Smart City Development Paths: Insights from the First Two Decades of Research

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Abstract

More than 20 years have now passed since the concept of smart city first appeared in a scholarly publication, marking the beginning of a new era in urban innovation. Since then, the literature discussing this new concept and the ICT-oriented urban-innovation approach it stands for has been growing steadily, along with the number of initiatives that cities all over the world have launched to pursue their ambition of becoming smart. However, current research still falls short of providing a clear understanding of smart cities and the scientific knowledge policy makers and practitioners both need to deal with their progressive development. In response to this shortfall, this paper offers a bibliometric study of the first two decades of smart-city research, whereby citation link-based clustering and text-based analysis are combined to: (1) build and visualize the network of scholarly publications shaping the intellectual structure of the smart city research field; (2) identify the clusters of thematically related publications; and (3) reveal the emerging development paths of smart cities that these clusters support and the strategic principles they embody. This study uncovers five main development paths: the Experimental Path; the Ubiquitous Path; the Corporate Path; the European Path; and the Holistic Path. Overall, this analysis offers a comprehensive and systematic view of how a smart city can be understood theoretically and as a scientific object of knowledge able to inform policy-making processes.

Keywords: smart cities; urban innovation; bibliometric analysis; co-citation analysis; content analysis; development paths

**1. Introduction: Smart city, One Term, Different Interpretations**

As Meijer and Bolivar (2016) note, there is still little agreement over what makes a city smart. Evidence of this trend is provided by Hollands (2008), Paskaleva (2011), Nam and Pardo (2011a; 2011b), Alkandari et al. (2012), Chourabi et al. (2012), Albino et al. (2015) and, more recently, by Komninos and Mora (2018) and Mora et al. (2017: 20), whose bibliometric analyses reveal that the disagreement in the ways of conceptualizing and defining the smart city results from the *“lack of intellectual exchange”* between smart-city researchers and their *“tendency […] to be subjective and follow personal trajectories in isolation from one another”*.

This paper suggests all these subjective, personal and isolated interpretations fall short of providing both a clear understanding of smart cities and the scientific knowledge policy makers and practitioners need to deal with their progressive development. Indeed, we suggest this division is now so entrenched within the scientific community that it has generated different development paths for smart cities. This critical insight is drawn from research by Lazaroiu and Roscia (2012), Zygiaris (2013), Komninos (2014), Deakin (2013), Hollands (2015), Bolici and Mora (2015) and Mora and Bolici (2016; 2017) and serves to corroborate their findings on the state of the art.

In the interests of bridging this division within the scientific community, this paper reports on the findings of a bibliometric study covering the first two decades of research on smart cities. In this study, citation link-based clustering and text-based analysis are combined to: (1) build and visualize the network of scholarly publications shaping the intellectual structure of the smart-city research field; (2) identify the clusters of thematically related publications that shape the intellectual structure of the smart-city research field; and (3) reveal the emerging development paths of smart cities that these clusters support, along with the strategic principles they embody. This analysis offers a comprehensive and systematic view of how a smart city is understood by the scientific community and helps to bridge the structural divisions affecting smart-city research by supporting *“the construction of [that] collaborative environment which is necessary to generate a possible agreement concerning the way of thinking about, conceptualizing and defining the smart city”* (Mora et al. 2017: 21).

**2. Research Methodology**

In this bibliometric study, the hybrid techniques proposed by Braam et al. (1991a; 1991b) and Glanzel and Czerwon (1996) are applied to analyze the intellectual structure of the smart-city research field and identify the main development paths. This structure is first outlined and graphically visualized and then split into sub-groups of publications by conducting a document co-citation analysis. The result is a co-citation network composed of 2,273 publications divided into 18 thematic clusters. After tracing the network of relationships between these documents, a description of the content relating to the most representative clusters is provided based on the identification of their core documents[[4]](#footnote-4) and the construction of word profiles.

The study begins with a keyword search that aims to develop a representative dataset of literature on smart cities. The literature search covers the period from the beginning of 1992 to the end of 2012 and is implemented by using multiple scholarly databases. This search makes it possible to identify all the English-language literature containing the term smart city in the title, abstract, keyword list or within the body of the text. The following search query is used: “smart city” OR “smart cities” (Baseline 1992)[[5]](#footnote-5). It is important to note that all types of documents are considered in this study, including grey literature[[6]](#footnote-6) (Schopfel and Farace 2010).

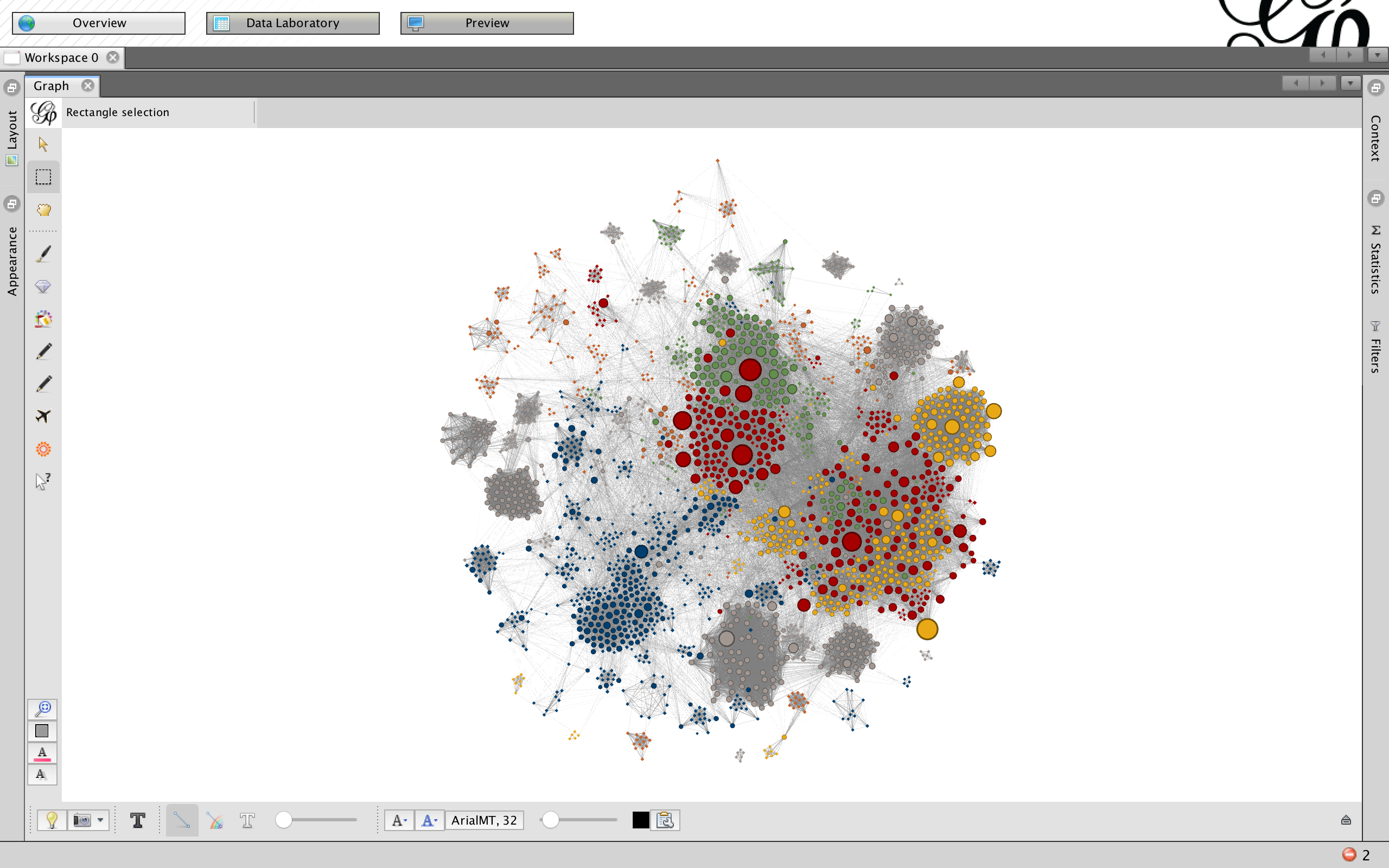
The documents found by using this search criteria are then included in a single dataset and checked to identify and correct any errors in the titles, names of authors and publication dates. Duplicate documents that are found in more than one database are eliminated. Finally, the title, abstract, keyword listand body of the text of each remaining publication are manually examined to verify the effective presence of the keyword. Documents for which this search is negative are eliminated.

After completing the search phase, the publications remaining in the dataset are 1,067, and all of them are used to collect the raw data needed to conduct the bibliometric study. For this reason, they can be considered as source documents (Small and Crane 1979; Schneider et al. 2009; Shiau and Dwivedi 2013; Ingwersen et al. 2014). Data for the co-citation analysis is collected manually by extracting the list of references from each source document. Altogether, 22,137 citations are extracted and used to build a frequency table showing each cited publication, along with the number of citations it has received. The total number of cited references is 17,574.

By considering only the 2,273 cited references with at least two citations, a co-citation network is then outlined, whereby each cited reference is represented as a node. Only 124 source documents are included in the network, where the nodes that are co-cited are connected with an edge. The total number of edges is 45,534 and their weight is measured considering the CoCit-Score, which is calculated according to the formula proposed by Allmayer and Winkler (2013) and Gmur (2003). Subsequently, nodes and edges are entered into the open source software Gephi (Version 0.8.2-beta) and the co-citation network is graphically visualized. The result is an undirected and weighted network which is subsequently split into sub-networks using Gephi’s modularity-class algorithm. The sub-networks represent the thematic clusters, i.e., groups of densely connected publications that are used to identify the main development paths within the smart-city research field.

**3. Results of Data Processing**

The results obtained through data processing are summarized in Table 1[[7]](#footnote-7) and displayed in Fig. 1, which graphically represents the co-citation network. Within the network, each publication is represented as a node in which the size of the circle is proportional to its 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 same approach is extended to clusters by summing up the values obtained for each of their publications.

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**Fig. 1**: Co-citation network: the intellectual structure of the smart-city research field for the period 1992-2012. Screenshot from Gephi. Within the network, each publication is represented as a node in which the size of the circle is proportional to its degree of centrality. Blue: mc.02; Yellow: mc.05; Green: mc.08; Orange: mc.14; Red: mc.17; Grey: others.

The network is composed of 18 thematic clusters in which the distribution of source documents varies considerably. The clusters are labelled from mc.01 to mc.18, and how they breakdown is shown 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 (Glanzel and Czerwon 1996; Glanzel and Thijs 2011; Meyer et al. 2013) and word profiles (Braam et al. 1991a; 1991b).

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

In addition, for each of the five clusters, a word profile with ten keywords is built by combining the full-texts of its source documents. More specifically, a file containing the textual data of each source document is created. These text files are then analyzed using the software WordStat (Version 6.0) to extract and combine the words and phrases contained in the source documents and estimate their frequency and occurrence. The keywords included in the word profiles are the phrases with the highest frequency that are found in at least 30% of the source documents belonging to the cluster (see Table 3).

**4. The Smart-City Research Field: Main Development Paths**

After completing the bibliometric analysis, word profiles and core documents are used to outline an in-depth description of the main thematic clusters and to shed light on the main development paths emerging from the intellectual structure of the smart city research field.

**4.1. Cluster mc.02 - Experimental Path: Smart Cities as Testbeds for IoT Solutions**

Interest in the technological component is dominant in the smart-city research field and represents one of the main driving forces behind its progressive growth. This becomes evident by observing 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. Additional evidence is also provided by the content analysis of the sub-network mc.02, which is the largest thematic cluster of the co-citation network. 25.4% of the total 2,273 publications are part of this cluster, where research focuses attention on ICT devices and infrastructures that have enabled ubiquitous computing and the Internet of Things (IoT), and stresses the potential contribution that they can offer in supporting cities’ sustainable development. Some of the technological components discussed in the core documents are indeed included in 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 work carried out by a group of researchers at Xerox PARC in Palo Alto, California. This group was led by Weiser (1991), who was the first to discuss this concept in a scholarly publication. As explained by Weiser et al. (1999), ubiquitous computing is based on the idea of spreading computers throughout the physical environment, moving away from the one-person-one-computer paradigm. According to his vision, formulated in the early 1990s, computers will be diffused in the real world and interconnected by ubiquitous networks. In addition, they will be able to control a countless range of functions in the physical space and work without human intervention, as autonomous and invisible agents (Weiser 1993). This vision becomes a reality with the advent of wireless technologies that activate a large number of networks composed of physical objects containing embedded technology to populate the Internet and communicate, sense and interact with both their internal states and the external environment in a completely autonomous way (Mitchell 2003).

This emerging wave of Internet-connected thingsleads to the appearance of the IoT, a new concept which is rapidly growing within the scenario of the potential benefits of ICTs in the sustainable development of urban environments. Despite difficulties in understanding what this term really means, due to the numerous interpretations provided by the scientific community, *“the basic idea of this concept is the pervasive presence around us of a variety of things or 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 neighbors to reach common goals”* (Atzori et al. 2010: 2787). All these things can be called smart objects, that are *“small computers with a sensor or actuator and a communication device, embedded in objects such as thermometers, car engines, light switches and industry machinery [which] enable a wide range of applications”* (Sundmaeker et al. 2010: 15).

The IoT can be considered as an integral part of the Future Internet (Atzori et al. 2010; ITU 2005; Tselentis et al. 2009) and an extension of the existing Internet, which generates new digital services and applications. The fields of application are many and include agriculture, home automation, 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), indeed, *“IoT technologies can find a number of diverse applications in smart cities’ scenarios”*. Based on this assumption, the thematic cluster mc.02 interprets smart cities as cities and urban territories that become testbeds for experimenting IoT technologies and analyzing their functioning, relevance and potential impact in real-life environments, as in the case of Santander, that is described in the cluster’s publications (Sanchez et al. 2011; 2013).

Located on the north coast of Spain, this small city has become an urban laboratory for the European research project SmartSantander. During the project, Santander and its surroundings have been equipped with more than 12,000 IoT devices (Sanchez et al. 2011) and transformed into *“a European experimental test facility for the research and experimentation of architectures, key enabling technologies, services and applications for the loT 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 loT and providing the research community with a […] platform for large scale loT experimentation and evaluation under realistic operational conditions”* (Sanchez et al. 2013: 1).

**4.2. Cluster mc.05 - Ubiquitous Path: the Korean Experience of Ubiquitous Cities**

Within the cluster mc.05, smart city and ubiquitous city are considered as two equivalent terms (Lee et al. 2008). Both are described as a technical evolution of the knowledge-city concept, which is discussed in a number of source documents of this thematic cluster (Dvir and Pasher 2004; Yigitcanlar et al. 2008a; 2008d) and in the core documents published by Yigitcanlar et al. (2008b; 2008c). Knowledge city is a term resulting from research on the knowledge economy and is used to identify cities where knowledge production is one of the main key drivers of their development strategy(Yigitcanlar et al. 2008d). As suggested by Yigitcanlar et al. (2008b), in the knowledge economy, urban development is mainly driven by global market forces and the role of knowledge in wealth creation has become a critical issue for cities. Therefore, it is necessary to define new approaches able to exploit the opportunities this abstract production offers for supporting sustainable growth and innovation in urban environments. This idea is supported in research carried out in the early years of 2000s by Landry (2000) and Florida (2002; 2005), both engaged in discussing and demonstrating 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 viable and 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 (or u-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 offer citizens and visitors the possibility to use digital services anywhere and anytime. Such services provide them with access to data and information, mainly collected in real time, which describe the functioning 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 together and everyone is connected to them(Shin and Kim 2010).

Most of the attention received by this concept comes from the Republic of Korea, where a national program on ubiquitous cities was launched by the central government in 2007. The aim was building the world’s first u-society based on the world’s best u-infrastructure (Republic of Korea 2007b). Only a few practical experiences linked to the ubiquitous city concept and developed outside the Korean territory can be found in scholarly literature. For example, Anthopoulos and Fitsilis (2010a; 2010b) describe the activity developed by the city of Trikala, Greece, while research by Gil-Castineira et al. (2011) and Shin and Lee (2011) report on a number of projects that are implemented in Oulu, San Francisco, Philadelphia, Tokyo, Singapore, Hong Kong, Taiwan and Malaysia.

The initiative of the South Korean government has driven many municipal administrations to integrate ubiquitous technologies in their urban environments. In 2007, the construction of u-cities extended to 22 cities (Republic of Korea 2007a), and, only three years later, they become 36, with a total number of 53 ubiquitous city initiatives in progress (Tekes 2011). Among the many projects developed under the ubiquitous city brand, Busan Green u-City, Songdo International Business District and Incheon Eco-City seem to be the most discussed in the cluster’s literature, in which they are described overlapping the terms smart city and u-city[[8]](#footnote-8) (GSMA 2012; Strickland 2011; Juan et al. 2011).

The Korean experience of ubiquitous cities has been analyzed in-depth and criticized by Shin (2007; 2009; 2010). His research sheds light on the limits and weaknesses of this national program, which is based on a top-down approach and *“is largely biased toward industrial and economic development, reflecting business providers' interests and leaving out users' […] 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 aspects and economic impacts, rather than city users and their needs. As a consequence, *“South Korean u-cities, in general, fall short of the ontologically bounded […] information society [and] tend to be designed primarily to serve the demands of major corporate suppliers and industry at the expense of public interests. The primary driving force to develop the u-cities has been the arrangement or outlay of technological equipment to increase technical capability”* (Shin 2009: 516).

**4.3. 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, which is expected to exceed hundreds of billion dollars by 2020 (Zanella et al. 2014; Buscher and Doody 2013). 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), Fujitsu (Tamai 2014) 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 working in the domain of urban technology and feeding the smart-city debate.

This trend has led to the growth of the corporate smart-city model discussed and criticized in recent research by Hollands (2008; 2015; 2016), Townsend (2013), Soderstrom et al. (2014) and McNeill (2016). According to Hollands (2015), in the corporate model, the smart city represents a technology-led urban utopia. Cities are conceived as systems of systems affected by inefficiencies that can be eliminated by using a massive dose of technological solutions provided by ICT companies (Soderstrom et al. 2014). The presence of these technologies automatically enable the transformation of ordinary urban environments in smart cities.

The corporate smart-city model has resulted in a new urbanism, whereby IT solution providers try to persuade municipalities to support urban development by adopting their smart technologies. IBM is one of the main supporter of this model and its relevant role and influence in the smart-city debate are demonstrated by the content analysis of the thematic cluster mc.08. This sub-network is almost totally linked to the vision proposed by the US 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), indeed, four out of five core documents are publications from IBM. What is more, the word profile contains the term smarter city*,* which is a trademark officially registered by this company and used for its smart-city campaign, under the motto: Building a Smarter Planet (Palmisano 2008).

The IBM’s Smarter Planet initiative is a commercial venture launched at the end of 2008 and has positioned IBM at the forefront of smart city construction (Palmisano 2008; IBM Corporation 2017). Many cities all over the world have embraced its view of a smart city, which is based on the following assumption: to build a smarter planet, its cities need to be instrumented, interconnected and intelligent (Harrison et al. 2010). As explained 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 smarter and, consequently, more efficient, democratic, livable, attractive, environment-friendly, and economically prosperous (Dirks and Keeling 2009).

One of the flagship project falling within the Smarter Planet initiative has been developed in Rio de Janeiro. With an investment of 14 million dollars, the municipal administration has worked with IBM to build an emergency response system. Their collaboration has resulted in the Rio Operations Center, which opened at the end of 2010. The Center is based on a digital platform applying the analytical models developed by IBM, which are asked to: (1) provide a holistic view of how the city is functioning; and (2) predict possible emergency situations, especially flood-related incidents, because every summer Rio de Janeiro faces the consequences of intense rainfall, including landslides and flooding. The data used for predicting emergency includes: real-time images captured by a surveillance system with 900 cameras located around the city; weather sensors; historical data series; and the messages that are sent by the city’s users via phone, Internet and radio (IBM Corporation 2011; Naphade et al. 2011; Kitchin 2014). The project has been criticized because: the top-down surveillance system generates negative social implications in terms of privacy; the civil society has not been engaged and actively involved in the implementation process; and IBM’s technological solutions and computer algorithms are put in charge of city management, leaving very limited space for the human component (Singer 2012; Townsend 2013).

**4.4. Cluster mc.14 - European Path: Smart City for a Low-Carbon Economy**

According to data provided by the American Association for the Advancement of Science (2001) and the United Nations Human Settlements Programme (2011), urban areas: host more than 50% of the world’s population; consume about 70% of the global energy; 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 this situation has become one of the most relevant priority for local and national governments, which are offering their contribution by implementing sustainable energy policies, initiatives and projects.

ICTs have proven to be a decisive means in helping governments to face up to this critical situation and enable the progressive growth of a low-carbon future. The core documents of the thematic cluster mc.14 explore this possibility, in particular the report *“SMART 2020”* published by The Climate Group, an international non-profit organization that supports leaders in government, business world and society to address climate risks and accelerate the transition to a low-carbon economy. This report demonstrates the ICT industry’s technological solutions can drastically unlock emissions reductions. 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). By acting on these five sectors, ICTs could *“deliver emissions saving of 15% […] of global […] emissions in 2020”* (The Climate Group 2008: 7).

This study and the other core documents make it clear that unlocking the potential of ICTs is the critical challenge which faces climate change globally. In addition, they identify the sector of smart grids as one of the most promising application domain. Smart grids are described as the electricity networks of the futurebecause they improve the efficiency of current power transmission and distribution networks while responding to the new challenges and opportunities arising from the energy market (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. The Indian government has been developing policies to overcome barriers that limit the implementation of smart grid initiatives since 2001 (The Climate Group 2008). In 2005, the European Commission has set up the SmartGrids Technology Platform, in which all the relevant European stakeholders working in the energy sector have been included. Together, they designed a joint vision for the European energy network of 2020 and beyond that is based on activating smart-grid solutions across Europe (European Commission 2006). The same aim is pursued by the US government, where specific interoperability standards and protocols for smart-grid devices and systems have been 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 is a key ambition of the European Union. This is demonstrated by the contents of the Strategic Energy Technology Plan (SET-Plan), that was published in 2009: a policy instrument that describes the strategy of the European Union for accelerating 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 the smart-city concept supported in the cluster mc.14 has grown. As reported in the SET-plan, according to the European Commission, smart cities are those that will *“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 […]. These cities will 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).

**4.5. Cluster mc.17 - Holistic Path: Digital, Intelligent, Smart**

The thematic cluster mc.17 is the second sub-network of the system in terms of size and 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 better understanding the relationship between ICT and the urban environment. This knowledge area starts growing between the end of 1990s and the early 2000s, and some of the first publications that have provided a significant contribution in laying down its intellectual structure are 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.

These publications and their authors started filling *“the gap left by the long neglect of telecommunications in urban studies and policy-making [by 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 started experimenting with the use of digital technologies for supporting urban innovation and development by implementing projects and initiatives which have been labeled by using three different terms: digital city; intelligent city; and smart city. These terms clearly emerges 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 20th century and is used as a label for a number of projects launched by European, North American and Asian cities(Ishida and Isbister 2000). These projects have resulted in the construction of websites that were used for providing access to cities’ digital services. The aim was supporting social and economic development in urban environments (Aurigi and Graham 2000). Research by Aurigi (2000) shows that these websites were mainly used to: stimulate local economic development; improve the image of a city; widen access to the Internet and support community networking; support the implementation of online debates, discourses and communities; and improve the management of cities’ physical infrastructures.

The digital city movement was very active in Europe, in which many cities have been involved in the construction of their digital counterparts (Aurigi 2000; 2003; Mino 2000). 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 the21st century, while the world was experiencing the construction of digital cities, the term intelligent city has emerged in research by Komninos (2002; 2006; 2008). Its interpretation is provided in a conference paper which was 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 supporting growth and innovation in urban environments while increasing the problem-solving capability of urban communities (Komninos 2002). Consequently, intelligent cities and digital cities share the same interest for ICT-driven urban development. However, while the former focuses 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 ability 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 technologies (Komninos 2011; Schaffers et al. 2011). On the other hand, there is a request for a more progressive view of ICT-driven urban innovation strategies, which emerges in recent smart city literature (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; Leydesdorff and Deakin 2011) and is supported in the work previously undertaken by Aurigi (2005; 2006), Mino (2000), Graham and Marvin (1999) and Castells (1996).

These authors propose a holistic interpretation of smart cities in which human, social, cultural, environmental, economic and technological aspects stand alongside one another. 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, and the strategies for building smart cities are grounded in collective intelligence, participatory governance, collaboration, community-led urban development, open innovation and user-driven innovation.

**5. Discussion and Conclusions**

This paper reports on a bibliometric study of the first two decades of research on smart cities (1992-2012) in which co-citation cluster analysis and text-based analysis are combined to map the publications dealing with the smart-city concept and provide a visual representation of their organization. The clusters of publications that are thematically related are then identified and the emerging development paths of smart cities and the strategic perspectives each of them embodies are revealed. The analysis shows five main development paths:

1. Experimental Path, in which smart cities are described as urban testbeds for experimenting Internet of Things infrastructures and service applications and analyzing their functioning, relevance and potential impact in real-life environments;
2. Ubiquitous Path, where smart cities and ubiquitous cities overlap and are considered as two equivalent concepts;
3. Corporate Path, in which urban areas become smart when they are equipped with a platform of digital solutions provided by ICT consultancies;
4. European Path, which represents smart cities as highly efficient urban systems in which digital technologies are used to tackle environmental degradation and fight climate change by transforming buildings, energy networks and transport systems;
5. Holistic Path, where smart cities are considered as urban settlements in which digital technologies are assembled to meet local development needs and their development process is grounded in collective intelligence, participatory governance, collaborative association, community-led urban development and open and user-driven innovation.

By comparing the strategic perspectives for smart-city development that each path stands for, however, divergent choices seem to emerge. This requires future research to produce the scientific knowledge necessary to improve decision-making processes in the field of smart cities:

* + - 1. While the Experimental Path, Ubiquitous Path and Corporate Path suggest smart-city development requires a technology-driven and market-oriented approach, the Holistic Path proposes a human-centric and people-driven vision;
      2. According to the Corporate Path and Ubiquitous Path, smart-city development needs to be top-down and centralized rather than bottom-up, decentralized and diffused, as the Holistic Path suggests;
      3. The Corporate Path also suggests that smart cities result from a double-helix collaborative model, where IT solution providers try to sell their products to local governments, but the Holistic Path is oriented towards accessing a more open and inclusive collaborative model where university, industry, government and civil society work together;
      4. The Holistic Path, Experimental Path, Ubiquitous Path and Corporate Path propose an integrated and multi-dimensional approach to smart-city development, which embraces as many smart-city domains as possible, and is opposed to the mono-dimensional intervention logic of the European Path, that focuses attention only on low-carbon technologies for smart transports, smart buildings and smart grids.

This study systematically captures the division affecting research on smart cities and provides the scientific knowledge necessary to start developing that clear and common understanding of smart cities which is still missing. However, an extension of this bibliometric analysis to the literature published after 2012 would be a relevant research activity for understanding whether and how the scenario represented in this paper and the smart-city development paths it reveals have evolved in relation to the most recently published material.

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**Appendix A**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CLUSTER** | **SIZE**  n° publications | % on total | n° source doc. | **DEGREE OF**  **CENTRALITY** |
| 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 |
| Total | 2,273 |  | 124 |  |

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **CLUSTER** | **CORE DOCUMENT** |  |  |  |  |
| Reference | Title | Year | Type | In-Degree |
| mc.02 | Weiser (1991) | The computer for the 21st century | 1991 | Art | 185 |
| **mc.02** | **Atzori et al. (2010)** | **The Internet of Things: a survey** | **2010** | **Art** | **100** |
| mc.02 | Polastre et al. (2004) | Versatile low power media access for wireless sensor networks | 2004 | Conf | 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** | **Art** | **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 | Grey | 37 |
| **mc.14** | **Karnouskos and Nass de Holanda (2009)** | **Simulation of a smart-grid city with software agents** | **2009** | **Conf** | **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** | **Conf** | **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 | Conf | 162 |
| mc.17 | Graham (2004b) | The cybercities reader | 2004 | Bo | 160 |

Table 2: Core documents. Source documents are in bold. Bo: books; Art: articles published in scholarly journals; Conf: conference papers; Gr: grey literature.

|  |  |
| --- | --- |
| **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%) |
| 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; Occurrence (oc.): percentage of cluster's source documents in which the keyword is included.

1. Edinburgh Napier University, School of Engineering and Built Environment, Edinburgh, UK, L.Mora@napier.ac.uk [↑](#footnote-ref-1)
2. Edinburgh Napier University, School of Engineering and Built Environment, Edinburgh, UK [↑](#footnote-ref-2)
3. Edinburgh Napier University, School of Engineering and Built Environment, Edinburgh, UK [↑](#footnote-ref-3)
4. In this study, core documents of a thematic cluster are considered as those publications with the highest number of connections with other publications in the same cluster. [↑](#footnote-ref-4)
5. The following databases are used to conduct the keyword search: Google Scholar; ISI Web of Science; IEEE Xplore; Scopus; SpringerLink; Engineering Village; ScienceDirect; and Taylor and Francis Online. Considering the specific interest of this study for smart cities, a decision was made to set the keyword search so that only the scholarly publications containing the singular of plural form of the term ‘smart city’ are identified and not the literature using other terms that are considered as equivalent despite having different meanings (Hollands 2008). These terms include sustainable cities, green cities, digital cities, intelligent cities, smarter cities, information cities, resilient cities, eco cities, low-carbon cities and liveable cities. This choice is based on research by de Jong (2015), which reveals these categories of cities are characterized by conceptual and practical differences and cannot be used interchangeably with the term “smart city”. [↑](#footnote-ref-5)
6. Grey literature can be considered as *“all the scholarly work that is published without a formal peer-review (or equivalent) process outside the traditional journal and book channels”* (Schopfel 2010). [↑](#footnote-ref-6)
7. All the tables (Table 1, Table 2 and Table 3) can be found in Appendix A. [↑](#footnote-ref-7)
8. This tendency can also be found in more recent studies by Yigitcanlar and Lee (2014), Clarke (2013) and Shwayri (2013). [↑](#footnote-ref-8)