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Exploring the Big Picture of Smart City Research

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Abstract: This paper analyses the ‘big picture’ of the smart city research field by means of a bibliometric analysis of the literature on smart cities produced between 1992 and 2012. The findings show that this new field of scientific inquiry has started to grow significantly only in recent years, mainly thanks to European universities and US companies. Its intellectual structure is complex and lacks cohesion due to the infinite possible combinations among the building blocks and components characterising the smart city concept. However, despite this complexity, the bibliometric analysis made it possible to identify three structural axes that traverse the literature, capture the main research perspectives, and reveal some key aspects of this new city planning and development paradigm.

Keywords: smart city research, urban studies, bibliometric analysis, intellectual structure

JEL Codes: O21, O31, O38

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1. Introduction

During the 2000s, a radical change of the city planning model and practice occurred due to the emergence of information, knowledge and digital technologies as key drivers of the organization and development of cities. In this context, as a new planning paradigm, the smart city marks a turning point in the history of cities, exactly as happened with the high density *"city of towers"* and the great rebuild of the European post-war period, which dominated the last part of the twentieth century (Hall, 1988). The implementation of this new city planning and development paradigm is forming a new urban reality in which software applications, sensors and embedded devices, along with flows of digital information and knowledge, are improving the functioning of urban environments, and are used to address issues limiting the sustainable development of cities.

The establishment of the smart city as a new city planning and development paradigm has been fast in both theory and practice. Data from recent studies suggest that the number of cities working on strategies and projects for smart city development is growing rapidly. While research by Lee and Hancock (2012) reports 143 cases around the world in 2012, a study by Manville et al. (2014) on the 28 EU Member States shows that 240 cities with more than 100,000 inhabitants have started working in the field of smart cities before 2014. The number of smart city cases seems to grow in parallel with the quantity of scientific publications discussing the paradigm. This consideration is based on a search performed in Google Scholar on 1st April 2016 using the search string "smart city" OR "smart cities" (baseline year 1980). The search found that the number of publications related to smart cities increased by 120 times over 20 years, rising from 138 in 1996 to 16,500 in 2015.
Thanks to a growing interest and a growing number of publications, the smart city can now be recognised as a new and interdisciplinary field of scientific inquiry. However, since little is known about its overall structure, the exploratory study presented in this paper is conducted to build and analyse the *"big picture"* (Moya-Anegon et al., 2004) of the smart city research field. The purpose is to provide researchers involved in construction of its intellectual structure with knowledge that encompasses this field of study as a whole, and to suggest future directions of research.[1] More specifically, the paper focuses on the following research questions:

1. How have the smart city research field and its intellectual structure evolved over time?
2. How large is the scientific community engaged in research on smart cities?
3. What are the influence and productivity levels of researchers in this community and the organizations to which they belong?
4. What are the structuring axes of the literature on smart cities?

To answer these questions, the paper uses bibliometrics and analyses the scientific publications on smart cities produced over a period of 21 years (1992-2012). The methodology used to perform the analysis is illustrated in the next section, which is followed by an in-depth description of the smart city concept and its genesis. The findings of the bibliometric analysis are discussed in the sections 4 and 5.

[1] From the perspective of bibliometric studies, the 'big picture' of a research field can be seen as a jigsaw consisting of a large number of publications which represent the output of any research conducted in the field during a specific timeframe (De Bellis, 2009; Small and Griffith, 1974).

2. Methodology

This bibliometric study is carried out by combining the analysis of the citations among 1,067 scientific publications with citation and publication counts, which are two basic bibliometric measures (Tijssen and van Leeuwen, 2003). In regard to the period 1992-2012, these publications represent the overall output of research conducted in the field of smart cities. Therefore, they compose its 'big picture' and can be considered as the source documents of the bibliometric analysis (Ingwersen et al., 2014). These publications are selected because they deal with the smart city concept and this is demonstrated by the presence of the term 'smart city' or 'smart cities' in their title, abstract or body of the text. All the source documents are found with a keyword search performed in eight scholarly databases: Google Scholar; ISI Web of Science; IEEE Xplore; Scopus; SpringerLink; Engineering Village; ScienceDirect; and Taylor and Francis Online. This extensive and multidisciplinary search made it possible to avoid the risk of building an incomplete picture of the smart city research field and the possible exclusion of highly representative publications. Only scholarly literature in English is considered in this study.

The source documents, after being identified, are grouped according to their type: editorials and abstracts (12), journal articles (320), books (10), conference papers[2] (387), book chapters (67), and grey literature (271). This last category includes the literature *"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). Moreover, each source document is also linked to additional information concerning its authors by collecting their full names and the name, type and location of the organizations for which they work. Four categories are defined to classify organizations: 1) education: universities, academies and colleges (492); 2) business: private companies operating in the ICT sector and involved in research and consultancy activities or in the distribution of goods and services (138); 3) government: public authorities and their research institutes (64); 4) other (85). In the case of organizations operating in multiple locations, the main headquarters are considered.[3]

Finally, before starting the analysis, citation data is collected manually from the source documents, tested for correctness, and used to build a frequency table showing both each cited publication and the number of times it is cited. Altogether, a total of 22,137 citations are extracted (957 to source documents and 21,180 to non-source documents) corresponding to 17,574 cited references (239 source documents and 17,335 non-source documents). Only citations to source documents are considered in the bibliometric analysis.

3. Genesis of the smart city concept

The concept of smart city has been shaped in a literature that spans 30 years, since the first writings on the subject at the beginning of 1980s to the current explosion of publications. An early phase in the use of the term and formulation of the concept was the period 1985-1995, while proper use and full meaning in the urban development and planning literature came after 2000. Definition of the concept of the smart city evolved in parallel with that of

[2] 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 were considered not to be grey literature.
[3] The number of source documents and organizations by type is given in brackets.

other similar or quasi-similar concepts like intelligent city, digital city, and cyber city. In the early writings, the demarcation lines between these concepts were fuzzy and all these terms attempted to capture the same information-based and knowledge-driven development process of cities.

A very rich literature is now available which reflects on the concepts of intelligent-smart-digital-cyber cities and captures the contribution of digital technologies, information and knowledge flows, and innovation systems to the development and planning of twenty-first century cities. This literature highlights a trajectory of urban change: it describes a series of innovations in urban systems sustained by broadband networks, sensors, data management technologies, software applications and e-services. Both the urban system and the innovation system of cities change as these technologies enable citizens, end-users, enterprises and organisations to develop innovative behaviours in relation to the use of urban spaces and more intelligent decision-making in the development of cities.

The formation of the intelligent-smart-digital-cyber city concepts took place in two distinct periods. Initially, the terms intelligent city and smart city appeared in the second half of the 1980s. Based on Google Scholar data, the first use of the term intelligent city can be traced to the period 1986-1990 in the framework of the literature on the innovation-led development of cities and the Japanese Technopolis Programme. Publications such as Lipman et al. (1986), Newstead (1989), Batty (1990), Masser (1990) outlined how the use of information technology and networks could sustain the technological development and competitive advantage of cities. In the same period, a first use was also made of the term smart city to denote innovations in urban mobility sustained by information technologies, the use of IT for the provision of city services, and the better performance of cities in environmental, economic and social terms (Hall, 1988; Raynal, 1988; Wemmerlöv, 1990).

The first use of the terms digital city and cyber city can be traced five years later, in the period 1990-1995. The expression 'cyber cities' refers to computer-generated 3D models of cities (Malina, 1993) and the management of technology centres with the use of information technology (Poggenpohl et al., 1995). The cyber city literature is then used to highlight the early wave of e-government applications for city management and other technologies for security and control over the urban space (Graham, 2004). The term digital city appears early (1985) in the title of the "Center for Digital City and Urban Landscape, Shenzhen Graduate School, Peking University", but the proper use of the term in the literature on cities appears later, in the period 1990-1995. Studies such as Towster et al. (1990), Schalken and Tops (1995) and Huang (1995) discussed gateways to public information networking, decision-making in virtual communities, information systems and urban regeneration. In the years after these initial publications, the digital city literature focused on the representation of the city, how a digital metaphor of the city is constructed by the media, and how the physical city can be better understood through its virtual representation (Ishida and Isbister, 2000; van den Besselaar and Koizumi, 2005).

This initial literature on intelligent, smart, cyber and digital cities (1985-1995) was characterised by two dichotomies: (1) innovation vs. information technology and (2) virtual city vs. city. Both the intelligent city and smart city concepts refer to cities as complex physical, social and digital entities, with respective emphasis on innovation and information technology. Both the cyber city and digital city concepts refer to cities as reality in the cyberspace, with respective emphasis on e-governance and virtual representation.

The decade that followed (2000-2010) saw the academic and technological establishment of the smart city paradigm. The literature on smart cities reflected the gradual shaping of this planning and development paradigm and how its technological bases (telecoms and virtuality) were enriched with various forms of networking, social intelligence and innovative IT functionalities, that made it possible to describe the urban space as intelligent. Mitchell (2007) argued that the new intelligence of cities resided in the increasingly effective combination of digital telecommunication networks, ubiquitously embedded intelligence, sensors and knowledge management software. This technological construction did not appear suddenly but it arose through continuous evolution starting with the development of the theory of digital interaction, the invention of packet switching, the Arpanet, Ethernet, the Internet, the World Wide Web, the rapid expansion of wired and wireless communications, the appearance of laptop computers and other end-user communication devices, mobile phones, Blackberries and iPods, tiny embedded microprocessors, digital sensors and tags, minuscule digital cameras and microphones, RFID tags, GPS and other positioning devices. Then large-scale software appeared and the literature on smart cities changed the older arguments about telecommunications in the city, cyber cities and digital cities (Isida and Isbister, 2000; van den Besselaar and Koizumi, 2005), making the previous metaphors of cyberspace and virtual worlds outmoded. However, there is an evident disagreement concerning what smart cities are and how they are constructed. Table 1 provides a sample of formal definitions of a smart city, which are gathered from the source documents and presented by chronological order of appearance. These definitions are indicative of the diversity among interpretations of the smart city and their building blocks.

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"*
Komninos, 2002	*"we use the term 'intelligent city' [smart city] to characterize areas (communities, neighbourhoods, districts, cities, regions) which have the ability to support learning, technological development, and innovation procedures on the one hand, with digital spaces and with information processing, knowledge transfer and technology tools on the other hand"*
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 [Smart economy (competitiveness); Smart people (social and human capital); Smart governance (participation); Smart mobility (transport and ICT); Smart environments (natural resources); and Smart living (quality of life)], built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens"*
Caragliu et al., 2011	*"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 realising 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 of the many definitions of smart cities provided in the source documents

Clearly, these definitions are far from being identical, making it difficult to obtain a common understanding and agreement about the meaning of the smart city concept. Apart from a shared reference to ICT as an enabler of smart city development, these definitions are divergent in nature and the division they generate becomes even more visible when trying to find out a commonly accepted interpretation of how smart cities work and the fields of their impact, as highlighted in various publications, such as Alkandari et al. (2012), Chourabi et al. (2012), Hollands (2008), and Paskaleva (2011).

4. Formation of the smart city research field

The bibliometric analysis shows that the production of publications dealing with smart cities starts growing significantly in 2009, along with the number of researchers involved in their development. These trends are illustrated in Figure 1.

An impressive growth

Between 1992 and 2001, less than 20 source documents are published and the community of researchers working in the smart city research field is particularly small. The situation starts changing in the following eight years, from 2002 to 2009, when the quantity of publications and authors slightly increase. While the number of researchers rises from 30 to 290, about 130 additional source documents are published. However, the period of greatest growth in the number of both source documents and authors is between 2010 and 2012. During these three years, 916 scientific documents are published, which is approximately 86% of the available literature on smart cities considering the first 21 years

of research in this field. In the same period, the scientific community grows following a similar trend, thanks to the research activity of nearly 2,300 new smart city researchers.

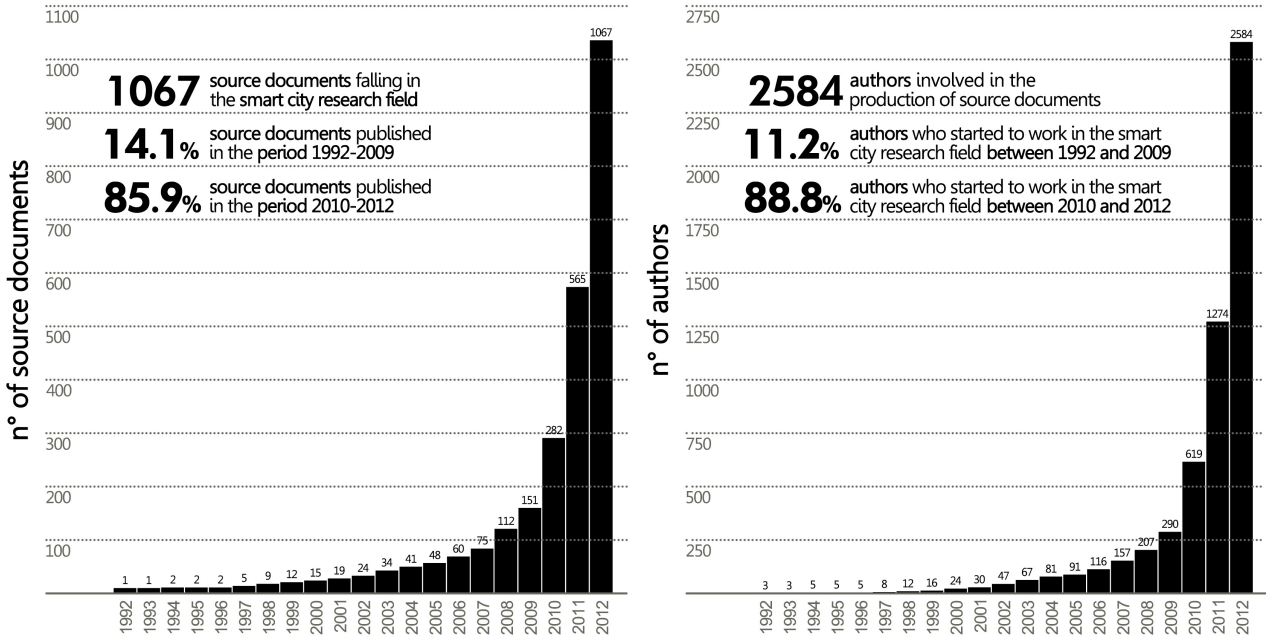

Figure 1. Cumulative growth in the number of source documents and in the number of authors involved in the production of source documents

The community of smart city researchers

Considering the period investigated, the scientific community conducting research on smart cities is composed of 2,584 researchers belonging to 779 organizations. Their influence and productivity is calculated by assigning each of them the numbers of both the source documents produced and the citations that they have received. In the case of publications with more than one author, the unit value of the document and its citations are divided by the number of authors involved and each is assigned an equal share. This approach made it possible not only to compare individual researchers, but also to extend the analysis to the organizations in which they work and the countries and continents where those organizations are located. The results of the counting process are reported in Table 2.

CONTINENT AND COUNTRY	% AUTHORS IN TOTAL					% SOURCE DOC. IN TOTAL					% CITATIONS IN TOTAL				
	Bus	Edu	Gov	Oth	Tot	Bus	Edu	Gov	Oth	Tot	Bus	Edu	Gov	Oth	Tot
Africa	**0.0**	**0.8**	**0.7**	**0.3**	**1.7**	**0.0**	**1.4**	**0.7**	**0.5**	**2.5**	**0.0**	**1.7**	**0.1**	**0.2**	**2.0**
South Africa	0.0	0.5	0.4	0.3	1.1	0.0	1.1	0.5	0.5	2.1	0.0	1.7	0.1	0.2	2.0
Others	0.0	0.4	0.3	0.0	0.7	0.0	0.2	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Asia	**5.8**	**17.8**	**1.5**	**0.7**	**25.8**	**5.0**	**16.3**	**1.3**	**0.6**	**23.3**	**2.2**	**7.6**	**0.2**	**0.3**	**10.3**
China	0.9	8.9	0.6	0.0	10.4	0.6	7.3	0.4	0.0	8.4	0.0	3.6	0.0	0.0	3.7
India	0.7	0.9	0.1	0.0	1.6	0.8	0.9	0.1	0.0	1.7	0.3	0.0	0.0	0.0	0.3
Japan	4.1	2.4	0.0	0.4	6.9	3.2	1.8	0.0	0.3	5.3	0.6	0.4	0.0	0.0	0.9
Korea	0.1	3.1	0.2	0.1	3.6	0.1	3.1	0.4	0.1	3.8	0.3	1.8	0.1	0.0	2.2
Malaysia	0.0	0.9	0.0	0.0	0.9	0.0	1.7	0.0	0.0	1.7	0.0	1.7	0.0	0.0	1.7
Taiwan	0.0	0.7	0.2	0.2	1.1	0.0	0.7	0.1	0.1	0.9	0.0	0.0	0.1	0.0	0.1
Other	0.1	0.9	0.4	0.1	1.4	0.3	0.9	0.2	0.1	1.5	1.0	0.1	0.0	0.3	1.4
Australia	**0.5**	**3.3**	**0.2**	**0.0**	**3.9**	**0.4**	**4.4**	**0.3**	**0.0**	**5.1**	**0.3**	**3.9**	**0.1**	**0.0**	**4.3**
Australia	0.5	3.0	0.2	0.0	3.6	0.4	4.1	0.3	0.0	4.8	0.3	3.9	0.1	0.0	4.3
Other	0.0	0.2	0.0	0.0	0.2	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Europe	**9.4**	**33.6**	**3.5**	**5.0**	**51.4**	**8.6**	**35.4**	**2.8**	**5.3**	**52.0**	**7.8**	**42.4**	**3.1**	**5.7**	**59.0**

Austria	0.9	1.0	0.0	0.1	2.0	0.8	0.9	0.0	0.1	1.8	0.2	5.0	0.0	0.0	5.2
Belgium	0.2	1.3	0.7	0.3	2.6	0.2	0.9	0.8	0.2	2.1	0.0	0.3	1.0	0.1	1.5
France	1.1	1.9	0.8	0.2	4.0	0.9	1.7	0.8	0.2	3.5	0.6	0.6	1.4	0.4	2.9
Germany	2.1	3.2	0.3	0.6	6.2	2.4	3.0	0.1	0.8	6.2	3.6	0.9	0.0	0.5	5.0
Greece	0.3	2.4	0.2	0.5	3.4	0.1	2.6	0.1	0.6	3.4	0.0	8.8	0.1	0.9	9.8
Italy	0.9	6.3	0.5	0.8	8.5	0.6	6.1	0.4	1.0	8.0	0.4	7.7	0.0	1.7	9.8
Netherlands	0.1	1.2	0.0	0.0	1.4	0.1	1.5	0.0	0.0	1.6	0.0	3.4	0.0	0.0	3.4
Spain	1.0	3.6	0.3	0.4	5.3	0.8	3.0	0.1	0.4	4.3	0.8	2.7	0.2	0.0	3.7
United Kingdom	1.1	5.3	0.2	0.6	7.2	1.4	6,4	0.1	0.8	8.7	1.0	8.2	0.0	1.7	10.9
Others	1.7	7.5	0.5	1.5	11.1	1.3	9.4	0.5	1.3	12.5	1.2	4.7	0.5	0.4	6.8
North America	**6.7**	**8.0**	**0.9**	**1.0**	**16.6**	**6.0**	**8.8**	**0.6**	**1.3**	**16.7**	**12.7**	**9.9**	**0.8**	**1.0**	**24.4**
United States	6.7	6.7	0.8	0.9	15.2	6.0	7.3	0.4	1.2	14.9	12.7	8.3	0.8	1.0	22.8
Others	0.0	1.2	0.1	0.1	1.4	0.0	1.5	0.2	0.1	1.8	0.0	1.5	0.0	0.0	1.5
South America	**0.1**	**0.5**	**0.0**	**0.0**	**0.6**	**0.1**	**0.3**	**0.0**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Table 2. Percentage of authors, source documents, and citations by country, continent and organization type (Bus: Business; Edu: Education; Gov: Government; Oth: Other)

Besides having produced more than half of the source documents, European organizations account for approximately 52% of the total authors and have the highest overall impact in smart city research. Despite lower values, also in North America there is a positive correlation between production and influence. 16.6% of the authors belong to American organizations, which have developed about 17% of the total source documents and obtained 24.4% of the total citations. In comparison to Asia, this is a better result: Asia is the second continent in terms of productivity and workforce, but the publications produced by its researchers have a limited influence (10.3% of citations). Finally, the participation of the remaining continents in the construction of the smart city knowledge structure is very limited, especially in Africa and South America.

Europe and North America are the largest contributors to the growth of smart city research and the regions that most influence the intellectual structure of this fast-expanding field of scientific inquiry. However, these two knowledge hubs are characterised by a significant difference that can be observed by looking at Table 3. European research on smart cities is conducted mainly by universities located in the geographical area comprised between Austria, Greece, Italy, the Netherlands, and the United Kingdom. Conversely, in North America, the greatest productivity is linked to the academic world and private companies operating in the ICT sector. However, the latter has acquired most of the citations to source documents, 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 that they have produced.

RANKING		**ORGANIZATION**	**TYPE**	**LOCATION**		**% ON THE TOTAL**		
Cit	Pro			**Country**	**Continen**	**Cit.**	**Doc.**	**Aut.**
02	**04**	Aristotle University of Thessaloniki	Edu	Greece	Europe	7.5	1.0	0.4
30	**07**	Edinburgh Napier University	Edu	United Kingdom	Europe	0.8	0.8	0.3
20	**08**	European Union	Gov	Belgium	Europe	1.0	0.8	0.7
05	76	Forrester	Bus	United States	North	2.9	0.3	0.3
41	**02**	Hitachi	Bus	Japan	Asia	0.5	2.2	2.9
01	**01**	IBM	Bus	United States	North	8.9	3.3	3.9
04	176	Newcastle University	Edu	United Kingdom	Europe	3.4	0.1	0.1
09	**03**	Politecnico di Milano	Edu	Italy	Europe	2.4	1.3	1.0
08	**05**	Queensland University of Technology	Edu	Australia	Australia	2.6	1.0	0.4
06	**06**	SAP Research	Bus	Germany	Europe	2.7	0.8	0.3
60	**09**	Tata Group	Bus	India	Asia	0.3	0.7	0.7
07	97	University of Chicago	Edu	United States	North	2.6	0.2	0.1

03	**10**	Vienna University of Technology	Edu	Austria	Europe	5.0	0.7	0.7
10	31	Vrije University Amsterdam	Edu	The Netherlands	Europe	2.2	0.4	0.2

Table 3. The 10 most cited and productive organizations working in the smart city research field (Cit: Most cited; Pro: Most productive; Bus: Business; Edu: Education; Gov: Government)

Fragmentation

The source documents that compose the intellectual structure of the smart city research field can be envisioned as a group of inter-connected publications and represented using mapping techniques that yield *"a spatial representation of the relationship among [them] as reflected in some formal, strictly quantifiable properties of scientific literature at a given time"* (De Bellis, 2009). In this structure, citations are the elements that generate the connections between the publications. They are *"a type of symbolic currency that signals intellectual influences"* and intellectual exchange between two authors. By using them, researchers can incorporate intellectual work from other research into their own studies (Small, 1973; 1978), and collaborate in the construction of the intellectual structure of their field of investigation.

The overall intellectual structure of the smart city research field is shown in Figure 2. It 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. The graph is obtained by using the Fruchterman-Reingold layout algorithm provided by the open-source software Gephi (Fruchterman and Reingold, 1991). Each source document is represented by a circle that has a diameter proportional to the number of citations received. The larger the diameter, the greater the number of citations.

Looking at the network, it is evident that fragmentation is one of the main features of the smart city research field. The impressive growth of scientific literature in recent years has been matched by a lack of cohesion among the researchers involved in the construction of its intellectual structure. As a result, this structure is divided into a multitude of unconnected publications. The core of the network is compact and well-articulated due to the presence of citations which suggest an active exchange of knowledge among researchers. However, moving towards the outer perimeter, the structure of the network changes completely: source documents are disconnected or combined in very small groups of publications that are detached from the central core. Statistical evidence of the network fragmentation can be found in the graphs in Figure 3 and Figure 4. Considering the period 1992-2012, about 80% of the source documents remaine completely disconnected from any other publications belonging to the smart city research field, and this lack of connections has increased considerably over the years.

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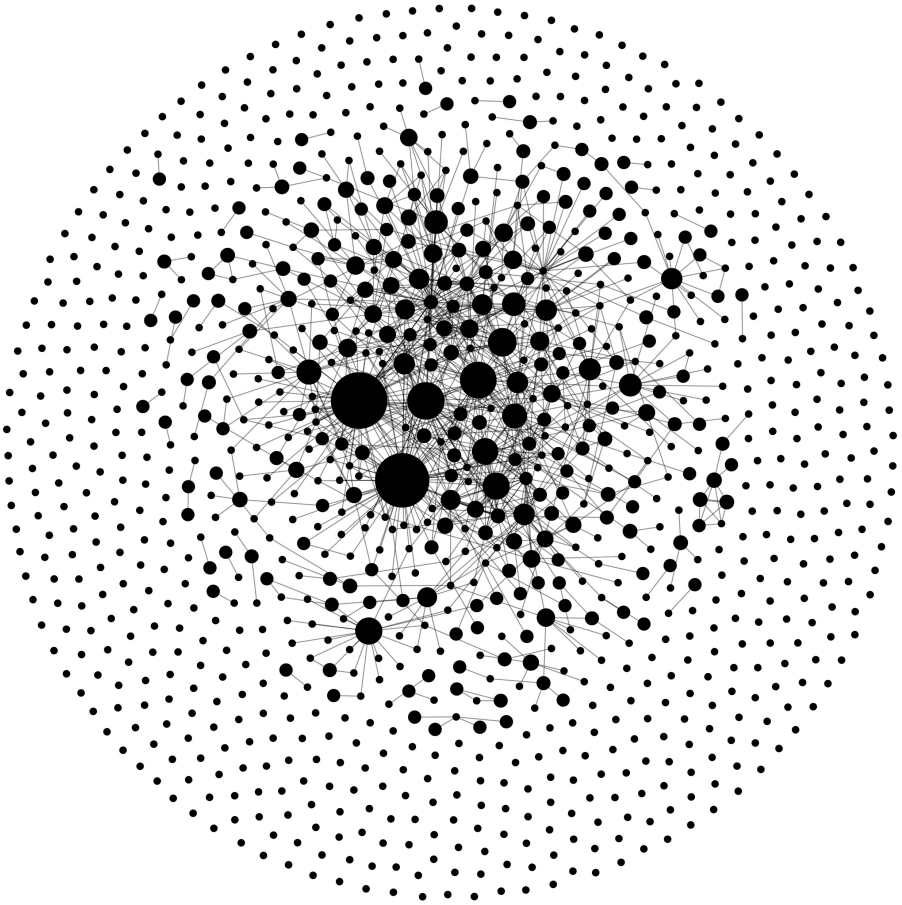

Figure 2. Intellectual structure of the smart city research field considering the period 1992-2012

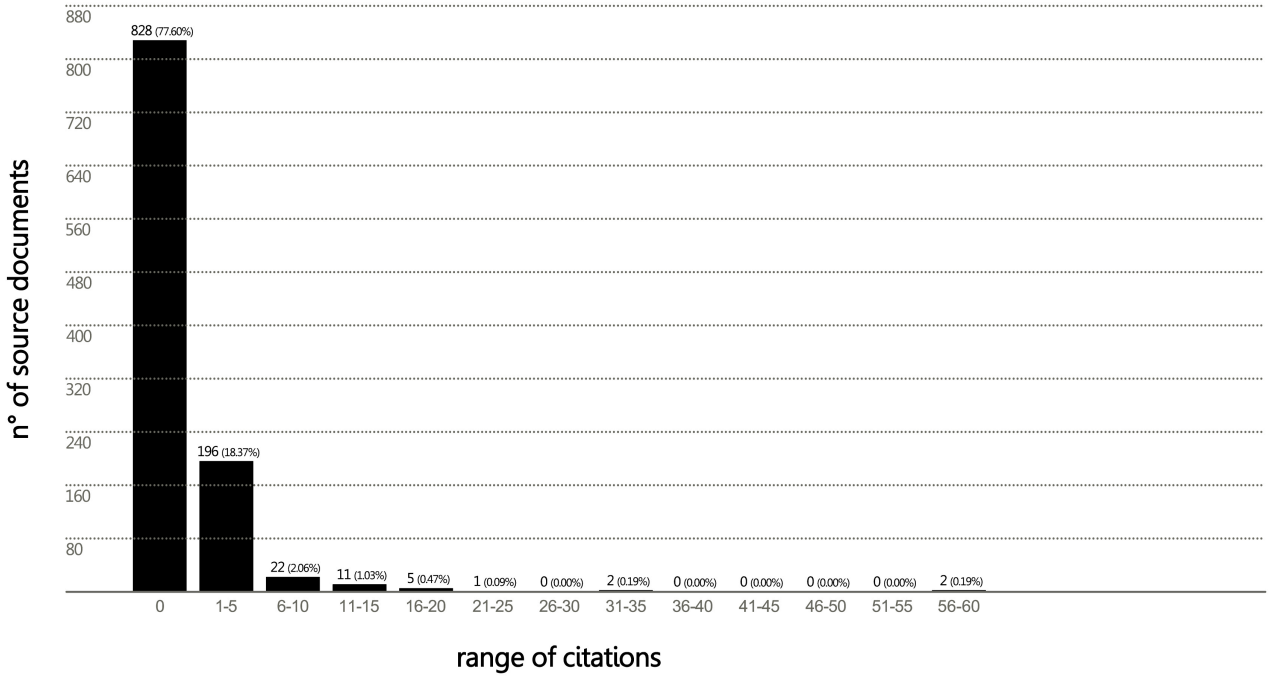

Figure 3. Distribution of the source documents by range of citations considering the period 1992-2012

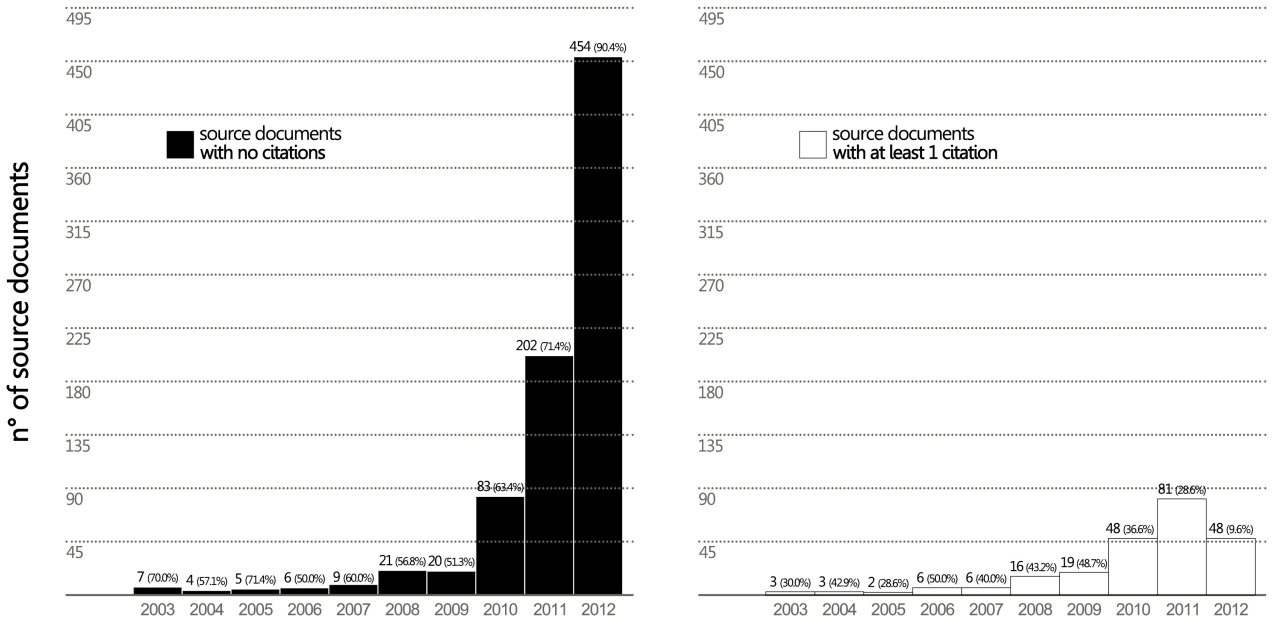

Figure 4. Distribution of cited and not-cited source documents by year of publication considering the period 2003-2012

5. Structural axes of the smart city literature

The divergence in defining the smart city concept and the fragmentation in the intellectual structure of the smart city research field reflect wide disparities in understanding: how smart cities are structured; what is the range of technologies that contribute to the functioning of smart cities; what is the role of citizens and technologies; and how the city planning process changes in this paradigm. This becomes quite evident when trying to determine the structural axes that characterise the literature on smart cities and capture the complexity of this new city planning and development paradigm. These axes are generated by three dichotomies that emerge from the review of the smart city literature considered in this bibliometric study.

Technology-driven vs. human-driven approach

A main difference between the two above-described knowledge hubs concerns the view of smart cities supported by their respective research activity. On the one hand, European researchers are leading a more holistic interpretation of smart cities, in which technological and non-technical factors are considered key drivers with equal importance in the transformation of ordinary cities into smart environments. On the other hand, the American business world interpret the smart city as *"a new kind of technology-led urban utopia"* (Hollands, 2015). In this vision, cities are conceived as systems of systems characterised by inefficiencies and *"urban pathologies"* that need to be cured using a massive input of technology, mainly provided by ICT companies (Soderstrom et al., 2014).

The technology-driven vision has led to the growth of the corporate smart city model, which is discussed and criticised in recent studies by Hollands (2015, 2016) and Soderstrom et al. (2014). Moreover, it has opened up the way to a new urbanism in which IT solution providers try to persuade city governments to support urban innovation and development by adopting their proprietary smart technology. IBM is a main supporter of this model, which is described in the source documents produced by its researchers (Chen-Ritzo et al., 2009; Dirks and Keeling, 2009; Dirks et al., 2009, 2010; Harrison et al., 2010),

and put into practice through its *Smarter Planet - Smarter Cities initiative*. This is a commercial venture launched at the end of 2008, that attempts to bring cities closer to IBM's expertise and technologies in order to address their most critical issues and make the city *"smarter"* and more efficient (Palmisano, 2008). Many cities around the world have already embraced this smart city vision. However, its connection with ideas of technology only and linear impacts upon the social, economic, environmental and spatial development of urban functions can be misleading in regard to the complexity and contradictory nature of urban systems (Aurigi, 2006; Graham and Marvin 1999; Graham 2000).[4]

On the contrary, the European perspective considers issues beyond technology and moves towards a more holistic interpretation of smart cities, highlighting that their development depends on a balance among human, social, cultural, environmental, economic and technological factors. This interpretation emerges in many source documents, starting from the report published by Giffinger et al. (2007), which describe a smart city as an urban area characterised not only by a high availability of ICTs, but *"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"*. A few years later, Caragliu et al. (2011) made a significant contribution to supporting and expanding this vision by stating that *"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 is an interpretation that aligns with Hollands (2008) and its request to provide a more progressive view of the smart city, 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"*. Other source documents that support the holist perspective of smart cities include those by Komninos (2002; 2008), Deakin and Al Wear (2011), and Schaffers et al. (2011)[5].

Top-down vs. bottom-up planning

How should smart cities be planned? Top-down or bottom-up? These questions are discussed not only in the source documents, but also in many recent studies such as Townsend (2013), Komninos (2014), Bolici and Mora (2015) and Mora and Bolici (2016; 2017), and they summarise an important dichotomy that marks smart city planning: the *"top-down, corporatized, centralized"* development path vs. the *"bottom-up, grassroots, decentralized and diffuse"* approach (Kitchin, 2014). The difference between these two visions in explained in research by Cocchia (2014), Damieri (2013) and Ratti and Townsend (2011). Top-down smart cities originate and are developed from the political and administrative leadership within city government, which defines a specific strategy to be followed. In this case, *"municipalities [assume] a leading role in defining and driving a comprehensive vision about the smart city"* (Cocchia, 2014). This approach is usually characterised by an extremely limited or even absent engagement of citizens (Damieri, 2013). Bottom-up smart city planning, by contrast, relies on self-organization and grass-roots efforts, which become more important than the presence of a comprehensive and

[4] A list of cities falling within the Smarter Planet programme is provided by IBM on the website https://smartercitieschallenge.org/cities.

[5] The paper describes the structural differences that characterize the way in which North American businesses and European universities deal with the smart city concept by reporting on the contents of their respective publications. Unfortunately, the database used in the study does not make it possible to acquire statistical evidence of such differences, which would be useful for further highlighting the presence of divergence in smart city research. This is an important aspect to be considered in future studies related to the smart city subject.

holistic strategic framework (Ratti and Townsend, 2011).

The interpretations of the smart city concept within the scholarly literature demonstrate that these two approaches have generated divergent views concerning their effectiveness. Lee and Hancock (2012) and their model for measuring the maturity level of smart cities, for example, suggest a formalised and centralised top-down smart city strategy revised on a regular basis and aligned with cities' strategic priorities is an important driver for supporting the construction of smart cities, and is preferable to a strategy based on a bottom-up approach. In addition, the top-down development path has already been applied in several smart city initiatives, such as Busan Green u-City, Songdo International Business District, and Incheon Eco-City, which are some of the most discussed cases in the smart city literature (GSMA, 2012; Strickland, 2011; Washburn et al., 2010). However, they have been strongly criticised (Deakin and Al Wear, 2011; Shin, 2007; 2009; 2010) for their inability to effectively serve people and their needs rather than "*the demands of major corporate suppliers and industry"* (Shin, 2009).

Ratti and Townsend (2011), instead, describe smart cities as the result of bottom-up movements, suggesting that their construction can be achieved only by shifting *"from top-down innovation processes to open and bottom-up innovation"* in which the users' involvement needs to remain high (Schuurman et al., 2012). Both authors believe that *"top-down visions ignore the enormous [and] innovative potential of grass-roots efforts"* and highlight the importance of maximising the involvement of citizens and civic groups in the development of ICT-driven urban solutions (Ratti and Townsend, 2011). This point of view is aligned with the source documents by Alawadhi et al. (2012), Hodgkinson (2011), and Schaffers et al. (2012), who stress the importance of empowering citizens and providing them with the opportunity to become active actors of change in the making of successful smart cities.

Collective intelligence vs. data-driven intelligence

How city smartness or intelligence is produced is another dichotomy that characterises the smart city literature. City intelligence emerges from the agglomeration and integration of three types of intelligence: the inventiveness, creativity and intellectual capital of the city's population; the collective intelligence of the city's institutions and social capital; and the artificial intelligence of public and city-wide communication infrastructure, software applications and smart environments. However, the emphasis on these components of intelligence varies considerably in smart city literature, which is also not able to clearly explain their respective role in smart city development.

Initially, the intelligence or 'smartness' of cities was attributed to collaboration and collective intelligence within human communities, sustained by IT applications that improve innovation, collaborative efforts and crowdsourcing to acquire and process information, sustain learning, experimentation, and problem-solving. From this perspective, an intelligent or smart city was a multi-layer territorial system of innovation based on knowledge-intensive activities, institutions for social cooperation and learning, digital infrastructure and applications that maximise the problem-solving capabilities of communities and cities (Komninos, 2002; 2008; Mitchell, 2007).

However, a different interpretation has become dominant since 2009, in which city intelligence is linked to awareness and produced by data and advancements in mobile devices, wireless networks, sensors, actuators embedded in the physical spaces of cities, and the Internet of Things. It is expected that smart cities, with the help of

instrumentation and interconnection of mobile devices, sensors and actuators, collect city wide data and elaborate them, improving the ability to forecast and manage urban flows and push city intelligence forward (Chen-Ritzo et al., 2009; Deakin, 2014). Within this perspective, the intelligence of cities moves out of applications and enters the domain of data, which is expected to enable real-time responses.

6. Conclusions

Using bibliometrics and the literature on smart cities produced during the period 1992-2012, we have outlined the emergence of the smart city concept, the formation of the smart city research field, and some structural axes characterising the growing body of literature composing its intellectual structure. The analysis shows that the main features of this emerging research field are fragmentation and the presence of diverging research strands. This is mainly due to the interdisciplinary approach and the gathering of researchers with different backgrounds and epistemologies, and the open choices concerning a series of main structural axes: 1) technology-driven vs. human-driven approach; 2) top-down vs. bottom-up planning; 3) collective intelligence vs. data-driven intelligence.

All these dimensions are related to the role of technology in the making of twenty-first century cities. There is no doubt that technology plays a major role in shaping the contemporary urban landscape and there is a wide range of technologies that drive urban innovation and sustainability, from renewable energy to electric cars and Internet-based solutions. In the smart city literature, there is no agreement about the range of actualising technologies: whether any field of technology-based innovation is included or only ICTs. Moreover, this technological dimension is connected to a stronger participatory and user-driven approach. The citizen is not a passive recipient of technology. On the contrary, technology should empower users and citizens for more informed and intelligent behaviour, in the framework of institutions and decision making.

Ultimately, the question is whether we want to conceive smart cities as a holistic technology-driven paradigm, incorporation of any kind of urban technology, or as a more specific approach based on the use of ICTs which complements other planning models, such as smart growth, new urbanism, and strategic urban planning. Whatever the choice, however, the global technological advancement which is pushing ICTs and their integration in urban environments, enabling the construction of smart cities, should be aligned with local urban dynamics and local needs. In this way, as suggested by Petrillo and Sardaro (2014), digital technologies can become an asset in the development of urban communities and effectively support their sustainable growth.

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