The First Two Decades of Smart-City Research: A Bibliometric Analysis

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This paper reports on the first two decades of research on smart cities by conducting a bibliometric analysis of the literature published between 1992 and 2012. The analysis shows that smart city research is fragmented and lacks cohesion, and its growth follows two main development paths. The first one is based on the peer-reviewed publications produced by European universities, which support a holistic perspective on smart cities. The second path, instead, stands on the grey literature produced by the American business community and relates to a techno-centric understanding of the subject. Divided along such paths, the future development of this new and promising field of research risks being undermined. For while the bibliometric analysis indicates that smart cities are emerging as a fast-growing topic of scientific enquiry, much of the knowledge which is generated about them is singularly technological in nature. In that sense, lacking the social intelligence, cultural artifacts, and environmental attributes which are needed for the ICT-related urban innovation such research champions to be smart in securing the physical infrastructure requirements of cities.

Keywords: smart city research; urban innovation; bibliometric analysis; development paths; corporate model; holistic interpretation

Introduction

Cities are complex and highly organized systems, *"a collection of elements that act independently of one another but nevertheless manage to act in concert"*. Their state of balance is extremely sensitive and subject to continuous changes dependent on *"how we intervene in their organization through different forms of planning"* (Batty and Marshall, 2009). The need to manage this difficult scenario has required the connection between many academic disciplines (Benevolo, 2011; Secchi, 2011) brought together in the unique field of urban studies (Liu, 2005), which is *"one of the longest established interdisciplinary fields within the modern academy"* (Kamalski and Kirby, 2012).

Computer science is one of these disciplines, and its continuous and progressive approach to urban studies started during the last years of the 20th century, when the digital revolution began to transform urban areas "*into a constellation of computers*" (Batty, 1997). During this period, *"many commentators seemed to suggest that the new frontier [of information technology] was to provide solutions for overcoming most spatial and social problems [and] cities looked like the ideal arena where this revolution would test and show itself, changing economic development, services, and above all, community life"* (Firmino, 2003). In this scenario, the information and communication technologies (ICTs) of urban areas are innovations supporting a new science of cities (Batty, 2014).

The exploration of the relationship between ICTs and urban areas began with Graham and Marvin's *"Telecommunications and the City"* (Graham and Marvin, 1996). Along with the work produced by Mitchell (1995; 1999; 2003) and Castells (1996), their research activity has allowed this new area of knowledge to take shape and develop in a concrete form. This process of knowledge production has resulted in the publication of numerous scientific documents (see Graham and Marvin 1996; 1999; 2001; 2004 and Graham 1997; 2000; 2001; 2002; 2004a). Many of these publications can be considered the most influential resources in the cognitive structure of *"urban ICT studies*" (Graham, 2004b), a sub-discipline of urban studies in which research is

carried out to study *"the complex and poorly understood set of relationships between telecommunications and the development, planning and management of contemporary cities"* (Graham and Marvin, 1996).

As an object of scientific enquiry, smart city studies fall in this research domain and first appeared in 1992 within the book entitled *"The Technopolis Phenomenon: Smart Cities, Fast Systems, Global Networks"* (Gibson et al., 1992). Over the years, smart cities have become the symbol of ICT-driven urban innovation and development, and started to attract the increasing attention of many researchers from universities, governments, and businesses. Thanks to their interest, smart city research has been growing sharply. Evidence of this trend can be found by analyzing Google Scholar's data. Following a request to identify the literature produced between 1992 and 2015 in which the term smart city is included in the singular or plural form, the scholarly engine developed by Google has sourced 25,770 documents[1]. Data shows that the annual production of publications on smart cities has increased by 600 times within 24 years, moving from 16 in 1992 to 9,494 in 2015[2].

The exploratory study reported on in this paper aims to provide an overall and detailed picture of what happened during the first two decades of research on smart cities, and lead to an improved understanding of the origins and progressive evolution of this fast-emerging research area and its intellectual structure. This aim is achieved by answering the following research questions:

- What are the characteristics of the literature produced during the period 1992-2012 in terms of type, influence, and impact?
- How large was the scientific community researching smart cities?
- What are the influence and productivity levels of researchers falling within this community and the organizations to which they belong?
- What is the interpretation of the smart city concept that emerges from their research?
- What factors have influenced the development of the intellectual structure resulting from the first two decades of smart city research?

To answer these questions, bibliometric analysis techniques are used to analyze both the literature on smart cities published between 1992 and 2012, and the community of researchers involved in its production. The methodology used to perform the analysis is illustrated in Section 2 of the paper. This is followed by an in-depth description of the findings which sheds light on the first 20 years of research in the field of smart cities (Section 3). These findings are then discussed in relation to the content of the smart city literature produced subsequent to the period under investigation (Section 4). The paper concludes with some recommendations aimed at guiding future research on smart cities in line with the findings reported on (Section 5).

Bibliometrics and the analysis of knowledge domains

Bibliometrics investigates the formal properties of knowledge domains by using mathematical and statistical methods (Pritchard, 1969; Ding et al., 2001; Godin, 2006; De Bellis, 2009). Interest in applying these methods to explore the development of smart cities as a knowledge domain has grown considerably over the past 5 years and has resulted in the production of the following publications:

- Durán-Sánchez et al. (2017): description of scientific research on smart cities by way of a bibliometric analysis and through a review of the literature indexed in Web of Science and Elsevier's Scopus databases;
- Ojo et al. (2016): examination of the smart city knowledge domain using Scopus' journal articles and conference papers related to both smart cities and intelligent cities, which the authors consider equivalent terms;
- Tregua et al. (2015): analysis of the relationship between sustainable and smart

cities using 367 journal articles and books indexed in Web of Science;

- Ricciardi and Za (2015): examination of about 100 documents stored in the websites of two international conferences on smart cities *"to define the boundaries of smart city research and to draw a map of [its] interdisciplinary community"*;
- de Jong et al. (2015): identification of the conceptual differences and relationships between twelve dominant city categories (sustainable city, eco city, low carbon city, liveable city, green city, smart city, digital city, ubiquitous city, intelligent city, information city, knowledge city, resilient city). This study is conducted by way of a bibliometric analysis and through the academic literature retrieved from Web of Science and Scopus.

What these studies have in common is a tendency to focus the attention on specific aspects of smart cities, or compare them to other different city categories rather than capturing an overall picture of the smart city research. Moreover, they generally conduct bibliometric analyses that are sourced from a limited number of publications and databases in which grey literature is not indexed (Hutton, 2009). Therefore, some relevant source documents may have been missed.

The bibliometric study reported in this paper aims to overcome the limitations of existing bibliometric analyses into smart cities by:

- focusing attention only on the overall intellectual structure of this knowledge domain;
- expanding the number of databases used to source documents[3];
- including both academic publications and gray literature.

This bibliometric study is carried out using 1,067 source documents identified with a keyword search and combining the analysis of the citations between them, together with citation and publication counts, which are the two most basic bibliometric measures (Tijssen and van Leeuwen, 2003; Martin and Daim, 2008). These documents represent all the smart city literature published in English language between 1992 and 2012. More specifically, that English language literature containing the term 'smart city' or the term 'smart cities', in the title, abstract, keyword list or body of the text, and stored in the following scholarly databases[4]: Google Scholar; ISI Web of Science; IEEE Xplore; Scopus; SpringerLink; Engineering Village; ScienceDirect; and Taylor and Francis Online[5].

The use of multiple databases makes it possible to conduct a comprehensive interdisciplinary search and broaden the field of investigation, avoiding the risk of not capturing the full extent of research on smart cities. However, it is important to note that this choice is particularly challenging and time consuming because the initial number of publications identified with the keyword search is 9,799. To extract the list of source documents, each publication is included in a single dataset and checked to correct typographical errors in the titles, authors' names or publication dates. Repeated documents that have been found in more than one database are then eliminated. Finally, the title, abstract, keyword list and body of the text of each remaining publication is manually examined to verify the effective presence of the keyword. Documents in which this search has shown to be negative are eliminated.

After completing the search phase, the source documents are cataloged considering their type: abstracts, editorials, journal articles, books, book chapters, conference papers[6], and grey literature[7] (Figure 1). The last category includes the documents generally defined as grey and*"represents a substantial part of the scientific production"*, especially in recent years (Schopfel and Farace, 2010). According to the most common definition, grey literature represents the literature that is *"produced on all levels of government, academics, business and industry in print and electronic formats, but […] not controlled by commercial publishers, i.e., where publishing is not the*

primary activity of the producing body" (Schopfel, 2010).

All source documents are then linked to authors by their full names and the organizations they represent. Details about organizations are found by searching their official websites, the source documents and the databases used for the keyword search. In this study, the most recent affiliation is attributed to each author. During this activity, data on both the type and location of each organization is also collected (Figure 2). Based on types, four main categories are identified: 1) research and education: universities, academies, and colleges; 2) research and business: private companies operating in the ICT sector which are involved in research and consultancy activities or in the distribution of goods and services; 3) research and government: public authorities and their research institutes); 4) other. In case of organizations operating in multiple locations, the main headquarters are considered.

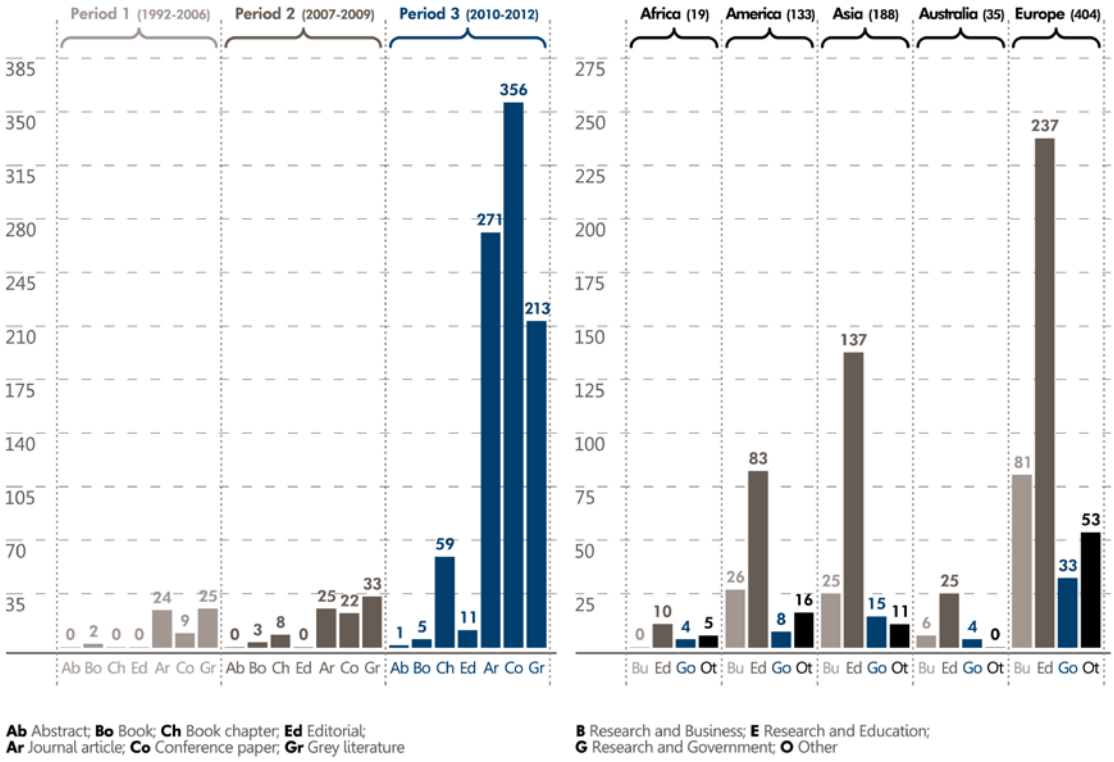

Figure 1. Source documents by type and period of publication
Figure 2. Organizations by type and location

Finally, before starting the analysis, citation data is extracted manually from the list of references included in each source document. In addition, considering that citation data often contain errors, which can lead to significant variations in the results of their analysis (Adam, 2002), all citations have been tested for correctness and completeness, so as to guarantee the highest degree of data reliability. Altogether, a total of 22,137 citations are collected (957 to source documents and 21,180 to non-source documents), and they are used to build a frequency table showing each cited publication, together with the number of times it has been cited. This makes it possible to determine that the total number of cited references is 17,574. Only citations to source documents are considered during the analysis.

The first two decades of smart city research

A new and fast growing research area

The analysis shows that smart city research established itself as a new area of scientific enquiry in 2009, and since then, it has been fast growing, arousing strong interest from an expanding scientific community of researchers. This growth is particularly evident when observing the rise in the production of source documents (Figure 3), which has continued to increase over time, together with the number of researchers involved in their development (Figure 4). Initially, this research area was very small, with only 19 source documents published during the first 10 years of research. Over the following eight years, from the beginning of 2002 to the end of 2009, the production has increased slightly. During this period 132 documents have been published, about 17 per year. The period between 2010 and 2012, instead, is characterized by a tremendous growth in the number of publications. More than 900 new source documents are produced in three years, and they represent approximately 86% of the smart city literature developed during the first two decades of research.

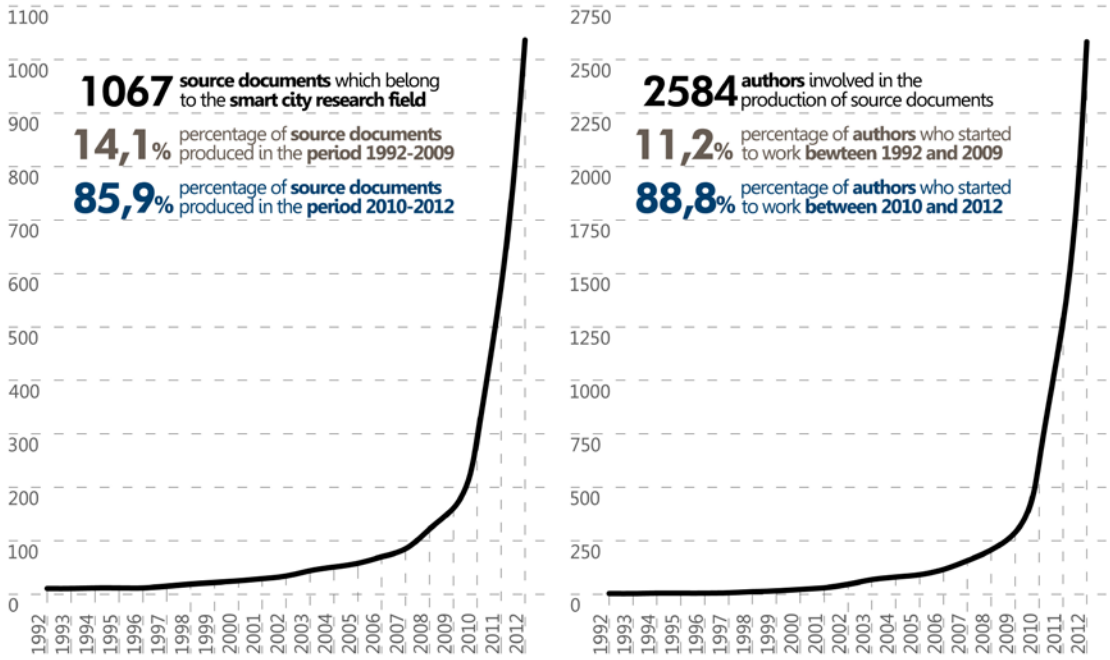

Figure 3. Cumulative growth in the number of source documents
Figure 4. Cumulative growth in the number of authors involved in the production of source documents

Fragmentation of knowledge

All branches of knowledge are composed of large groups of interconnected publications, and their structure can be represented through the use of complex mapping techniques, allowing the scientific community involved in their production to easily grasp *"the big picture"* (Moya-Anegon et al., 2004): *"a spatial representation of the relationship among […] individual documents as reflected in some formal, strictly quantifiable properties of scientific literature at a given time"* (De Bellis, 2009). Citations are the elements that create the connections between publications. They represent *"a type of symbolic currency that signals intellectual influences"* and serve as an indicator by which the influence and impact of any scientific document can be assessed

(Jacobsen et al., 2013). By using citations, researchers can incorporate intellectual work from other research into their own studies (Small 1973; 1978; Garfield, 1970), and collaborate in the construction of the intellectual structure of their field of investigation.

The use of these techniques made it possible to visualize the overall intellectual structure that results from the first 20 years of research in the field of smart cities. The structure is illustrated in Figure 5, and is represented by a network of undirected and unweighted links in which the 1,067 source documents are nodes and the 957 citations referring to them are the connecting elements. This graph has been obtained using the Fruchterman-Reingold layout algorithm provided by the open-source software Gephi (Fruchterman and Reingold, 1991). Within the graph, the source documents are represented by a circle with a diameter proportional to the number of citations they have received. Therefore, the larger the circle, the greater number of citations. In addition, source documents with at least one citation are shown in blue, whereas those without citations are grey.

By observing the organization of the nodes, it becomes evident that fragmentation and divergence are the main features of this structure, and they result from the absence of connections between the source documents. This means that the impressive growth of available scientific literature observed in the last three years of the second decade goes hand in hand with the lack of cohesion between the researchers involved in their production. As a result, the intellectual structure of the smart city research area is divided into a multitude of unconnected publications. The central core of the network, indeed, is compact and well-articulated thanks to the presence of citations, which indicate an active exchange of knowledge between researchers. However, moving towards the outer perimeter, the organization of the network changes completely. Source documents are disconnected or combined in groups that are small in number and detached from the main core.

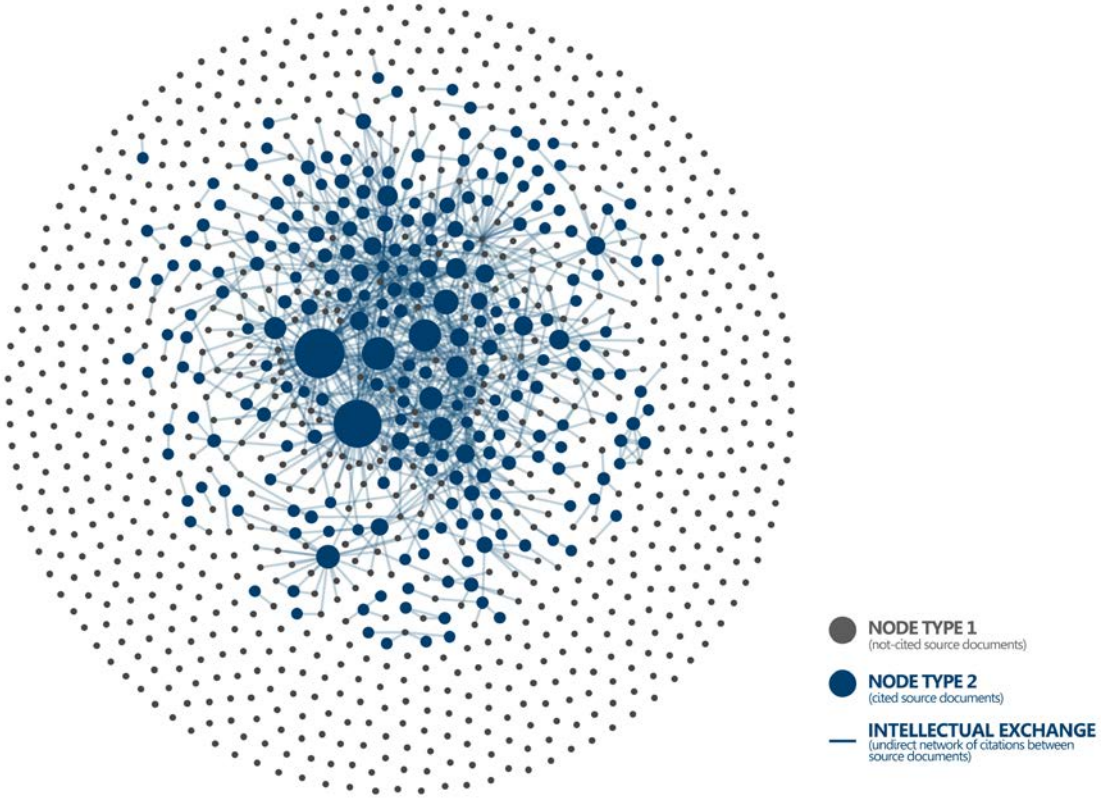

Figure 5. Knowledge structure of the smart city research field

The divergent roots of smart cities

Divergence, lack of cohesion, and limited intellectual exchange among researchers become even more evident when trying to find out a commonly accepted interpretation of smart cities, which is missing. This absence is highlighted in various source documents, such as those produced by Alkandari et al. (2012), Chourabi et al. (2012), Hollands (2008), and Paskaleva (2011). Many definitions of the smart city are provided in scholarly literature and they overlap one another, making it difficult to obtain a common understanding and agreement as to what it means. To illustrate this trend, some of these definitions have been extracted from the source documents and reported in Table 1.

SOURCE DOCUMENT	DEFINITION
Hall et al., 2000	*"[The smart city is] the urban center of the future, made safe, secure environmentally green, and efficient because all structures - whether for power, water, transportation, etc. are designed, constructed, and maintained making use of advanced, integrated materials, sensors, electronics, and networks which are interfaced with computerized systems comprised of databases, tracking, and decision-making algorithms"*
Odendaal, 2003	*"A smart city […] is one that capitalizes on the opportunities presented by Information and Communication Technology (ICT) in promoting its prosperity and influence"*
Partridge, 2004	*"A smart city is [a city that] actively embraces new technologies [seeking] to be a more open society where technology makes easier for people to have their say, gain access to services and to stay in touch with what is happening around them, simply and cheaply"*
Giffinger et al., 2007	*"A Smart City is a city well performing in a forward-looking way in […] six characteristics […], built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens"*
Caragliu et al., 2009	*"The concept of the 'smart city' has recently been introduced as a strategic device to encompass modern urban production factors in a common framework and, in particular, to highlight the importance of Information and Communication Technologies (ICTs) in the last 20 years for enhancing the competitive profile of a city"*
Paskaleva, 2009	*"In the context of the present study, the smart city is defined as one that takes advantages of the opportunities offered by ICT in increasing local prosperity and competitiveness - an approach that implies integrated urban development involving multi-actor, multi-sector and multi-level perspectives"*
Belissent et al., 2010	*"Forrester defines the smart city as […] a "city" that uses information and communications technologies to make the critical infrastructure components and services of a city - administration, education, healthcare, public safety, real estate, transportation, and utilities - more aware, interactive, and efficient"*
Hernández-Muñoz et al., 2011	*"Smart Cities can represent an extraordinary rich ecosystem to promote the generation of massive deployments of city-scale applications and services for a large number of activity sectors"*
Alkandari et al., 2012	*"A smart city is one that uses a smart system characterized by the interaction between infrastructure, capital, behaviours and cultures, achieved through their integration"*
Lazaroiu and Roscia, 2012	*"A new city model, called "the smart city", which represents a community of average technology size, interconnected and sustainable, comfortable, attractive and secure"*
Schaffers et al., 2012	*"The smart city concept is multi-dimensional. It is a future scenario (what to achieve), even more it is an urban development strategy (how to achieve it). It focuses on how (Internet-related) technologies enhance the lives of citizens […] The smart city is about how people are empowered, through using technology, for contributing to urban change and realizing their ambitions. The smart city provides the conditions and resources for change. In this sense, the smart city is an urban laboratory, an urban innovation ecosystem, a living lab, an agent of change"*

Table 1. Some definitions of smart cities extracted from the source documents

In this confused scenario, two dominant interpretative models emerge from the analysis of the relationship between the 10 most cited source documents (Figure 6) and their content. These publications can be split into two different groups, and their division depends on the interpretation of smart cities they support. The first group of

publications is connected by a single network of citations, which provide evidence of an active exchange of knowledge between researchers, and promotes an interpretation which can be defined as holistic. In this case, smart cities are described as the result of the balanced combination of human, social, cultural, economic, environmental, and technological aspects, which stand alongside one another. The second group of publications, instead, is composed of source documents which are disconnected, and provide a techno-centric interpretation of smart cities.

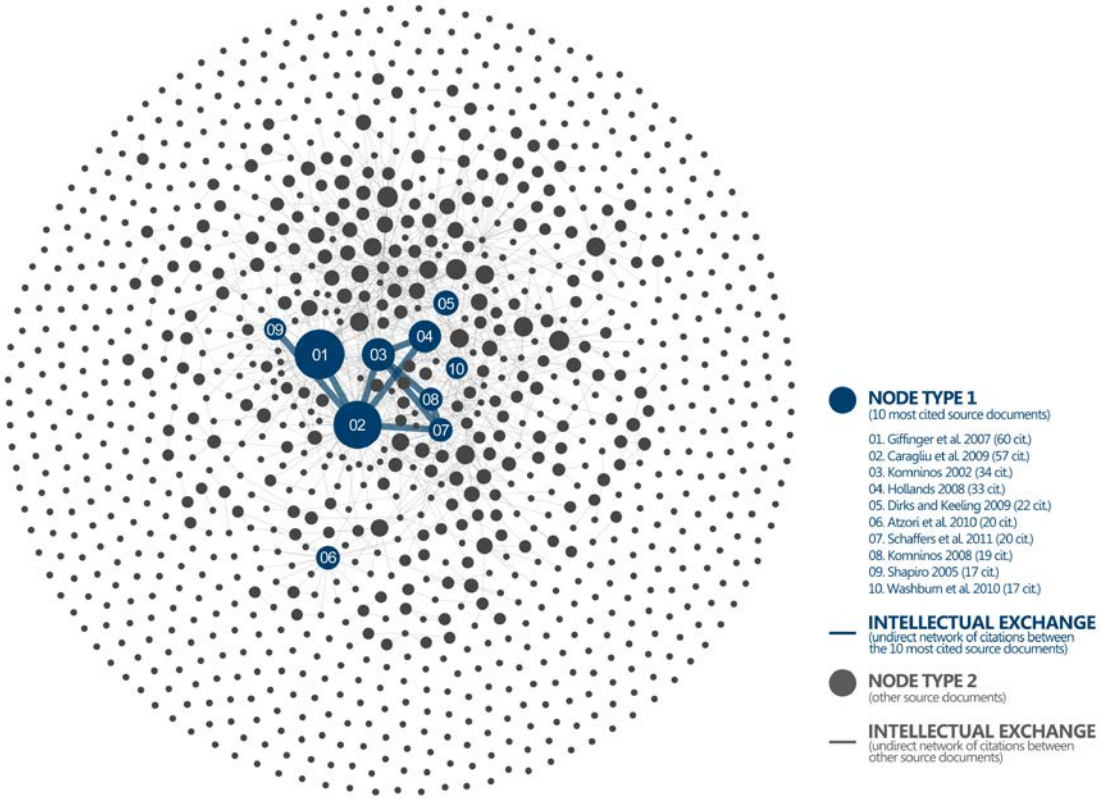

Figure 6. Relationship between the 10 most cited source documents included in the smart city knowledge structure

The holistic perspective is supported in the research report published by Giffinger et al. (2007), which is the most influent source document published between 1992 and 2012. This publication moves the smart city concept away from an excessively technological perspective, and offers a human-centric reading of the subject. Here smart cities are not simply places with a high availability of ICTs, but urban areas *"well performing in a forward-looking way in […] six characteristics [economy, people, governance, mobility, environment, and living], built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens"*. The conference paper by Caragliu et al. (2009) makes a significant contribution to this vision, and the authors take this further with the journal article Caragliu et al. (2011). According to their vision: *"a city [is] smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance"*.

This holistic interpretation is also supported by Schaffers et al. (2011), but more importantly, responds to the request made by Hollands (2008) for a more progressive view of the smart city concept, which *"must seriously start with people and the human capital side of the equation, rather than blindly believing that IT itself can automatically*

transform and improve cities". This is a point already stressed in research by Komninos (2006, quoted in Hollands, 2008), where the smart city concept is merged with the intelligent city concept. The latter defined as: *"territories with high capacity for learning and innovation, which is built-in to the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management"*. According to Komninos, therefore, a smart city is an urban area in which the technological, human, social and cultural capital of a community offers the means to generate new knowledge of urban problems and an increased capability to face them (Komninos, 2002; 2008).

In direct contrast to this interpretation, the smart city conceived by Dirks and Keeling (2009), both researchers at IBM (International Business Machines Corporation), is an urban environment permeated with ICTs, where all physical infrastructures are interconnected. In this case, the focus is almost exclusively on the singular role of new technologies in developing integrated platforms of city services. This is the same interpretation provided by a group of researchers from Forrester Research: *"what makes a [city] smart is the combined use of software systems, server infrastructure, network infrastructure, and client devices - which Forrester calls Smart Computing technologies - to better connect seven critical city infrastructure components and services: city administration, education, healthcare, public safety, real estate, transportation, and utilities"* (Washburn et al., 2010). All this is made possible by the continuous and rapid diffusion of electronic devices capable of retrieving and transmitting data, such as smartphones and sensors, which have supported the growth of the Internet of Things (IoT). That web-based service development which is reported by Atzori et al. (2010).

The geography of knowledge production

The scientific community working in the field of smart cities between 1992 and 2012 is made up of 2,584 researchers, divided among 779 organizations which are located in 434 cities and 69 countries. To assess their productivity and influence, a calculation has been made as to the quantity of source documents produced by each author and the number of citations they have acquired. For publications produced by two or more authors, the unit value of the document and the number of citations it has acquired have been divided by the number of authors involved, so each can be assigned an equal share. In this way, individual researchers have become the basic elements for extending the analysis to the organizations in which they work, as well as the countries and continents where they are located. The process just described is shown in Figure 7.

The results show that smart city research starts in Australia and North America. Subsequently, interest in the subject grows and the production of literature on smart cities has developed in Europe, Asia, and Africa, between 1997 and 2000, and in South America, but not before 2010. Up to 2002, North America maintains the greatest number of authors and the highest number of publications, but this condition changes between 2002 and 2012, a period during which the number of European authors increases from 17 to 1,327 (Table 2). These authors represent more than half of the global scientific community involved in smart city research (51.4%) between 1992 and 2012. The rest of this community is located in other continents, especially Asia, in which 667 researchers have been identified (25.8%). If compared with American organizations (16.6%), Australia (3.9%), and Africa (1.7%), this value is certainly much higher.

Europe is also the largest contributor to the growth of smart city research and the region that has influenced most the intellectual structure of this fast-expanding field of scientific enquiry. The majority of source documents are produced by organizations located in Europe (52%) and they have the greatest overall impact. The situation is

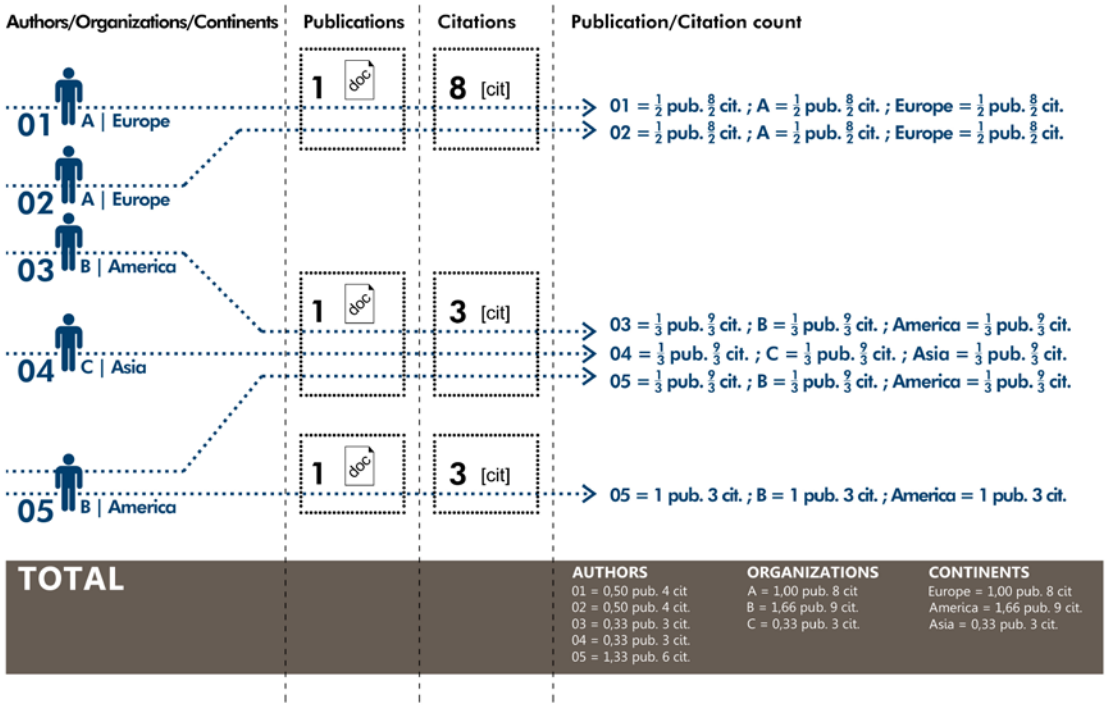

Figure 7. Procedure for estimating productivity and influence of authors, organizations, countries, and continents

YEAR	NUMBER OF AUTHORS (Annual growth / Cumulative growth)					
	Africa	Asia	Australia	Europe	North America	South America
1992	0 (0)	0 (0)	0 (0)	0 (0)	+3 (3)	0 (0)
1993	0 (0)	0 (0)	0 (0)	0 (0)	0 (3)	0 (0)
1994	0 (0)	0 (0)	+2 (2)	0 (0)	0 (3)	0 (0)
1995	0 (0)	0 (0)	0 (2)	0 (0)	0 (3)	0 (0)
1996	0 (0)	0 (0)	0 (2)	0 (0)	0 (3)	0 (0)
1997	0 (0)	0 (0)	0 (2)	+3 (3)	0 (3)	0 (0)
1998	0 (0)	+1 (1)	0 (2)	0 (3)	+3 (6)	0 (0)
1999	0 (0)	+1 (2)	+3 (5)	0 (3)	0 (6)	0 (0)
2000	+1 (1)	0 (2)	0 (5)	+1 (4)	+6 (12)	0 (0)
2001	0 (1)	0 (2)	+1 (6)	+1 (5)	+4 (16)	0 (0)
2002	0 (1)	0 (2)	+5 (11)	+12 (17)	0 (16)	0 (0)
2003	+1 (2)	0 (2)	+2 (13)	+14 (31)	+3 (19)	0 (0)
2004	+2 (4)	+2 (4)	+3 (16)	+1 (32)	+6 (25)	0 (0)
2005	+3 (7)	0 (4)	+5 (21)	0 (32)	+2 (27)	0 (0)
2006	+1 (8)	+3 (7)	0 (21)	+19 (51)	+2 (29)	0 (0)
2007	+1 (9)	+16 (23)	+6 (27)	+9 (60)	+9 (38)	0 (0)
2008	+7 (16)	+12 (35)	+5 (32)	+20 (80)	+6 (44)	0 (0)
2009	+1 (17)	+25 (60)	+2 (34)	+34 (114)	+21 (65)	0 (0)
2010	0 (17)	+81 (141)	+11 (45)	+148 (262)	+84 (149)	+5 (5)
2011	+9 (26)	+152 (293)	+24 (69)	+351 (613)	+119 (268)	0 (5)
2012	+19 (45)	+374 (667)	+31 (100)	+714 (1327)	+162 (430)	+10 (15)

Table 2. Growth in the number of authors involved in the production of source documents by continent

also positive in North America, where researchers have published 16.6% of the source documents, accounting for 24.4% of the total citations. In the case of Asia, indeed, the relationship between production and influence is negative. Here the overall impact is much smaller (10.3%), despite a greater share of source documents (23.3%). This data

is included in Figure 8.

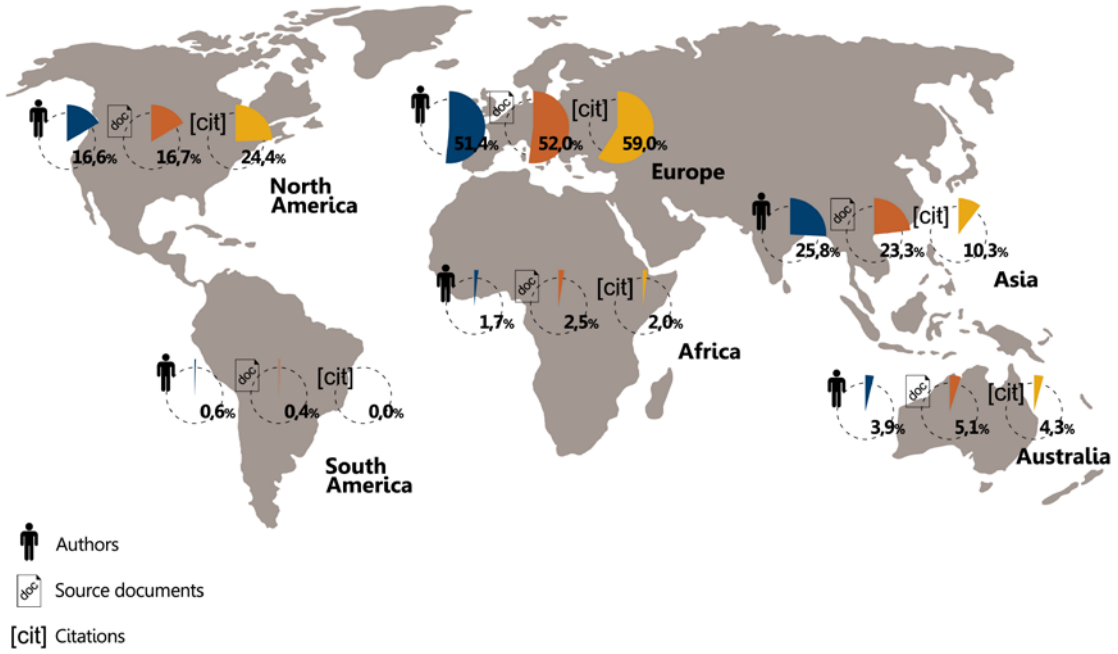

Figure 8. Percentage of authors, source documents, and citations by continents

Therefore, Europe and North America have become the main knowledge hubs in the field of smart cities. However, they are characterized by three important differences. A cross-cutting reading of the data reported in Table 3, Table 4, and Table 5 makes it possible to analyze the first one. This data shows that European research on smart cities is conducted mainly in universities, which have the greatest impact and highest productivity. It also shows that most of the European authors are from academics and these account for not only 68% of the European source documents, but also about 72% of the citations. Conversely, in North America, the highest productivity is linked to both universities and businesses operating in the ICT sector. However, between these two knowledge producers, the latter has certainly a dominant role, especially IBM and Forrester Research. Altogether, these two companies account for about 50% of the total citations acquired by US organizations during the period 1992-2012, and nearly 70% of the source documents they have produced. Moreover, with 100 researchers working in the field of smart cities, at the end of 2012, IBM was the world's leading organization in terms of authors, productivity, and influence over the development of this research area.

The remaining two differences, instead, regard: 1) the divergent interpretation of the smart city provided by each knowledge hub; 2) the approach used by its researchers to produce and diffuse the literature on smart cities which describe these interpretations. Both differences can be observed by comparing the most cited source documents produced respectively in Europe (Table 6) and North America (Table 7). The European knowledge hub supports the holistic interpretative model of smart cities. This model stems mainly from grey literature (Caragliu et al., 2009; Giffinger et al., 2007), but over the years, it has been progressively consolidated within the peer-reviewed literature of the academic world (Komninos, 2002; 2008; Hollands, 2008; Schaffers et al., 2011; Paskaleva, 2009). On the contrary, North American businesses support the techno-centric interpretation, whose foundations are built primarily by publications passing through the more informal channels of grey literature (Dirks and

Keeling, 2009; Washburn et al., 2010; Moss Kanter and Litow, 2009; Dirks et al., 2009; 2010; Belissent et al., 2010; Hall et al., 2000).

Finally, African and Asian organizations do not seem to have significantly influenced the development of smart city research. This situation reflects the production volume of the few researchers working in the African continent. However, this is not the case in Asia, because some of the most productive organizations are based in India and Japan. For example, Hitachi and the Tata Group, which have produced almost 4% of the total source documents, thanks to the work of 92 researchers. These are very high numbers, matched only by IBM. However, the American company has been able to gain a completely different influence, with 9% of the total citations as against the 0.8% attributed to the two Asian companies.

ORGANIZATION	TYPE	LOCATION		% ON TOTAL		
		Country	Continent	Cit.	Doc.	Auth.
IBM	B	United States	North America	8.9	3.3	3.9
Aristotle University of Thessaloniki	E	Greece	Europe	7.5	1.0	0.4
Vienna University of Technology	E	Austria	Europe	5.0	0.7	0.7
Newcastle University	E	United Kingdom	Europe	3.4	0.1	0.1
Forrester Research	B	United States	North America	2.9	0.3	0.3
SAP Research	B	Germany	Europe	2.7	0.8	0.3
University of Chicago	E	United States	North America	2.6	0.2	0.1
Queensland University of Technology	E	Australia	Australia	2.6	1.0	0.4
Politecnico di Milano	E	Italy	Europe	2.4	1.3	1.0
Vrije University Amsterdam	E	The Netherlands	Europe	2.2	0.4	0.2

Table 4. The 10 most cited organizations in the world. B: Research and Business; E: Research and Education; G: Research and Government; O: Other

ORGANIZATION	TYPE	LOCATION		% ON TOTAL		
		Country	Continent	Cit.	Doc.	Auth.
IBM	B	United States	North America	8.9	3.3	3.9
Hitachi	B	Japan	Asia	0.5	2.2	2.9
Politecnico di Milano	E	Italy	Europe	2.4	1.3	1.0
Aristotle University of Thessaloniki	E	Greece	Europe	7.5	1.0	0.4
Queensland University of Technology	E	Australia	Australia	2.6	1.0	0.4
SAP Research	B	Germany	Europe	2.7	0.8	0.3
Edinburgh Napier University	E	United States	Europe	0.8	0.8	0.3
European Union	G	Belgium	Europe	1.0	0.8	0.7
Tata Group	B	India	Asia	0.3	0.7	0.7
Vienna University of Technology	E	Austria	Europe	5.0	0.7	0.7

Table 5. The 10 most productive organizations in the world. B: Research and Business; E: Research and Education; G: Research and Government; O: Other

SOURCE DOCUMENTS	ORGANIZATIONS	TYPE	CITATIONS
Giffinger et al., 2007	Delft University of Technology (E); University of Ljubljana (E); Vienna University of Technology (E)	Gr	60
Caragliu et al., 2009	Politecnico di Milano (E); University of Milan (E); Vrije University Amsterdam (E)	Gr	57
Komninos, 2002	Aristotle University of Thessaloniki (E)	Bo	34
Hollands, 2008	Newcastle University (E)	Ar	33
Atzori et al., 2010	Mediterranea University of Reggio Calabria (E); University of Catania (E); University of Cagliari (E)	Ar	20
Schaffers et al., 2011	INRIA (G); Aristotle University of Thessaloniki (E); ESoCE Net (O); Alfamicro (B); Lulea University of Technology (E)	Ch	20
Komninos, 2008	Aristotle University of Thessaloniki (E)	Bo	19
Paskaleva, 2009	University of Manchester (E)	Ar	15

The Climate Group, 2008	The Climate Group (O)	Gr	14
Karnouskos and Nass de Holanda, 2009	SAP Research (B)	Co	12
Hernández-Muñoz et al., 2011	Alexandra Institute (B); University of Cantabria (E); Polytechnic University of Madrid (E); Telefonica I+D (B); Lulea University of Technology (E)	Ch	12

Table 6. The 10 most cited source documents produced by European organizations. Ab: Abstract; Ed: Editorial; Ar: Journal article; Bo: Book; Ch: Book chapter; Co: Conference paper; Gr: Grey literature; B: Research and Business; E: Research and Education; G: Research and Government; O: Other

SOURCE DOCUMENT	ORGANIZATIONS	TYPE	CITATIONS
Dirks and Keeling, 2009	IBM (B)	Gr	22
Shapiro, 2005	University of Chicago (E)	Gr	17
Washburn et al., 2010	Forrester Research (B)	Gr	17
Naphade et al., 2011	IBM (B)	Ar	13
Coe et al., 2001	University of Ottawa (E)	Ar	12
Moss Kanter and Litow, 2009	Harvard University (E); IBM (B)	Gr	12
Dirks et al., 2009	IBM (B)	Gr	11
Dirks et al., 2010	IBM (B)	Gr	11
Belissent et al., 2010	Forrester Research (B)	Gr	10
Hall et al., 2000	Brookhaven National Laboratory (G)	Gr	8

Table 7. The 10 most cited source documents produced by North American organizations. Ab: Abstract; Ed: Editorial; Ar: Journal article; Bo: Book; Ch: Book chapter; Co: Conference paper; Gr: Grey literature; B: Research and Business; E: Research and Education; G: Research and Government; O: Other

A new, promising, but divided research area

This bibliometric analysis provides an overall picture of the first two decades of research on smart cities. The results show the amount of literature shaping this new research area and its intellectual structure has grown continuously during the period under investigation, especially since 2009. However, the limited intellectual exchange and lack of cohesion characterizing this structure have resulted in a situation whereby smart city researchers illustrate a tendency to follow personal trajectories in isolation from one another. As a result, the publications that they produce remain separated from one another as objects of knowledge divided along lines of enquiry that do not converge. In this scenario, the growth of smart city research follows two main development paths. The first one is based on peer-reviewed publications produced by European universities and those developing a holistic interpretation of smart cities. The second path, on the contrary, stands on the grey literature produced by the North American business world and its consultancy firms, which are promoting a techno-centric understanding of this subject.

This big picture on smart city research only relates to developments taking place between 1992 and 2012, but it nevertheless does serve to highlight the source of that division which still preoccupies many of the ongoing enquiries. For if we review the literature produced after 2012, indeed, the situation does not seem to change. This is because, while leading academics in the field continue to characterize smart cities as a new and promising topic of research, *"there is still not a clear and consistent understanding of [this] concept"* (Chourabi et al., 2012) and the work of defining and conceptualizing it is still in progress (Albino et al., 2015; Fernandez-Anez, 2016; Cocchia and Damieri, 2016; Ojo et al., 2016). Consequently, rather than overcoming the fragmentation that has been generated over the first 20 years, smart city research remains divided along the same lines of enquiry, and researchers are still left searching

for definitions which are capable of bridging them. Some examples are Kitchin (2014), Townsend (2013), Greco and Cresta (2015), Urzaiz et al. (2014) and Christopoulou et al. (2014).

The bibliometric analysis of the smart city research reported on in this paper shows the locus of the academic exchange currently taking place on the defining features of smart cities, as a point of intersection between two development paths. Two competing development paths, which are structurally divided in terms of both the form and content that each advances to define the smart city as an object of scientific enquiry.

On one hand, there is the development path promoting the techno-centric vision of smart cities. This vision proposes the smart city as an engine that fuels ICT companies and which is expected to exceed hundreds of billions of dollars by 2020 (Zanella et al., 2014). Driven by the desire to exploit this new and promising market, because it can *"provide [them] with alternative growth initiatives, particularly in a recession environment"* (Paroutis et al., 2014), large companies such as Cisco Systems (Amato et al., 2012), ABB (2013) and Fujitsu (Tamai, 2014) have decided to follow IBM, and deploy ICTs as vehicles of urban innovation that drive smart city development.

This corporate smart city model is criticized for the reason it fails to account for the social and cultural challenges that smart city developments pose in anything but technological terms. For in the corporate model, smart cities are assumed to arise from: 1) the concentration and interconnection of technological solutions able to capture and manage large amounts of data; 2) computing models and algorithms which use such data to cure the inefficiencies that cities exhibit (Townsend, 2013; Soderstrom et al., 2014; Hollands, 2015, 2016; McNeill, 2016). The ineffectiveness of this model is empirically demonstrated by Shin (2007; 2009; 2010), who highlights the weaknesses of the corporate and techno-centric smart cities developed by South Korea. Some examples of these smart cities are reported on by Yigitcanlar (2016), Townsend (2013), Anttiroiko (2013), Yigitcanlar and Lee (2014) and Shwayri (2013). They include the limitations of smart city development in Busan, Seoul, and Songdo International Business District, which is located along the waterfront of Incheon.

On the other hand, over the last four years, a holistic interpretation of smart cities has emerged within the academic world and acquired support from the scientific community. This interpretation is based on a progressive and human-centric perspective of ICT-driven urban innovation and development, and the balanced combination of human, social, cultural, environmental, economic and technological aspects (Hemment and Townsend, 2013; Townsend, 2013; Angelidou, 2014; Komninos, 2014; Hollands, 2015; 2016; Christopoulou et al., 2014; Concilio and Rizzo, 2016). However, as reported by Lee et al. (2014), the research supporting this vision of smart cities still *"remains at a preliminary stage"*, because the knowledge gap between theory and practice has not yet been filled. *"What elements go into making up a smart city"* (Hollands, 2015) and how to both design and implement strategies capable of building smart cities continue to be relevant subject-matters of investigation (Lazaroiu and Roscia, 2012; Zygiaris, 2013; Komninos, 2014; Bolici and Mora, 2015). But unfortunately, there is currently little agreement across the scientific community on how to conduct research capable of generating the evidence needed to bridge this gap (Deakin, 2014).

As Lee et al. (2014) also go on to state: *"discussions in academic literature of relevant [theories] or frameworks are few [and the] analysis lags behind the actual practice of how different cities [...] are moving towards transforming themselves into a smart [...] city. Even though actual practice often remains fragmented, real world implementation still generally outstrips any discussion in academic literature capable of generalization"*. As a result, the knowledge necessary to understand the process of building effective smart cities in the real world has not yet been produced, and neither

are the tools for supporting the actors involved in this activity.

Conclusion

The results of this analysis indicate that the main reason for the confusion around the scientific status of smart city research rests with the:

- lack of intellectual exchange between those conducting research in the field of smart cities;
- tendency smart city researchers have to be subjective and follow personal trajectories in isolation from one another;
- divisions that smart city research opens up in the scientific community;
- struggle the community has to find any common currency between the knowledge smart city research produces;
- disagreement the research generates as to the ways of conceptualizing and defining the smart city, which emerges as one of the main terms of reference for ICT-related urban innovation.

This situation leaves smart city research fragmented and divided along two main development paths and in a position whereby the future development of this new, promising, but divided area of research is put at risk. For while the bibliometric analysis indicates that smart cities are emerging as a fast-growing topic of scientific enquiry, much of the knowledge which is generated about them is singularly technological in nature. In that sense, lacking the social intelligence, cultural artifacts, and environmental attributes which are needed for the ICT-related urban innovation such research champions to be smart in securing the physical infrastructure requirements of cities.

To address the challenge which is posed by this situation, the intellectual exchange between the members of the scientific community researching smart cities need to increase markedly. Rather than running the risk of becoming entrenched along the lines of division reported on in this paper, researchers should instead begin to search out the grounds to transcend them by ‘acting in concert’. What is more, smart city researchers need to achieve this aim by integrating their respective fields of specialization using a model or mode of scientific enquiry which not only manages to bridge the structural division that is highlighted, but does it in a form whose content adds up to more than the ‘sum-of-the-parts’. This will support the construction of the collaborative environment which is necessary to generate a possible agreement concerning the way of thinking about, conceptualizing, and defining the smart city.

Notes

1. The keyword search has been performed on April 2016 using the search query: “smart city” OR “smart cities” (Baseline 1992).
2. This growth is documented and discussed in other recent studies produced by Wolfram (2012) and D’Auria et al. (2014).
3. As suggested by De Bellis (2009) and Small and Griffith (1974), any field of research can be envisioned as a mosaic or puzzle of individual units (scientific documents) clustered together by way of subject-related repositories (journals) and produced through the research activities performed by a community of scholars (authors). These publications represent the output of research conducted into a specific field of study and raw data for performing bibliometric analyses. Therefore, they are defined as source documents (Small and Crane, 1979; Shiau and Dwivedi, 2013.
4. No searches are done to retrieve all available literature on smart cities. The keyword search is limited to English language documents.

5. *"Many new categories of cities have entered the policy discourse: sustainable cities; green cities; digital cities; smart cities; intelligent cities; information cities; knowledge cities; resilient cities; eco cities; low carbon cities; liveable cities; and even combinations, such as low carbon eco cities and ubiquitous eco cities"* (de Jong et al., 2015). However, within the literature on urban development and innovation, these categories of cities are used interchangeably, even if they are characterized by conceptual and practical differences (Jong et al., 2015). This generates the terminological confusion described by Hollands (2008) and Deakin and Al Wear (2011). Taking such differences into account and mindful of this study's specific interest in smart cities, a decision was made to set the keyword search so that only documents containing the term 'smart city' in singular or plural form were captured. These are considered to be the core documents for exploring what smart cities mean as knowledge objects. No varying or related terms are therefore considered in this search. This avoids the risk of adversely affecting the bibliometric study by including documents not directly connected to smart cities as a knowledge domain.
6. Considering the definition provided by Schopfel (2010), only conference papers included in repositories controlled by commercial publishers such as Springer, ACM (Association for Computing Machinery), IEEE (Institute of Electrical and Electronics Engineers), and Elsevier are not considered as grey literature.
7. Most of the grey literature is extracted form Google Scholar, which is a database particularly recommended for identifying this kind of publications (Hutton 2009).

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