Smart' encapsulated in the definition.

Taken together, there are 7*5*8*3*6*5 = 25,200 potential components of a Smart City encapsulated in the definition. A truly smart city is one that has realized a significant proportion of them. Thus, cities may be smart in different ways and to different degrees. Four illustrative components are listed below:

- *Architecture to sense economic information by/from citizens for QoL*. The architecture to periodically sense the QoL of the citizens of the city, and to make the data available to the citizens.
- *Systems to process environmental data by governments for livability*. Systems to determine air and water pollution levels, and warn the citizens when they exceed acceptable thresholds.
- *Policies to communicate technological knowledge by professionals for resilience*. Policies to share knowledge about the technological vulnerabilities of a city, for example its data networks, to assure quick response and recovery in the event of a natural disaster.
- *Processes to translate political information to citizens for sustainability*. Processes (for example, town-hall meetings, online forums) to translate the political manifestos into policies and practices that may affect the sustainability of the city.

A component of a Smart City may be instantiated in many ways, not just one. Thus, the 25,200 components encapsulated in the definition may be reflected in innumerable ways in research and practice. Similarly, the innumerable instantiations may be mapped onto the 25,200 components to obtain a comprehensive view of the 'bright', 'light', 'blind/blank' spots/themes in Smart Cities research and practice. The 'bright' spots/themes are those that are heavily emphasized because they are important or are easy. The 'light' spots/themes are those that are lightly emphasized because they are unimportant or are difficult. The 'blind/blank' spots/themes are those that have been overlooked or are logically infeasible.

The ontological framework defines the Smart City concept simply and visually, without compromising its underlying combinatorial complexity. It is systemic and systematic. Its dimensions (columns) are based on research and practice in the domain. Further, the definition encapsulates all possible components of a Smart City, however many there are. We can describe any research or practice in the domain using the definition.

In summary, the ontological framework represents our conceptualization of Smart Cities (Gruber 2008). It is an "explicit specification of [our] conceptualization," (Gruber 1995) and can be used to systematize the description of the complexity of domain knowledge (Cimino 2006). The ontological framework organizes the terminologies and taxonomies of the domain. "Our acceptance of [the] ontology is… similar in principle to our acceptance of a scientific theory, say a system of physics; we adopt, at least insofar as we are reasonable, the simplest conceptual scheme into which the disordered fragments of raw experience can be fitted and arranged." (Quine 1961) The many definitions of a Smart City can also be mapped onto the ontological framework. It is a domain ontology that "helps identify the semantic categories that are involved in understanding discourse in that domain." (Chandrasekaran et al. 1999, p.23) Ontologies are used in computer science, medicine, and philosophy. Our ontology of Smart City is less formal than computer scientists', more parsimonious than medical terminologists', and more pragmatic than philosophers'. It is designed to be actionable and practical, and not abstract and meta-physical. Its granularity matches that of the discourse in research and facilitates the mapping and translation of the domain-text to the framework and the framework to the domain-text.

Methods

We synthesize the state of Smart City research by mapping it onto the ontological framework. The mappings are then used to generate ontological maps to visualize the landscape of the domain. The domain corpus was collected from Scopus—one of the largest curated databases of scholarly literature across major disciplines such as business and technology. We searched for the articles which contain a simple keyword "smart city" in title, abstract, and keywords. We retained only journal articles written in English which represent a high-quality collection of peer-reviewed research on Smart City. We also excluded articles without available abstract and those that are not related to Smart City research. In addition, we limited the mapping to articles published in 2016 which is likely the most recent period with a complete set of Smart City research already indexed in the Scopus database. Figure 2 details the search process and results, following the PRISMA reporting guidelines (Liberati et al. 2009). We then downloaded the selected articles and imported them into an Excel spreadsheet for mapping.

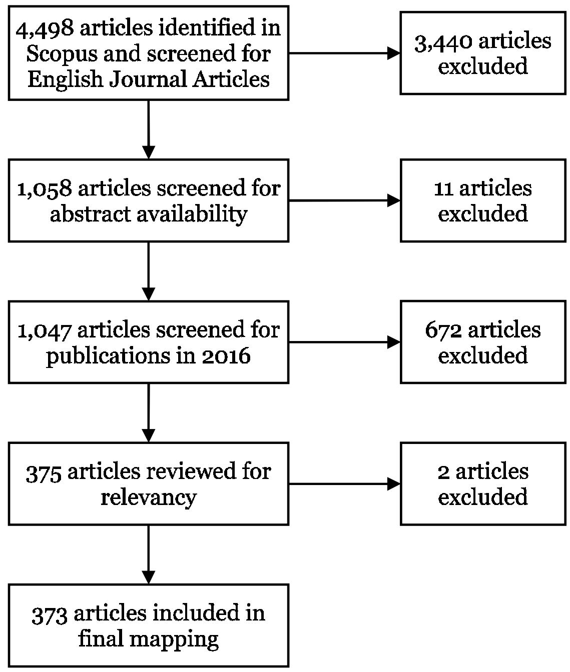

Figure 2 Search Process and Results

The corpus of 373 articles was mapped onto the framework by one of the authors with an extensive knowledge of the domain. She reviewed the title, abstract, and keywords of each article and identified the presence of reference to each ontological element. She marked those elements present for each article in the custom-designed mapping spreadsheet in Excel. The mapping is binary—either present (1) or absent (blank or 0)—and not weighted. Not all articles are mapped onto all elements. Only the dimensions and elements explicitly articulated in the title, abstract, and keywords are mapped.

Analysis and Results

We present the results in the ontological map of monads and clusters. In the following, we will discuss them in greater detail. We will analyze the ontological map of Smart City research in terms of the dominant, less-dominant, and non-dominant categories and components. The analysis is visual and subjective. There are no predetermined frequency bands for the dominant and less-dominant spots—the differences are easy to see. The non-dominant spots by definition have zero or very close to zero frequency. It is a form of gap analysis which is systemic and systematic, and hence more comprehensive than traditional gap analysis. By highlighting all the gaps, both surpluses (more than desired) and deficits (less than desired), it facilitates a synoptic strategy instead of an incremental strategy for Smart City research. It is a simple, yet practical, representation of a complex phenomenon.

Ontological Map of Smart City Research

The bars in the ontological map of monads (Figure 3) are proportional to the parenthetical numbers and represent the frequency of the respective category in the Smart City research studied. Thus, for example, the Stakeholders dimension is mentioned in 45 of the 373 articles in the final mapping. Further, among the stakeholders Citizens are mentioned in 30 articles and Governments in 21. Since an article may mention multiple stakeholders, the Stakeholder frequency is less than the sum of the frequencies of its constituent elements (55). In the following, we will discuss each dimension in greater detail.

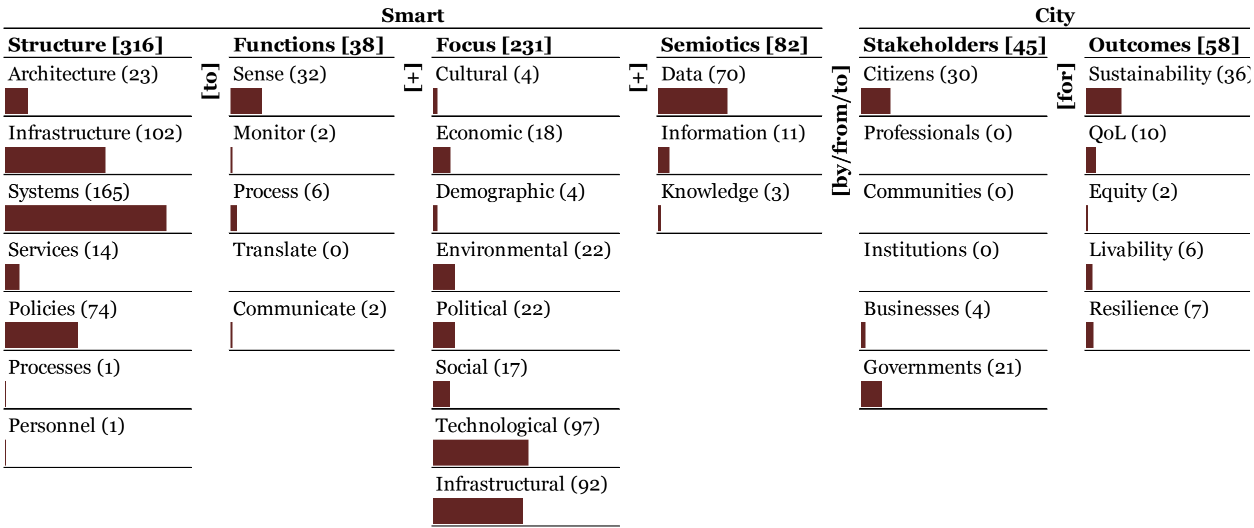

Figure 3 The Ontological Map of Monads of Smart City Research

Most the articles in the corpus primarily discuss Structure (316) and Focus (231) dimensions—more than 61.9% of the articles to be exact. Other dimensions, Semiotics (82), Functions (38), Outcomes (58), and Stakeholders (45) sparsely appear in less than 22% of the corpus.

In the Structure dimension, Systems (165) is the dominant element. Infrastructure (201) and Policies (74) are less dominant than Systems, but more so than Architecture (23) and Services (14). Processes (1) and Personnel (1) are virtually non-existent.

Among the smart Functions, Sense (32) is the only one that garners significant attention. Others such as Process (6), Monitor (2), Communicate (2), and Translate (0) receive little or no attention.

The focus is dominantly on Technological (97) and Infrastructural (92) aspects of Smart City management systems. Environment (22), Political (22), Economic (18), and Social (17) receive only marginal focus. Cultural (4) and Demographic (4) receive almost no attention.

Data (70) is the most dominant semiotics discussed in the Smart City research. Information (11) receives marginal and Knowledge (3) negligible attention.

The most frequently studied stakeholders are Citizens (30) and Governments (21). Businesses (4) is marginally present and Professionals (0), Communities (0), and Institutions (0) are not present at all.

Among the outcomes, Sustainability (36) is the most dominant. The remaining ones—QoL (10), Resilience (7), Livability (6), and Equity (2) are mostly secondary.

Cluster Analysis

We also conducted a hierarchical cluster analysis in SPSS using the binary distance measure of simple matching coefficient (SMC) (Sokal and Michener 1958). The resulting clusters complement the dominant elements identified in the ontological map of monads. We identify five equidistance clusters in the dendrogram. The clusters are highlighted in the ontological framework in Figure 4.

A single element, Systems, constitutes the first cluster. It is also the most dominant theme of the Smart City research. The second cluster contains Infrastructure and Technological representing the secondary theme of research. The third cluster represents the tertiary theme of Policies [for] Infrastructural Data. The fourth cluster is solely concerned with the Sustainability outcome. The remaining elements constitute the fifth cluster that represents the theme largely missing in the Smart City research. It includes the many Functions required for smartness, the non-Technological/Infrastructural Focuses, going beyond Data to Information and Knowledge, the Stakeholders, and the Outcomes beyond Sustainability.

Smart								City		
Structure		**Functions**		**Focus**		**Semiotics**		**Stakeholders**		**Outcomes**
Architecture	[to]	Sense	[+]	Cultural	[+]	Data	[by/from/to]	Citizens	[for]	Sustainability
Infrastructure		Monitor		Economic		Information		Professionals		QoL
Systems		Process		Demographic		Knowledge		Communities		Equity
Services		Translate		Environmental				Institutions		Livability
Policies		Communicate		Political				Businesses		Resilience
Processes				Social				Governments		
Personnel				Technological						
				Infrastructural						

Cluster 1 - Primary
Cluster 2 - Secondary
Cluster 3 - Tertiary
Cluster 4 - Quaternary
Cluster 5 - Quinary

Figure 4 The Cluster Map of Smart City Research

Discussion

This paper presents an ontological framework, logically constructed but firmly grounded in the literature and practice of smart cities and related disciplines, and maps 373 journal articles published in 2016 onto the framework.

Smart city is a compound construct of two parts, Smart and City, and each one of them is at the same time composed of other dimensions and elements. In this sense, the proposed framework functions as a multi-disciplinary lens where researchers from the related disciplines may see their object of study. The analysis of the Smart City definitions in the literature showed that researchers focus their conceptual definition of the term according to their field of study. For example, researchers in the information technology field focus their definitions on the Smart part of the Smart City construct in the framework (Structure, Functions, Focus, and Semiotics) emphasizing IT and its function with little attention to the desired outcomes. However, researchers from social sciences and disciplines associated to urban design emphasize the City part of the construct (Stakeholders and Outcome) in their definitions with focus on sustainability and quality of life.

The mapping of the Smart City research published in the year 2016 shows few bright and many light and blind spots. Bright spots are in the Structure dimension of the framework where the element Systems occupies a dominant role, appearing in 44% of all mapped articles. The second dominant element is Infrastructure that is present in 27% of the corpus. The whole Outcome dimension has received negligible attention with the highest element, Sustainability, accounting only for 9.7% of all articles analyzed. The blind spots are mainly in the City part of the construct where research in some Stakeholders elements (Professionals, communities, Institutions) are not present. These results were not only found at the primary level (monads) but also in the cluster analysis where the first three clusters are in the smart dimension of the construct. We discovered that the focus of the Smart City research is still at the level of efficiency or optimizations of the city's processes using IT, but the City part of this compound concept has almost been forgotten. Hence, there are significant gaps in the Smart City research. Unless the gaps are bridged, the translation of research to practice in realizing smart cities may be limited.

Conclusion

Ontological analysis helps characterize the logic of the Smart City, study this domain from many perspectives (at different levels of complexity), and highlight the gaps in Smart City research. The ontological framework proposed for Smart City can be used by planners and government officials to: a) assess the level of smartness of their cities from many perspectives at different levels of complexity, b) provide a roadmap for new Smart City designs, c) guide cooperative thinking among government agencies and other stakeholders, and d) map the state-of-the-practice to the framework to unveil the bright, light, and blind/blank spots.

The ontological framework is in structured natural English, as opposed to linear natural English. Thus, it retains its semantic interpretability while at the same time encapsulating the complexity of the construct. Further, the framework can be adapted as the construct evolves and to different contexts, because of its modular structure. It can be plastic. The framework can be expanded by adding an additional dimension (column), and reduced by eliminating a dimension. For example, Temporality of Outcomes (Short-term, Medium-term, and Long-term) can be an additional dimension; or the elements of Outcomes can be aggregated under the broad term of Smart City, and the dimension could be eliminated. The framework can be refined by adding subcategories of an element, and coarsened by combining several elements. For example, Governments (Stakeholder), can be subcategorized as Federal, State, and Local Governments; and Institutions and Businesses can be combined as Organizations.

Finally, the mapping of the state-of-the-research of the domain permitted to systematically identify the 'bright', 'light', and 'blind/blank' spots in the literature. This mapping revealed that most articles published in 2016 on Smart City were about the Smart part of the construct, specifically its Structure dimension and the Systems element. Further, conceptually, information technology was the dominant concept in Smart Cities' definitions, and coincidentally it plays a dominant role in research published in the topic during 2016. Therefore, the gaps which are evident in the mapping of the literature present opportunities for research in those dimensions that have received little or no attention.

There is no doubt that the information technology development has increased the complexity of the Smart City concept, and therefore researchers have attempted to address this issue by focusing primarily on this technology development. This polarization on research with utmost importance given to the technological aspects of the Smart City can possibly neglect the needs of common citizens and other stakeholders to the detriment of the city official's decision and the outcome of those decisions for the city as a whole. New city's projects are frequently announced supposedly framed within the context of the Smart City but most of those projects are not encompassing the minimum elements to deserve the Smart City label.

Researchers should consider the interdisciplinary nature of the Smart City research, and must integrate technological, social, and urban aspects of the Smart City with the aim to achieve the desired outcome in a more unified approach. This study has focused only on research published in 2016. In the future, we will extend the analysis to all research articles published on Smart City and explore the evolution of Smart City research over the years. We also plan to extend the mapping to the state-of-practice and compare it against that of the state-of-research. These extensions will provide deeper insights into the gaps and how to bridge them.

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