

Combining Co-Citation Clustering and Text-Based Analysis to Reveal the Main Development Paths of Smart Cities

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Abstract: Bibliometrics is a powerful tool for analyzing knowledge domains and revealing their cognitive-epistemological structure. Different mathematical models and statistical techniques have been proposed and tested to carry out bibliometric analyses and demonstrate their effectiveness in uncovering how fields of research are intellectually structured. These include two hybrid techniques that allow clusters of related documents obtained from a co-citation analysis to be labeled using textual data. This paper reports on the findings of a bibliometric study in which these hybrid techniques are combined to: (1) build and visualize the network of publications shaping the intellectual structure of the smart city research field by considering the first two decades of literature dealing with this subject; (2) map the clusters of thematically-related publications; and (3) reveal the emerging development paths of smart cities that each thematic cluster represents and the strategic principles they embody. The five development paths which the analysis uncovers and the strategic principles each stands on are then compared by reviewing the most recent literature on smart cities. Overall, this bibliometric study offers a systematic review of the research on smart cities produced since 1992 and helps bridge the division affecting this research area, demonstrating that it is caused by the dichotomous nature of the development paths of smart cities that each thematic cluster relates to and the strategic principles they in turn support.

Keywords: smart city, sustainable urban development, urban innovation, bibliometrics, co-citation analysis, content analysis, development paths

1. Introduction

This paper reports on a bibliometric study in which two hybrid techniques combining citation link-based clustering and text-based analysis (Braam et al. 1991a; 1991b; Glanzel and Czerwon 1996; Glanzel and Thijs 2011; Meyer et al. 2014) are deployed to help bridge the structural division affecting the research on smart cities, in which there is still little agreement about what a smart city is and what needs to be done in order to make a city smart. This division is captured by Albino et al. (2015), Alkandari et al. (2012), Chourabi et al. (2012), Deakin and Reid (2016), Hollands (2008), Paskaleva (2011), Nam and Pardo (2011a; 2011b) and Meijer and Bolivar (2016), and it seems to be caused by the lack of intellectual exchange among smart city researchers (Komninos and Mora 2018) and the tendency they currently have *“to be subjective and follow personal trajectories in isolation from one another”* (Mora et al. 2017: 20).

This paper suggests these subjective, personal and isolated interpretations fall short in providing both a clear understanding of smart cities and the scientific knowledge that policy makers and practitioners require to deal with their development¹. Also, it suggests this division

¹ How to design and implement strategies for smart city development represents an important line of investigation, in which researchers are investing significant efforts (Lazaroiu and Roscia 2012; Zygiaris 2013; Komninos 2014;

in smart city research is now so deeply entrenched within the scientific community that it has generated divergent development paths of smart cities, which prove challenging for policy makers to make sense of and practitioners to follow.

This bibliometric study aims at mapping and analyzing these development paths, making them visible and understandable within the big picture of smart city research. This will provide the community of smart city researchers with a comprehensive and systematic view of how a smart city is understood and the knowledge necessary to start building “*a possible agreement concerning the way of thinking about, conceptualizing and defining the smart city*” (Mora et al. 2017: 21). This aim is achieved by focusing attention on the first two decades of research on smart cities and the large body of literature produced during such a period (1992-2012), which is analyzed to: (1) build and visualize the network of publications shaping the intellectual structure of the smart city research field; (2) map the clusters of thematically-related publications belonging to this network; and (3) reveal the emerging development paths of smart cities that these thematic clusters support and the strategic principles able to inform practice that they embody.

The methodology applied to conduct the bibliometric analysis and the results of the data processing are illustrated in Section 3 of the paper, which is anticipated by a short description of the rationale behind the two hybrid techniques that are deployed and the need to combine co-citation clustering and text-based analysis in bibliometric studies (Section 2). The analysis provides evidence of the division affecting the smart city research area and uncovers five main development paths, which are presented in Section 4. The main strategic principles describing how to approach smart city development that each path proposes are then compared against one another in Section 5 by reviewing the literature on smart cities produced between 2013 and 2018. Four main dichotomies emerge from this comparison, along with a set of unanswered research questions. The paper concludes with a final section in which the findings of the study are summarized and considered to define some possible recommendations for guiding future research on smart cities.

2. Hybrid Techniques for Thematic Cluster Analysis

By using bibliometrics, researchers can outline complex knowledge maps representing the intellectual structure of research fields and investigate their properties by means of statistical and mathematical methods (Pritchard 1969; De Bellis 2009; Ding et al. 2001; Godin 2006). These maps are complex networks in which large groups of individual words, authors, documents, journals or subject categories become interconnected nodes (see Ding et al. 2001; Leydesdorff and Rafols 2009; Zhao et al. 2009; Heersmink et al. 2011; Leydesdorff et al. 2011; Liu et al. 2012; Jacobsen et al. 2013; Hashem et al. 2016; Randhawa et al. 2016; Reyes-Gonzalez et al. 2016; Song et al. 2016; Zhu and Hua 2017) and their analysis makes it possible to understand “*how specific [...] research fields are conceptually, intellectually and socially structured*” (Cobo et al. 2011: 1382). The degree of connection between each node depends upon their degree of similarity, which can be measured by using co-citation analysis or co-word analysis, two bibliometric techniques that involve counting the number of times certain elements co-occur in the group of publications composing the research field under investigation (He 1999; Glanzel and Thijs 2011). Each technique is based on different theoretical foundations and both of them have their own strengths and weaknesses, some of which are discussed in research by King (1987), MacRoberts and MacRoberts (1989), Leydesdorff (1997), Adam (2002) and Glanzel and Thijs (2011).

Co-citation analysis is based on the relevance of citations, which are a reliable indicator of scientific communication and can be used to measure the interaction and impact of authors, publications, institutions, subject areas and entire academic disciplines. By means of citations, researchers can incorporate intellectual work from other studies into their own research (Garfield 1970; 1979a; 1979b; Small 1973; 1978; Small and Griffith 1974; Jacobsen et al.

Deakin 2014; Hollands 2015; Bolici and Mora 2015; Mora and Bolici 2016; 2017). However, their research is still at an early stage of development and has not been able to fill the gap between theory and practice yet.

2013; Gmur 2003). When performing a co-citation analysis, different units of analysis can be considered: documents (Jacobsen et al. 2013; Zhao et al. 2009); authors (McCain 1986; 1990; White 1990); journals (Ding et al. 2000; Liu 2005; McCain 1991; Tsay et al. 2003); or subject categories (Leydesdorff and Rafols 2009).

In the case of document co-citation analyses, starting from a group of scientific publications, a co-citation exists when two references appear together in the same publication. The number of co-citations defines the similarity between two documents in terms of cognitive proximity and contents (Gmur 2003; Small 1973). This means that the more co-citations two documents have, the higher the degree of similarity between them. By considering the proximity between each couple of publications belonging to the initial sample, different sub-groups of scientific documents can be identified. These sub-groups are considered as *“thematic clusters”* (Kovács et al. 2015) and they can be used to map out the relationship between the main subject areas, lines of discussion and emerging topics characterizing a specific research field (De Bellis 2009).

The same outcome can be achieved by using co-word analysis, a content analysis technique in which the strength of interrelationship between scientific publications is measured by comparing the words included in their full-text instead of the references that they cite (Callon et al. 1983; 1986; 1991; He 1999). By measuring the co-occurrence of pairs of either single terms or phrases belonging to scientific publications representative of a research field, this technique makes it possible to define the proximity of these documents and divide them into clusters. As with co-citations, each cluster contributes to identifying the emerging research topics within a narrowly-defined field of study (Ding et al. 2001; Heersmink et al. 2011; Liu et al. 2012).

Unfortunately, compared to knowledge mapping techniques based on textual data, the co-citation analysis *“does not provide an immediate picture of the actual content of the research topics dealt with in the literature”* belonging to a thematic cluster (Ding et al. 2001: 818). In response to this limit, two hybrid techniques have been developed and tested, in which clusters obtained from a document co-citation analysis are labelled using textual components in order to describe research fields in both structural and semantic terms. The first technique is proposed by Braam et al. (1991a; 1991b) and based on the following assumption: *“if publications sharing citations to documents within the same co-citation cluster [...] represent the current work of a research specialty, then these (citing) publications are cognitively related and, as a consequence, are expected to contain [...] the same content-related words. Thus, topics involved in a particular research specialty can be indicated by aggregating and listing these words, together with their frequency of occurrence for the set of citing publications of each cluster. In this way a cluster word profile can be constructed that represents the research topics involved in the current work of a specialty indicated by the cluster”* (Braam et al. 1991a: 236). As noted by the authors, the words that make up the profiles can be extracted from titles, lists of keywords, abstracts and full texts. In addition, indexed terms and classification codes can also be used.

The second hybrid technique combining citation link-based clustering and text-based research for analyzing thematic clusters and their research topics is provided by Glanzel and Czerwon (1996), who re-introduce the concept of core documents (Glanzel and Thijs 2011). In a thematic cluster, core documents are those publications with the highest centrality, which is expressed by the number of connections they have with other publications belonging to the same cluster (Glanzel and Thijs 2011; Glanzel and Czerwon 1996; Meyer et al. 2014). *“Since core documents are, by definition, strongly linked with a large number of other documents”,* they can be considered as its most representative publications and *“are expected to form the very cognitive nodes”* (Meyer et al. 2014: 477). According to this technique, the content-analysis of thematic clusters can be undertaken by conducting a document co-citation clustering analysis and then labelling the resulted thematic clusters by directly using bibliographic data extracted from their core documents. This includes, for example, their titles, list of keywords, authors' names and abstracts (Glanzel and Czerwon 1996; Glanzel and Thijs 2011; Meyer et al. 2014; Chi and Young, 2013).

3. Research Methodology and Results of the Data Processing Phase

This bibliometric study combines the two hybrid techniques previously described to analyze the intellectual structure of the first two decades of smart city research and identify the main development paths of smart cities it promotes. This structure is outlined, graphically visualized and split into thematic clusters of publications by conducting a document co-citation analysis. The result is a co-citation network in which 2,273 publications are divided into 18 thematic clusters. After tracing the network of relationships between these publications, a description of the development paths supported by the most representative thematic clusters is provided based on both the identification of their core literature and the construction of word profiles.

The study begins with a keyword search based on a multi-database approach aiming at developing a representative dataset of literature on smart cities. The keyword search covers the first 21 years of research on smart cities, from the beginning of 1992 to the end of 2012, and is implemented by using the following scholarly databases: Google Scholar; Web of Science; IEEE Xplore; Scopus; SpringerLink; Engineering Village; ScienceDirect; and Taylor and Francis Online.² The search is set to identify all the English-language literature in which the term smart city is included in the title, abstract, keyword list or body of the text.³ All types of publications are considered in this study, including working papers, unpublished reports and any other grey literature, which represents a substantial part of the scientific production, especially in recent years⁴ (Schopfel and Farace 2010).

The publications caught during the keyword search are then organized in a single dataset and checked to identify and correct possible typographical errors in the titles, authors' full names and publication dates. Duplicate documents that have been found in more than one database are eliminated. Finally, the title, abstract, keyword list and body of the text of each remaining publication is manually checked 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, 1,067 publications remain in the dataset (see Figure 1) and they represent the output of the first 21 years of research in the field of smart cities. These documents are used to collect the raw data needed for carrying out the bibliometric study. For this reason, they are defined as source documents (Casillas and Acedo 2007; Ingwersen et al. 2014; Schneider et al. 2009; Shiau and Dwivedi 2013; Small and Crane 1979). The data for the co-citation analysis is collected by extracting the list of references cited by each source document. As citation data often contain errors which can lead to significant variations in the results of their analysis (Adam 2002), all the citations are extracted manually and tested for correctness. This guarantees the highest degree of data reliability. Altogether, 22,137 citations are collected and used to build a frequency table showing the cited publications and the number of citations each of them has received. The total number of cited references is 17,574.

² Using a multi-database approach makes it possible to conduct more comprehensive keyword searches and avoid the risk of building an incomplete representation of the research field under investigation, either due to the analysis of an excessively limited literature sample or the exclusion of highly representative publications (Jacobsen et al. 2013; Zhao et al. 2009).

³ The keyword search is performed by using the search query: "smart city" OR "smart cities". The baseline search is set on 1992, the year in which the book *"The technopolis phenomenon: smart cities, fast systems, global networks"* is published by Gibson et al. (1992). This book is considered as the first scientific publication introducing the smart city concept (Kominos 2011).

⁴ Grey literature can be considered as "all scholarly work that is published without a formal peer-review (or equivalent) process outside the traditional journal and book channels" (Schopfel 2010). Most of the grey literature collected during the search is extracted from Google Scholar, which is a database particularly recommended for identifying this type of publications (Hutton 2009). In the case of conference papers, considering the definition provided by Schopfel (2010), only those publications included in repositories controlled by commercial publishers are not considered as grey literature.

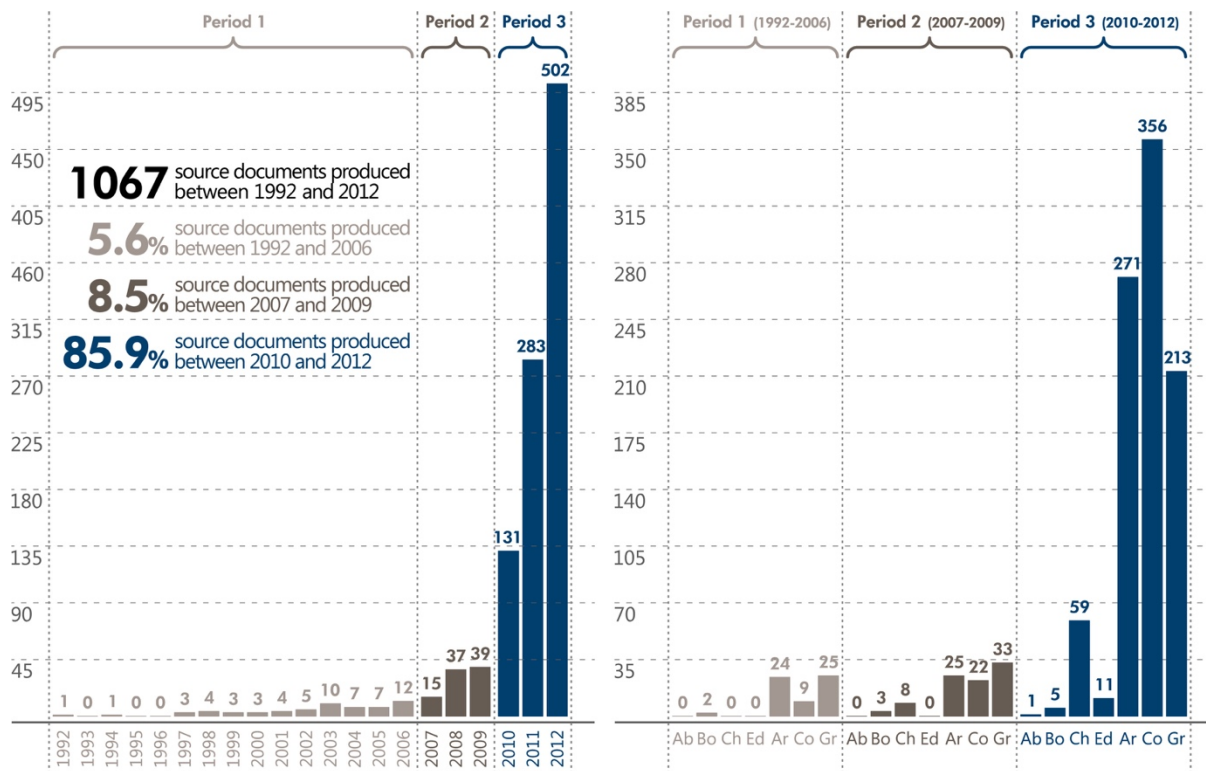


Figure 1. Cumulative growth in the number of source documents and number of source documents by type and period of publication. Ab: Abstracts; Bo: Books; Ch: Book chapters; Ed: Editorials; Ar: Journal articles; Co: Conference papers; Gr: Grey literature

A co-citation network is then built by considering only cited references with at least two citations. The network is composed of 45,534 edges connecting 2,273 nodes, of which only 124 are source documents. The edges' weight is measured using the CoCit-Score,⁵ which is calculated according to the following formula (Allmayer and Winkler 2013; Gmur 2003):

$$\text{CoCit}_{AB} = \frac{(\text{Co-citation}_{AB})^2}{\text{minimum}(\text{citation}_A; \text{citation}_B) \times \text{meanvalue}(\text{citation}_A; \text{citation}_B)}$$

Nodes and edges, with their weight, are entered into the open source software Gephi (version 0.8.2-beta) and the co-citation network is graphically visualized by using the OpenOrd layout algorithm (Bastian et al. 2009). The result is an undirected weighted network which is subsequently split into sub-networks by using the modularity class algorithm implemented by Blondel et al. (2008). The sub-networks represent the thematic clusters, i.e. groups of densely connected publications.

The results obtained through the data processing are summarized in Table 1 and displayed in Figure 2, which provides a graphical representation of the co-citation network. Within the network, each publication is shown as a node in which the size is proportional to the degree of centrality. This attribute is calculated by adding up the number of times the publication is co-cited. The greater the quantity of co-citations associated with a node, the greater its number of links within the network and, consequently, its centrality in the whole system. The degree of

⁵ Co-citation networks are composed of two elements: (1) the nodes corresponding to the cited references extracted from the source documents; and (2) the edges connecting the references that are co-cited in the same source document. The weight of an edge linking two nodes depends on their degree of textual similarity. More often two documents are co-cited, more similar they are in terms of content and the higher their level of proximity is. The weights can be calculated by adopting several approaches, however, research by Gmur (2003) shows that the CoCit-Score is the most suitable method for clustering references and analysing the intellectual structure of research fields.

centrality of the thematic clusters is defined by summing together the values related to their nodes.

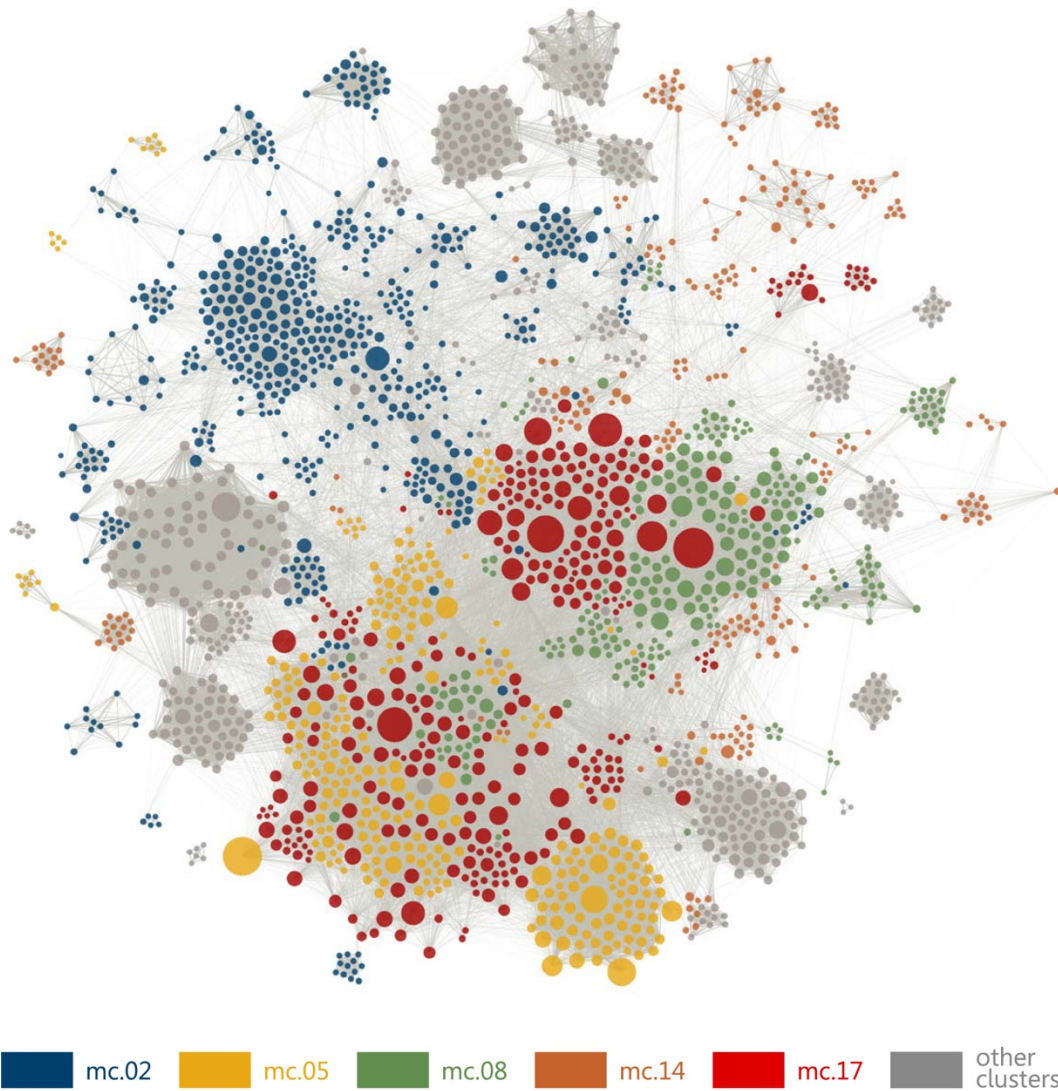


Figure 2. Co-citation network: the intellectual structure of the smart city research field considering the period between 1992 and 2012.

CLUSTER	SIZE			DEGREE OF CENTRALITY
	n° of publications	% on the total	n° of source doc.	
mc.01	57	2.5%	0	2,944
mc.02	578	25.4%	18	15,435
mc.03	25	1.1%	0	449
mc.04	26	1.1%	0	461
mc.05	306	13.5%	9	16,446
mc.06	78	3.4%	1	1,811
mc.07	109	4.8%	4	4,636
mc.08	283	12.4%	35	11,373
mc.09	56	2.5%	1	1,400
mc.10	6	0.3%	0	30
mc.11	21	0.9%	0	382
mc.12	3	0.1%	0	6
mc.13	6	0.3%	0	30
mc.14	261	11.5%	22	4,120

mc.15	13	0.6%	1	183
mc.16	58	2.6%	1	2,710
mc.17	324	14.2%	32	24,206
mc.18	63	2.8%	0	4,446

Table 1. Thematic clusters' size and degree of centrality. Main clusters are in bold

The network is composed of 18 thematic clusters, in which the distribution of source documents differs considerably. The clusters are labelled from mc.01 to mc.18 and their structure is described in Table 1. The sub-networks mc.02, mc.05, mc.08, mc.14 and mc.17 can be considered as the main thematic clusters: in addition to containing the largest number of publications, they also include most of the source documents. Given their dominant role in the co-citation network, these clusters are used to provide insight into the intellectual structure of the smart city research field. To achieve this aim, their content is analyzed by combining the use of core documents and word profiles.

Five core documents for each cluster are selected by considering the in-degree measurement of the publications belonging to them. This attribute represents the sum of internal relationships that a document has with other publications in the same cluster and can be used to measure their degree of centrality. Because of their high connectivity, these documents provide most of the information describing the content of the clusters (Gmur 2003). A list of the core documents is provided in Table 2.

CLUSTER	CORE DOCUMENT	Title	Year	Type	In- Degree
mc.02	Weiser (1991)	The computer for the 21st century	1991	Ar	185
mc.02	Atzori et al. (2010)	The Internet of Things: a survey	2010	Ar	100
mc.02	Polastre et al. (2004)	Versatile low power media access for wireless sensor networks	2004	Co	97
mc.02	ITU (2005)	ITU Internet Reports 2005: The Internet of Things	2005	Gr	90
mc.02	Sundmaeker et al. (2010)	Vision and challenges for realising the Internet of Things	2010	Bo	86
mc.05	Florida (2002)	The rise of the creative class: and how it's transforming work, leisure, community and everyday life	2002	Bo	157
mc.05	Landry (2000)	The creative city: a toolkit for urban innovation	2000	Bo	157
mc.05	Yigitcanlar et al. (2008b)	Creative urban regions: harnessing urban technologies to support knowledge city initiatives	2008	Bo	124
mc.05	Yigitcanlar et al. (2008c)	Knowledge-based urban development: planning and applications in the information era	2008	Bo	120
mc.05	Florida (2005)	Cities and the creative class	2005	Bo	106
mc.08	Dirks et al. (2010)	Smarter cities for smarter growth: how cities can optimize their systems for the talent-based economy	2010	Gr	100
mc.08	Moss Kanter and Litow (2009)	Informed and interconnected: a manifesto for smarter cities	2009	Gr	90
mc.08	Dirks and Keeling (2009)	A vision of smarter cities: how cities can lead the way into a prosperous and sustainable future	2009	Gr	84
mc.08	Harrison et al. (2010)	Foundations for smarter cities	2010	Ar	81
mc.08	Washburn et al. (2010)	Helping CIOs understand "Smart City" initiatives	2010	Gr	80
mc.14	European Commission (2006)	European SmartGrids Technology Platform: vision for Europe's electricity networks of the future	2006	Bo	47

mc.14	US Department of Commerce - NIST (2010)	NIST framework and roadmap for smart grid interoperability standards	2010	Gr	37
mc.14	Karnouskos and Nass de Holanda (2009)	Simulation of a smart grid city with software agents	2009	Co	34
mc.14	The Climate Group (2008)	SMART 2020: enabling the low carbon economy in the information age	2008	Gr	28
mc.14	European Commission (2009a)	Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Investing in the development of low carbon technologies (SET-Plan)	2009	Gr	26
mc.17	Komninos (2002)	Intelligent cities: innovation, knowledge, systems and digital spaces	2002	Bo	194
mc.17	Caragliu et al. (2009)	Smart cities in Europe	2009	Co	180
mc.17	Ishida and Isbister (2000)	Digital cities: technologies, experiences, and future perspectives	2000	Bo	170
mc.17	Komninos (2006)	The architecture of intelligent cities: integrating human, collective and artificial intelligence to enhance knowledge and innovation	2006	Co	162
mc.17	Graham (2004b)	The cybercities reader	2004	Bo	160

Table 2. Core documents. Source documents are in bold. Bo: Books; Ar: Journal articles; Co: Conference papers; Gr: Grey literature

In addition, a word profile with 10 keywords is built for each cluster by combining the full texts of its source documents. Five Rich Text Format files (.rtf) with the textual data of each clusters' source documents are created and analyzed by using WordStat (version 6.0), a software programme for content analysis and text mining⁶. This software makes it possible to extract all the words and phrases contained in the source documents and estimate both their frequency and co-occurrence. The keywords included in the word profiles of each thematic cluster are the phrases with the highest frequency that are found in at least 30% of the source documents belonging to the cluster (Table 3).

CLUSTER	WORD PROFILE
mc.02	INFORMATION TECHNOLOGY (fr. 1998 - oc. 100,0%); INTERNET OF THING (fr. 1433 - oc. 38,9%); UBIQUITOUS COMPUTING (fr. 517 - oc. 38,9%); INFORMATION AND COMMUNICATION TECHNOLOGY (fr. 494 - oc. 38,9%); SENSOR NETWORK (fr. 215 - oc. 61,1%); MOBILE DEVICE (fr. 175 - oc. 44,4%); MOBILE PHONE (fr. 171 - oc. 55,6%); RFID TAG (fr. 136 - oc. 33,3%); SMART CITY (fr. 128 - oc. 100,0%); WIRELESS SENSOR (fr. 116 - oc. 61,1%)
mc.05	INFORMATION TECHNOLOGY (fr. 293 - oc. 100,0%); INFORMATION AND COMMUNICATION TECHNOLOGY (fr. 157 - oc. 77,8%); KNOWLEDGE CITY (fr. 73 - oc. 55,6%); URBAN DEVELOPMENT (fr. 55 - oc. 66,7%); LOCAL GOVERNMENT (fr. 47 - oc. 66,7%); ECONOMIC DEVELOPMENT (fr. 46 - oc. 66,7%); SMART CITY (fr. 39 - oc. 100,0%); URBAN INFRASTRUCTURE (fr. 39 - oc. 44,4%); UBIQUITOUS COMPUTING (fr. 27 - oc. 33,3%); KNOWLEDGE ECONOMY (fr. 25 - oc. 55,6%)
mc.08	INFORMATION TECHNOLOGY (fr. 2265 - oc. 100,0%); SMART CITY (fr. 838 - oc. 100,0%); INFORMATION AND COMMUNICATION TECHNOLOGY (fr. 354 - oc. 62,9%); DIGITAL CITY (fr. 235 - oc. 34,3%); LOCAL GOVERNMENT (fr. 87 - oc. 45,7%); QUALITY OF LIFE (fr. 79 - oc. 48,6%); SMARTER CITY (fr. 68 - oc. 31,4%); CITY INFRASTRUCTURE (fr. 56 - oc. 31,4%); PUBLIC SERVICE (fr. 55 - oc. 48,6%); URBAN DEVELOPMENT (fr. 50 - oc. 37,1%)

⁶ During the production of the Rich Text Format files, each document is searched to detect acronyms and abbreviations, which are subsequently converted to their extended form. In addition, bibliographic references and data concerning authors and their affiliations are eliminated because they are considered as irrelevant to the content analysis and risk generating unexplained variations in the sample.

mc.14	INFORMATION TECHNOLOGY (fr. 642 - oc. 100,0%); INFORMATION AND COMMUNICATION TECHNOLOGY (fr. 471 - oc. 73,9%); SMART CITY (fr. 307 - oc. 100,0%); ENERGY EFFICIENCY (fr. 129 - oc. 56,5%); SMART GRID (fr. 105 - oc. 52,2%); CLIMATE CHANGE (fr. 84 - oc. 34,8%); ENERGY CONSUMPTION (fr. 70 - oc. 60,9%); URBAN DEVELOPMENT (fr. 63 - oc. 30,4%); SMART METER (fr. 55 - oc. 56,5%); RENEWABLE ENERGY (fr. 51 - oc. 34,8%)
mc.17	INFORMATION TECHNOLOGY (fr. 2056 - oc. 96,9%); SMART CITY (fr. 1148 - oc. 100,0%); INTELLIGENT CITY (fr. 586 - oc. 53,1%); INFORMATION AND COMMUNICATION TECHNOLOGY (fr. 426 - oc. 78,1%); LIVING LAB (fr. 296 - oc. 46,9%); DIGITAL CITY (fr. 280 - oc. 37,5%); INNOVATION SYSTEM (fr. 273 - oc. 34,4%); INTERNET OF THING (fr. 161 - oc. 31,3%); SOCIAL CAPITAL (fr. 129 - oc. 40,6%); URBAN DEVELOPMENT (fr. 98 - oc. 59,4%)

Table 3. Word profiles. Frequency (fr.): number of times the keyword appears in the cluster's source documents; Co-occurrence (oc.): percentage of cluster's source documents in which the keyword is included

4. Thematic Clusters and Smart City Development Paths

After completing the bibliometric analysis, word profiles and core documents are then used to describe the main thematic clusters and present the development paths of smart cities each of them supports. The thematic clusters and contents of their literature are discussed in the following sections.

Cluster mc.02 - Experimental Path: smart cities as testbeds for IoT solutions

Technology is one of the main drivers fueling the progressive growth of smart cities and this becomes immediately evident when analyzing the clusters' word profiles, in which Information Technology (IT) and Information and Communication Technology (ICT) are always two of the keywords with the highest frequency and co-occurrence. Additional evidence is also provided by the content analysis of the sub-network mc.02. With a structure composed of 578 publications, which corresponds to 25.4% of the total 2,273 publications, this is the largest thematic cluster of the co-citation network and its literature focuses attention on ICT devices and infrastructures that have enabled both ubiquitous computing and the Internet of Things (IoT). In addition, it stresses the potential contribution that these two concepts can offer in supporting urban sustainable development. Some of the devices and infrastructures discussed in the core documents are indeed part of the cluster's word profile: sensor networks; RFID tags; mobile devices; mobile phones; and wireless sensors.

Ubiquitous computing is one of the key technical visions underlying the IoT (ITU 2005) and originates from the studies carried out by a group of researchers at Xerox PARC in Palo Alto, California. This group was led by Weiser (1991,1993), who is the first to discuss this concept in a scholarly publication. As explained by Weiser et al. (1999: 693), ubiquitous computing is based on *"the idea of spreading computers ubiquitously, but invisibly, throughout the [physical] environment"*, moving away from the *"one person-one computer desktop paradigm"*. According to his vision, which is formulated in the early 1990s, computers would have been diffused in the real world and interconnected by ubiquitous networks. In addition, they would have been able to control a countless range of functions in the physical space and work as invisible and autonomous agents, without any human intervention. This vision becomes a reality with the advent of wireless technologies, that allow a large number of networks composed of physical objects containing embedded technology to populate the Internet and interact with both their internal states and the external environment in a completely autonomous way (Mitchell 2003).

This emerging wave of Internet-connected devices enables the IoT, a new concept which is rapidly growing within the scenario of the potential positive impacts that ICTs can generate in urban environments. *"The basic idea of this concept is the pervasive presence around us of a variety of [smart] objects, such as Radio-Frequency IDentification (RFID) tags, sensors, actuators, mobile phones, etc., which [...] are able to interact with each other and cooperate with their neighbours to reach common goals"* (Atzori et al. 2010: 2787). According to Sundmaeker et al. (2010: 15), smart objects represents *"small computers with a sensor or*

actuator and a communication device” and their use “*enable a wide range of applications*”.

The IoT can be considered as an extension of the existing Internet, which generates new digital services and applications (Atzori et al. 2010; ITU 2005; Tselentis et al. 2009). The fields of application are many and include, for example, agriculture, building automation, factory monitoring, health management systems, education, smart grids, transportation and, in a broader vision, smart cities (Holler et al. 2014; Sundmaeker et al. 2010). As reported by Miorandi et al. (2012: 1510), “*IoT technologies can find a number of diverse application in smart cities scenarios*”. Based on this assumption, the thematic cluster mc.02 supports a vision of smart cities as urban areas characterized by a large deployment of IoT solutions. This is an interpretation in which cities and urban territories become testbeds for experimenting IoT technologies and analyzing their functionality, relevance and potential impact in real-life environments,

Santander is an example of smart city resulting from the application of this development path. Located in the north coast of Spain, this small city has become an urban laboratory for the European research project SmartSantander, which is described in a number of publications belonging to this cluster. During the project, Santander and its surroundings have been equipped with more than 12,000 IoT devices (Sanchez et al. 2011) and transformed in “*a European experimental test facility for [...] research and experimentation of architectures, key enabling technologies, services and applications for the IoT in the context of a smart city*” (Sanchez et al. 2013: 1). According to the consortium leading the project, this facility should be “*instrumental in fostering key enabling technologies for IoT and providing the research community with a [...] platform for large scale IoT experimentation and evaluation under realistic operational conditions*” (Sanchez et al. 2013: 1).

Cluster mc.05 - Ubiquitous path: the Korean experience of ubiquitous cities

Within the thematic cluster mc.05, smart city and ubiquitous city are considered as two equivalent terms and are described as a technical evolution of the knowledge city (Lee et al. 2008), which is a concept discussed in both a number of source documents belonging to this sub-network (Dvir and Pasher 2004; Yigitcanlar et al. 2008a; 2008d) and the core documents published by Yigitcanlar et al. (2008b; 2008c). Knowledge city is a concept resulting from research on the knowledge economy and is used to identify “*cities that choose knowledge production as a key goal in their development strategy*” (Yigitcanlar et al. 2008d: 8). Research by Yigitcanlar et al. (2008b) suggests the role of knowledge in wealth creation has become a critical issue in cities, and local governments need to discover new approaches to harness the considerable opportunities that knowledge production offers to support sustainable growth and innovation in urban areas. This idea starts emerging in the early 2000s, from research by Landry (2000) and Florida (2002; 2005), who both highlight the growing importance of knowledge and information in urban development processes, especially in terms of economic development and competitiveness.

Knowledge cities “*firmly encourage and nurture locally focused innovation, science and creativity within the context of an expanding knowledge economy and society*” (Yigitcanlar et al. 2008a: 63). This implies the progressive implementation of a growth-oriented path based on more sustainable models of urban development. According to Yigitcanlar et al. (2008a) and Lee et al. (2008), the possibility to achieve this aim by leveraging ICTs has marked the shift from the knowledge city to the ubiquitous city. This term comes from the concept of ubiquitous computing proposed by Weiser (1991) and is used to identify urban areas equipped with ubiquitous technologies that provide its users with access to digital services anywhere and anytime. Using these services, anyone can get data and information that are mainly collected in real time and describe the functionality of the city (Shin 2007; 2010; Shin and Kim 2010; Lee et al. 2008). Ubiquitous cities are therefore places where “*all information systems are linked and [...] everyone is connected to*” them, and they result from the combination of a large variety of technological devices and infrastructures (Shin and Kim 2010: 148). For example, as described by Shin and Kim (2010: 148), these include “*broadband convergence networks, RFIDs, ubiquitous sensor networks, home networking, wireless broadband, digital multimedia broadcasting, telematics, geographic information systems, location-based systems and smart-*

card systems".

Most of the attention that this concept has received comes from the Republic of Korea, in which a national programme on ubiquitous cities was launched in 2007 by the central government. The aim of this programme was to build the world's first u-society based on state-of-the-art u-infrastructure (Republic of Korea 2007a; 2007b). Only a few urban areas working on the ubiquitous city concept can be found outside the South Korean territory. Anthopoulos and Fitsilis (2010a; 2010b), for example, describe the activity developed by the Greek city of Trikala, while research by Gil-Castineira et al. (2011) and Shin and Lee (2011) report on a number of projects which are implemented in Oulu, San Francisco, Philadelphia, Tokyo, Singapore, Hong Kong, Taiwan and Malaysia.

The initiative of the South Korean government has encouraged many municipal administrations to integrate ubiquitous technologies into urban environments. At the end of 2007, after one year into the programme, "22 cities [were already] pursuing the construction of u-cities throughout the country" (Republic of Korea 2007a: 15) and, only three years later, this figure became 36, with a total of 53 ubiquitous city initiatives in progress. This trend is captured in the research report produced by Tekes (2011), the Finnish Funding Agency for Technology and Innovation. Among the many projects developed under the ubiquitous city brand, Busan Green u-City and Songdo IBD (International Business District) seem to be the most discussed in the cluster's literature, in which both are discussed by overlapping the terms smart city and ubiquitous city (GSMA 2012; Strickland 2011; Juan et al. 2011).

The Korean experience of ubiquitous cities has been analyzed and criticized by Shin (2007; 2009; 2010). The results of his research have shed light on the limits and weaknesses of this national programme, which is based on a top-down approach and "is largely biased toward industrial and economic development, reflecting business providers' interests [rather than] users' interests and benefits" (Shin 2007: 636). According to Shin (2009; 2010), the many actors involved in the development of u-cities only appear to be interested in technical and market perspectives, competitiveness, financial interests and economic impacts, rather than city users and their needs.

Cluster mc.08 - Corporate Path: IBM and the corporate smart city model

The technology-led vision of smart cities proposed in the cluster mc.05 is the engine that fuels ICT multinational companies and their involvement in the smart city market. Driven by the will to acquire a strong position in this new and promising market, companies such as Cisco Systems (Amato et al. 2012a; 2012b; 2012c), Hitachi (Kohno et al. 2011; Kurebayashi et al. 2011; Yoshikawa et al. 2011) and IBM (Brech et al. 2011; Cosgrove et al. 2011; Kehoe 2011; Katz and Ruano 2011; Paul et al. 2011; Ruano et al. 2011; Schaefer et al. 2011; Chen-Ritzo et al. 2009; Harrison et al. 2010; 2011) have started operating within the domain of urban technology and have begun to actively participate in the smart city debate.

The literature produced by such companies has led to the growth of the corporate smart city model, that conceives smart cities as urban systems which are equipped with a platform of digital solutions provided by ICT companies. IBM is one of the main supporter of this model and its relevant role and influence in the smart city debate is demonstrated by the content analysis of the thematic cluster mc.08, which correlates significantly to the vision proposed by the American multinational company. The cluster's most cited source documents are produced by its researchers and their degree of centrality is significantly high (Moss Kanter and Litow 2009; Dirks et al. 2009; 2010; Dirks and Keeling 2009; Harrison et al. 2010). Four of the five core documents are indeed publications from IBM. What is more, the cluster's word profile contains the term smarter city. This term is a trademark officially registered by IBM and used for its smart city campaign, which is driven by the motto "*building a Smarter Planet*" (Palmisano 2008).

The IBM's Smarter Planet initiative is a commercial venture launched at the end of 2008, which has positioned the American multinational company at the forefront of smart city development (Palmisano 2008). This initiative suggests smart city development follow a standardized three-phase process (Harrison et al. 2010): (1) Instrumentation; (2) Interconnection; and (3) Intelligence. The process is described by Dirks et al. (2009: 1): "*Instrumentation enables cities*

to gather more high-quality data in a timely fashion than ever before. For example, utility meters and sensors that monitor the capacity of the power generation network can be used to continually gather data on supply and demand of electricity [...]. Interconnection creates links among data, systems and people [...], opening up new ways to gather and share information. Intelligence - in the form of new kinds of computing models and new algorithms - enables cities to generate predictive insights for informed decision making and action. Combined with advanced analytics and ever-increasing storage and computing power, these new models can turn the mountains of data generated into intelligence to create insight as a basis for action". According to IBM, this ICT-based transformation can automatically make any city smart and, consequently, more efficient, democratic, livable, attractive, environment-friendly and economically prosperous (Dirks and Keeling 2009).

Cluster mc.14 - European Path: smart city for a low-carbon economy

According to the data provided by both the American Association for the Advancement of Science (2001) and the United Nations Human Settlements Programme (2011), urban areas account for approximately 70% of the global energy consumption and release more than 70% of the carbon dioxide which is damaging the Earth's atmosphere. These numbers provide a clear picture of the role played by the urbanized world in intensifying the environmental crisis and accelerating climate change. Fighting against climate change has become a high priority for local and national governments, which have started implementing sustainable energy policies and initiatives.

ICTs have proven to be a decisive means of helping governments to face this critical situation and enable the progressive growth of a low-carbon future. The core literature of the thematic cluster mc.14 explores this possibility, in particular the report "SMART 2020" published by The Climate Group (2008), an international non-profit organization that supports leaders in government, business and society to address climate risks and accelerate the transition to a low-carbon economy. This report demonstrates the ICT industry is a key player in creating a low-carbon society and the technological solutions this sector offers can drastically unlock emissions reductions and energy saving. More specifically, according to the authors, "*the biggest role ICTs could play is in helping to improve energy efficiency in power transmission and distribution (T&D), in buildings and factories that demand power and in the use of transportation to deliver goods*" (The Climate Group 2008: 9).

This report and the other core documents make it clear that unlocking the potential of ICTs is critical to win the challenge posed by climate change and they all identify smart grids as one of the most promising application domain (European Commission 2006; 2009a; The Climate Group 2008; Karnouskos and Nass de Holanda 2009; US Department of Commerce - NIST 2010). Smart grids are the electricity networks of the future because they improve the efficiency of current power transmission and distribution networks while responding to the new challenges and opportunities arising from the energy market. With these networks, it is possible to: manage flexible demand for energy, flexible storage and highly variable prices; increase power transfers and the degree of automation; reduce energy losses; face the issues imposed by traditional energy sources; apply efficient investments to replace ageing infrastructure; develop strategies for local demand modulation and load control; increase social responsibility and sustainability by using smart meters and establishing a two-way flow of information between supplier and user; improve the long-distance transport and integration of renewable energy sources (microgeneration opportunities); and manage the integration of new products and services, such as electric vehicles (European Commission 2006; The Climate Group 2008; Karnouskos and Nass de Holanda 2009).

The importance and urgency of modernizing current electric power infrastructures by transforming them into smart grids is widely recognized. For example, the Indian government has been developing policies to overcome barriers that limit the implementation of smart grid initiatives since 2001 (The Climate Group 2008), while in 2005, the European Commission sets up the SmartGrids Technology Platform, in which a large number of stakeholders working in the European energy sector are included. Together, they have designed a joint vision for the European energy network of 2020 and beyond which is based on activating smart grid

solutions across Europe (European Commission 2006). The same aim is pursued by the government of the United States of America, where interoperability standards and protocols for smart grid devices and systems are established to accelerate their diffusion in the US territory (US Department of Commerce - NIST 2010).

Mobilizing ICTs to facilitate the transition to an energy-efficient and low-carbon economy has become a key ambition of the European Union's Member States, which have developed "a set of [...] measures that focus on what can be achieved in the short term both by the ICT sector and by fully exploiting the enabling capacity of ICTs in all sectors of society and the economy" (European Commission 2009b: 2). This set of measures is published in 2009, along with the Strategic Energy Technology Plan (SET-Plan), a policy instrument that describes the strategy pursued by the European Union to accelerate innovation in cutting edge low-carbon technologies and their diffusion across Europe (European Commission 2009a).

This is the context in which the European interpretation of smart cities has grown, which is supported by the cluster mc.14. As reported in the SET-plan, according to the European Commission, smart cities are those cities that "create the conditions to trigger the mass market take-up of energy efficiency technologies [by transforming] their buildings, energy networks and transport systems into those of the future, demonstrating transition concepts and strategies to a low-carbon economy" (European Commission 2009a: 7). These cities are expected to be "the nuclei from which smart networks, a new generation of buildings and low-carbon transport solutions will develop into European wide realities that will transform [the] energy system" (European Commission 2009a: 7). Such interpretation is in line with the cluster's word profile in which the smart city concept is strongly connected to key terms such as energy efficiency, smart grid, climate change, energy consumption, smart meter and renewable energy.

Cluster mc.17 - Holistic Path: digital, intelligent, smart

The thematic cluster mc.17 is the second largest sub-network of the system but has the highest degree of centrality. Here the debate on smart cities is linked to the scientific foundations of "urban ICT studies" (Graham 2004a: 3), a sub-discipline of urban studies in which research aims at developing a better understanding of the relationship between ICTs and urban innovation processes. This knowledge area starts growing between the late 1990s and the early 2000s, and some of the publications that have provided a significant contribution in laying down its intellectual structure form part of this cluster (Castells 1996; Graham and Marvin 1996; 2001; Mitchell 1995; 1999; 2003), including the book "The Cybercities Reader" (Graham 2004b), which is one of the core documents.

The literature produced started filling "the gap left by the long neglect of telecommunications in urban studies and policy-making [exploring] the complex and poorly understood set of relationships between telecommunications and the development, planning and management of contemporary cities" (Graham and Marvin 1996: XII). In the meantime, cities all over the world began experimenting with the use of digital technologies for supporting urban innovation and sustainability by implementing projects and initiatives which have been labeled using different terms: digital city; intelligent city; and smart city. Such terms clearly emerge in both the cluster's word profile and the core documents by Ishida and Isbister (2000), Komninos (2002; 2006) and Caragliu et al. (2009).

The term digital city dates back to the end of the twenty century and is used as a label for a number of projects launched by cities located in Europe, North America and Asia. These projects resulted in the construction of Internet websites which were used by each city to provide access to their digital services. The aim was supporting social and economic development in urban environments (Aurigi and Graham 2000; Ishida and Isbister 2000). Research by Aurigi (2000) shows that these websites were developed mainly to: stimulate local economic development; improve the visibility of the city and its image; widen access to the Internet and support community networking; support the growth of online communities and democratic debates related to subjects of public interest; and improve the management of cities' physical infrastructures.

The digital city movement has been particularly active in Europe, where many cities have

prioritized the development of their digital counterparts (Aurigi 2000; 2003; Mino 2000). Examples of successful experiences have been identified in Amsterdam (van den Besselaar 2001), Helsinki (de Bruine 2000), Antwerp, Newcastle upon Tyne (Peeters 2000; Firmino 2004), Bologna and Bristol (Aurigi 2003; 2005).

At the beginning of the twenty-first century, while the world was experiencing the construction of digital cities, the term intelligent city emerges in research by Komninos (2002; 2006; 2008). Its interpretation is provided in a conference paper which is published in 2006: *"intelligent cities [...] are 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"* (Komninos 2006: 13). According to this definition, the distinguishing feature of intelligent cities is their capacity to exploit ICTs for increasing the problem-solving capability of urban communities and therefore their ability to support innovation within urban environments (Komninos 2002). Consequently, intelligent cities and digital cities share the same interest for ICT-driven urban development. However, while the former focuses the attention on facilitating some aspects of the social and economic life of urban areas, in the latter, ICT infrastructures and applications aim at strengthening their capability to produce new knowledge and innovation.

The transition from intelligent to smart seems to be the result of two different forces. On the one hand, there is the technological innovation in the ICT sector that has produced the huge wave of smart objects which are discussed in the cluster mc.02, opening up new possibilities in addressing cities' issues and development priorities using digital solutions (Komninos 2011; Schaffers et al. 2011). On the other hand, there is a request for a more progressive view of ICT-driven strategies for sustainable urban development, which clearly emerges from the literature of this cluster (Caragliu et al 2009; Hollands 2008; Schaffers et al. 2011; Paskaleva 2009; Ratti and Townsend 2011; Townsend et al. 2011; Deakin and Al Wear 2011) and had been already highlighted in research previously undertaken by Aurigi (2005; 2006), Mino (2000), Graham and Marvin (1999) and Castells (1996).

Moving away from the technological determinism and top-down entrepreneurial-based business logic of both the corporate smart city model (cluster mc.08) and the ubiquitous city experience (cluster mc.05), there is a call for a holistic interpretation of smart cities in which human, social, cultural, environmental, economic and technological aspects stand alongside one another (Deakin and Al Wear 2011; Leydesdorff and Deakin, 2011). In this cluster, smart cities are urban areas where ICT is adopted to meet local development needs, be they of social, economic or environmental nature. In addition, the approach this cluster proposes for transforming urban areas is grounded in the collective intelligence of a bottom-up approach and based upon participatory governance, open and user-driven innovation and community-led urban development.

5. The Divergent Nature of Smart City Research

This bibliometric analysis reveals five main thematic clusters which offer different interpretations of smart cities and their development paths:

- Experimental Path (mc. 02): smart cities are described as urban testbeds for experimenting IoT infrastructures and service applications and analyzing their functioning, relevance and potential impact in real life environments;
- Ubiquitous Path (mc. 05): smart cities and ubiquitous cities are considered as two equivalent categories of cities whereby digital services are provided everywhere and anytime and their development is driven by corporate suppliers' financial interests, market perspectives and economic impacts rather than public good;
- Corporate Path (mc. 08): urban areas become smart when they are equipped with a platform of digital solutions provided by ICT consultancies;
- European Path (mc. 14): smart cities are highly efficient urban systems in which digital technologies are used to develop a new generation of buildings, energy networks and

transport systems, which are instrumental in tackling environmental degradation and fighting climate change;

- Holistic Path (mc. 17): smart cities are urban environments in which digital technologies are assembled to meet local development needs and their development process is grounded in collective intelligence, bottom-up approach, participatory governance, open and user-driven innovation and community-led urban development.

These paths emerge from the literature on smart cities which is produced between 1992 and 2012, but the division that their presence generates still resonates in the publications which have surfaced since then. Comparing the strategic principles each path stands on, four main dichotomies can be identified and the knowledge gap they open up remains evident by reviewing the literature produced during the period 2013-2018, resulting in uncertainty on how to approach the development of smart cities in real-life environments.

Dichotomy 1: Techno-led or holistic?

All the development paths share the same notion of smart cities as being urban areas in which ICTs become a mean for supporting urban innovation and sustainable development. However, the approach they suggest for transforming urban areas in smart environments represents one of the main point of divergence emerging from their comparison. Two competing visions can be identified, which are explored in research by Niaros (2016) and Mora et al. (2017).

The Experimental Path, Ubiquitous Path and Corporate Path suggest a technology-led and market-oriented approach to smart cities, which is based on the following rationale: information technologies and market perspectives represent the primary driving forces shaping smart cities, which are the result of a massive input of technological solutions in the urban environment. According to Townsend (2013), Cugurullo (2013), Soderstrom et al. (2014), Hollands (2015, 2016), Carvalho (2015), Niaros, (2016), Selada (2017), Kitchin (2014), Viitanen and Kingston (2014) and McNeill (2016), this approach paves the way to “*a new kind of technology-led urban utopia*” (Hollands, 2015: 61) which is empowered by global technology providers and their ambition for profit maximisation, rather than an interest in improving the quality of life in urban areas. In addition, their research points out additional negative consequences and tensions that this approach can produce, which are related to privacy, democracy, security and the importance of considering both “*local diversity and the socio-political dimensions of cities*” (Ersoy 2017: 28). Despite these critiques, however, the literature supporting this approach is increasing, thanks to those ICT companies such as ABB (2013), Fujitsu (Tamai, 2014) and Siemens (2014), which have decided to follow IBM and expand the smart city market with their ICT products and services.

In response to the technology-led and market-oriented vision, the Holistic Path proposes a human-centric and people-driven approach to smart cities, in which technological development is aligned with human, social, cultural, economic and environmental factors. In this case, the smart city is not conceived as a technological object but as a socio-technical system in which ICTs serve public interests. This approach is described as the most suitable for smart city development and finds support in many recent studies (see for example Zygiaris 2013, Hemment and Townsend 2013; Townsend 2013; Komninos 2014; Deakin 2014; Bolici and Mora 2015; Hollands 2015; 2016; Mora and Bolici 2016; 2017; Christopoulou et al. 2014; Concilio and Rizzo 2016; Sujata et al. 2016; March 2016; Mora et al. 2017; Colding and Barthel 2017; Wiig 2018). However, research investigating the human-centric and people-driven approach “*remains at a preliminary stage*” (Lee et al. 2014: 80) and has not yet been able to provide the knowledge necessary to move from theory to practice.

Dichotomy 2: Top-down or bottom-up?

Which is the most suitable approach for building smart cities? Top-down and centralized, as suggested by the Corporate Path and Ubiquitous Path, or bottom-up, decentralized and diffused as in the Holistic Path’s vision (Kitchin 2014). The distance between these two different approaches generates a second dichotomy, which is discussed by Dameri (2013), Lee et al. (2014), Townsend (2013), Komninos (2014), Kitchin (2014), Breuer et al. (2014),

Neirotti et al. (2014), Walravens (2015), Exner (2015), Gooch et al. (2015) and Ludlow et al. (2016).

Top-down smart cities originate from the political and administrative leadership of the city government, which defines a specific strategy to be followed. In this case, city governments assume *“a leading role in defining and driving a comprehensive vision about the smart [...] city”* (Cocchia 2014: 40). This approach is often characterised by limited opportunity for citizen to become engaged in the development process (Dameri 2013). Bottom-up smart city development, on the contrary, stands on self-organization and grass-roots efforts, which become more important than the presence of a comprehensive strategic framework (Ratti and Townsend 2011).

The literature discussing these two ideologically-opposed approaches have generated diverging opinions concerning their effectiveness. Lee and Hancock (2012) and their model for measuring the maturity level of smart cities, for example, suggest that a formalised and centralised top-down smart city development strategy aligned with the city's strategic priorities is an important driver for supporting the transition to smart city and is preferable to a strategy based on a bottom-up approach. However, top-down smart cities are first criticised by Shin (2007; 2009; 2010) and then by Townsend (2013) and Gooch et al. (2015) for their incapability to effectively serve people and their needs rather than *“the demands of major corporate suppliers and industry”* (Shin 2009: 516).

Townsend (2013) describes smart cities as the result of bottom-up movements and suggests their development requires a radical shift from top-down innovation processes to open and bottom-up innovation (Schoorman et al. 2012; 2016). He also suggests *“top-down visions ignore the enormous [and] innovative potential of grass-roots efforts”* and highlights the importance of maximising the involvement of citizens and civic groups in the development of ICT-driven urban solutions (Ratti and Townsend 2011: 45). This line of thinking is aligned with previous research by Deakin and Al Wear (2011), Alawadhi et al. (2012) and Schaffers et al. (2012), who share the importance of empowering citizens and providing them with the opportunity to become active actors of change in the making of successful smart cities.

However, according to the alternative reading which is put forward by Breuer et al. (2014) and Exner (2015), both top-down and bottom-up approaches are affected by restrictions that can be overcome only by combining them together: *“a purely top-down view on the smart city carries a danger of authoritarianism with it, while a bottom-up-only approach leans towards chaos and lack of long-term vision”* (Breuer et al. 2014: 162). This idea is also supported by Mora and Bolici (2016; 2017) and by Lee et al. (2014: 95): *“smart city planning driven by a dedicated organization or cross-departmental task force team, may be helpful to set up smart city governance especially at an early stage, while a more decentralized governing system may be more effective at the growth stage”*.

Dichotomy 3: Double or triple/quadruple-helix?

The divergence between the Holistic Path and Corporate Path becomes even more evident by analysing the collaborative model they suggest considering when transforming ordinary urban areas into smart cities. On the one hand, the Corporate Path's technology-driven, market-led and top-down smart city vision has resulted in a new urbanism whereby IT solution providers try to persuade local governments in supporting urban innovation by adopting their smart technologies. The collaborative model characterising this development path is based on a double-helix structure (Soderstrom et al. 2014; McNeill 2016; Paroutis et al. 2014).

On the other hand, cities like Amsterdam, Barcelona, Genova, Ghent, Helsinki and Vienna have implemented smart city development strategies characterized by more open and collaborative ecosystems that keep together governments, universities, research centres, businesses and, in some cases, even civil society (Dameri 2014; Mora and Bolici 2016; 2017; Baccarne et al. 2014a; 2014b; Mora et al. 2018a; 2018b). Their approach is based on the triple/quadruple-helix collaborative model for smart city implementation that the Holistic Path stands for, which finds support in recent studies by Selada (2017), van Waart et al. (2016), Deakin and Leydesdorff (2014), Kourtit et al. (2014) and Dameri (2017). According to these researchers, a double-helix model is insufficient when building smart cities and need to be

extended. A city interested in becoming smart needs to consider “*all its stakeholders [...] because [the transformation process requires] knowledge sharing and collaboration across all levels of society*” (Selada 2017: 217).

Dichotomy 4: Mono-dimensional or integrated?

The fourth dichotomy is related to the intervention logic. The European Commission's path focuses attention only on the energy sector, promoting a mono-dimensional vision of smart cities, which are described as low-carbon and resource efficient urban environments fully committed to invest in smart transport solutions, smart buildings and smart grids. The European Commission has been promoting and spreading this energy-driven vision of smart cities since 2009, by: (1) launching the Smart Cities and Communities Initiative (European Commission 2009a); (2) activating the European Innovation Partnership on Smart Cities and Communities (2013), which involves a community of more than 3,000 partners represented by public authorities, academic and research institutions, businesses, non-governmental organisations and private individuals⁷ (European Commission 2012b); and (3) continuing to launch calls for project proposals related to the Smart Cities and Communities topic, which have provided public and private actors with the financial support necessary to deliver new smart city solutions for supporting cities' transition towards a low carbon and resource efficient economy (European Commission 2011; 2012a; 2016).⁸

However, the Holistic Path, Experimental Path, Ubiquitous Path and Corporate Path propose an integrated and multi-dimensional approach to smart city development. The IBM's Smarter Planet initiative, for example, describes urban areas as a collection of high-volume systems operating in close proximity to one another, and their transformation into smart cities requires the widespread adoption of digital technologies. These include systems such as transportation, energy and utilities, education, healthcare and public safety (IBM Corporation 2017). As in the case of IBM, research by Manville et al. (2014) suggests smart city development requires an integrated and multi-dimensional approach. More specifically, the authors identify six different smart city domains, which are aligned with Giffinger et al. (2007)'s dimensions (living, economy, people, environment, mobility, governance) and use them to measure the success of European smart cities. This is done by considering the following rationale: a successful smart city has a range of initiatives that cover all of the policy domains.

6. Conclusion

In this bibliometric study, two hybrid techniques are combined to: build and visualize the network of publications shaping the intellectual structure of the smart city research field by considering the first two decades of literature dealing with this subject; map the clusters of thematically-related publications; and reveal the emerging development paths of smart cities that each thematic cluster represents and the strategic principles they stand on.

The analysis reveals that five main development paths have emerged over the past 20 years: (1) Experimental Path; (2) Ubiquitous path; (3) Corporate Path; (4) European Path; and (5) Holistic Path. It also serves to expose the presence of a deeply rooted division in the cognitive-epistemological structure of smart city research, which surfaces as a set of dichotomies questioning as to whether smart city development should be:

- technology-led or holistic?
- based on a top-down or a bottom-up approach?
- founded on a double or triple/quadruple-helix model of collaboration?
- mono-dimensional or integrated?

⁷ This data is reported in the info graphic that can be downloaded from the European Innovation Partnership on Smart Cities and Communities' website (<http://ec.europa.eu/eip/smartcities>)

⁸ More information about the European Commission's smart city vision can be found on the following online portals: (1) <http://ec.europa.eu/eip/smartcities>; (2) <https://ec.europa.eu/inea/en/horizon-2020/smart-cities-communities>; (3) <https://eu-smartcities.eu>; (4) <http://cordis.europa.eu>.

The knowledge gap that such dichotomies generates in the scientific community, along with the strategic challenges they pose, have now become a matter of particular significance. This is because they show research on smart cities is currently leaving some fundamental questions about how to proceed unanswered. In that sense, whether the urban transformation, which smart cities develop as pathways to the future, can be mono-dimensional, vis-à-vis technical, or if they need to integrate a multitude of other human-centric and people-driven factors.

In failing to answer these questions, smart city research appears unable to bring about the critical synthesis of the literature produced to date and generate the knowledge which is needed to begin closing the gap that currently exists between: (1) what ongoing experiments into the ubiquity of the corporate model claim about smart cities; and (2) the call from others for a holistic development path that is not only human-centric and people-driven, but which is also bottom-up in nature. In order to start closing this gap, future smart city research needs to be conducted into the divergent strategic principles that each development path stands on. This would provide the community of smart city researchers, policy makers and practitioners with the knowledge they need to break with the dichotomous nature of the development paths and start underpinning strategies able to support smart city development paths founded on a clear understanding of the effects that the strategic choices they solicit generate as urban transformations.

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