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Smart City and information technology: A review

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ABSTRACT

Smart City is a recent concept that is gaining momentum in public opinion, and thus, it is making its way into the agendas of researchers and city authorities all over the world. However, there is no consensus of what exactly is a smart city, and academic research is, at best, building applications in numerous silos. This paper explores the computer science and information technology literature about Smart City. Using data analysis techniques, we contribute to present the domain from an objective data-based point of view, aiming to highlight its major trends, and providing a single entry point for newcomers.

1. Introduction

Nowadays, nearly 55% of the World population lives in urban areas, and it is expected that the number will increase up to 66% by 2030 (United Nations, 2016). As the city grows, new problems arise (e.g., traffic congestion, waste management, pollution, parking allocation, etc.) and the resources are scarce. Therefore, working on the adaptation of the city to the current (and future) needs is a priority for all of us, and researchers are no exception.

The urgency of making the city a more suitable place for quality living is triggering many initiatives around the world (European Commission, n.d.; U.S. Department of Transportation, n.d.), from city councils and companies to research laboratories. People from different disciplines, culture, history, and interests are finding a commonplace: make the city *smart*.

The *Smart City* (SC) concept emerged a few years ago as a combination of "ideas about how information and communication technologies might improve the functioning of cities" (Batty et al., 2012). While the term SC is gaining popularity (every day more cities are labeled as *smart*), the concept is considered to be still a work-in-progress (Manville et al., n.d.; Caragliu et al., 2011; Cocchia, 2014).

Moreover, several concepts relate to the same idea, but with slightly different perspectives, e.g., *digital city* (Ishida, 2002) or *intelligent city* (Komninos, 2006). Even worse, few studies systematically study the SC concept and its implications. Therefore, it is hard to tell if we are going in the right direction and if we are not missing important opportunities to make our cities smart.

On the other hand, speaking about SC is not just talking on technology but on something more complex and human. It is important to stress that cities are human settlements and they are supposed to serve us. Hence, in this review, we propose to systematically study the status of SC research from information technology (IT) and computer science (CS) point of view, aiming to provide a comprehensive picture of the domain, i.e., not focusing on the technology itself but on how it serves to the SC development. It is important to highlight that we include CS and IT to cover both the use and development of technology.

Therefore, the main contributions of this work are:

1. **Broad and Objective Review**: This study is conducted by the analysis of all CS/IT publications on SC, using data analysis techniques. Therefore, we automatically process a large number of works (larger than the number a human can handle), treating all publications equally. Hence, the results of this study are objective (based on calculated metrics) and guaranteed to encompass all publications (within a set of restrictions).
2. **Trend Analysis**: This work presents a quantitative appraisal of the distribution and growth of CS/IT research in the SC domain.
3. **Single entry point**: We discuss the applications, techniques, and the relations between fields and existing articles as well as we show a network of interactions, point out foundational works and provide a unique point of view in considering CS/IT for SC that could help as an introduction to the research area.

The rest of this article is organized as follows: Section 2 introduces the methodology used to analyze the state-of-the-art and reviews the basic concepts used in this work, Section 3 presents the results and discusses the

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Table 1
City related concepts that overlap with Smart City.

Concept	Definition	Reference
Digital City	"An arena in which people in regional communities can interact and share knowledge, experiences, and mutual interests"	Ishida (2002)
Eco City	"An ecological healthy city"	Register (1987)
Green City	A city that complies with "fostering economic growth and development while ensuring […] the resources and environmental services"	OECD (2013)
Intelligent City	"Territories with high capacity for learning and innovation, which is built-in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management"	Komninos (2006)
Knowledge City	"Purposely designed for encouraging and nourishing the collective knowledge, i.e. intellectual capital, as capabilities to shape efficient and sustainable actions of welfare over time"	Edvinsson (2006)
Sustainable City	"One in which its people and businesses continuously endeavor to improve their natural, built and cultural environments at neighborhood and regional levels, while working in two ways which always support the goal of global sustainable development"	Haughton and Hunter (1994)
Wired City	"A community in which all kinds of electronic communication services are available to households and businesses"	Dutton et al. (1987)

Table 2
Commonly cited Smart City definitions.

Reference	Definition
Hall et al. (2000)	"A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails/subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens… systems and structures will monitor their own conditions and carry out self-repair, as "needed""
Harrison et al. (2010)	"Connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city"
Caragliu et al. (2011)	"We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (Information and Communications Technology, ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance"
EU (Manville et al., n.d.)	"A Smart City is a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally based partnership"
Giffinger et al. (2007)	"A Smart City is a city well performing in a forward-looking way in these six characteristics, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens"
Dameri (2013)	"A smart city is a well defined geographical area, in which high technologies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well being,inclusion and participation, environmental quality, intelligent development; it is governed by a well defined pool of subjects, able to state the rules and policy for the city government and development"

validity of them, and Section 4 outlines our conclusions and proposes future work.

2. Methodology and background

In this section, we introduce the methodology used to perform the analysis and present the core concepts of SC. Indeed, by using the guidelines proposed by Vom Brocke et al. (2009), we will seek to (1) define the review scope (Section 2.1), (2) conceptualize the topic (Section 2.2), (3) perform a literature search (Section 2.3), (4) analyze and synthesize the relevant literature (Section 3), and (5) propose a new research agenda (Section 4). By doing this in a structured form, we expect to grant to reproducibility of this work and settle the basis for future extensions.

2.1. Scope

The scope proposed in this review is defined using the taxonomy of Cooper (1988), aiming to ease its *reproducibility*. Thus, we can define several conditions needed for this job, starting with a focus on (*a*) all type of articles indexed in the Journal Citation Report (JCR) (Clarivate Analytics, 2017), (*b*) selecting representative works, (*c*) organizing the literature by means of the concept, (*d*) assuming a neutral position (with the aim of identifying the central issues), and (*e*) targeting a specialized audience.

With this selection of articles (condition *a*), we allow us to be inclusive for all of the domains presently accepted in smart cities: *economy*, *mobility*, *governance*, *people*, *living*, and *environment* (Manville et al., n.d.; Caragliu et al., 2011). That is important, not only because it offers a comprehensive view of the SC field beyond existing partial approaches, but also because it will prevent us (and our readers) to go ahead with personal ad-hoc definitions of the fields of work in SC (largely settled in the knowledge community several years ago).

By studying the keywords of the surveyed works, titles and actual aims addressed inside of them, we will define the *representative* works (condition *b*). We will organize our discussion according to relevant concepts in the core of this field (condition *c*). We, of course, can do nothing different from taking a neutral position (condition *d*) in our findings and recommendations just driven by data evidence. And finally, we will target to a scientific audience (condition *e*).

2.2. Concepts: *-city

In this section, we address the concepts (and ideas) commonly attached to 'city'. First, we need to put in common all these concepts (still converging, if judged at world level), setting the basis for a meaningful review.

According to recent literature reviews and studies (Manville et al., n.d.; Mali and Kanwade, n.d.; Cocchia, 2014; Dameri et al., 2016; Meijer and Bolívar, 2016; Nam and Pardo, 2011; Neirotti et al., 2014), there are multiple city related concepts overlapping with SC, such as Digital City, Intelligent City, and Sustainable City, among others. Table 1 presents some of the most relevant relative concepts found in the literature regarding these terms. Amid these concepts, Digital City is usually accepted as a *synonym* of SC (Manville et al., n.d.; Cocchia, 2014). Thus, we will focus on SC and 'Digital City' from now on. The other concepts will not be used during this literature review to ease the search process and to avoid the inclusion of off topics.

Several definitions of SC have been given, however, there is no consensus one. Furthermore, finding a working definition on every publication appears to be rather common at this moment. For this reason, we summarize in Table 2 the most frequently cited definitions to highlight the common parts found in them.

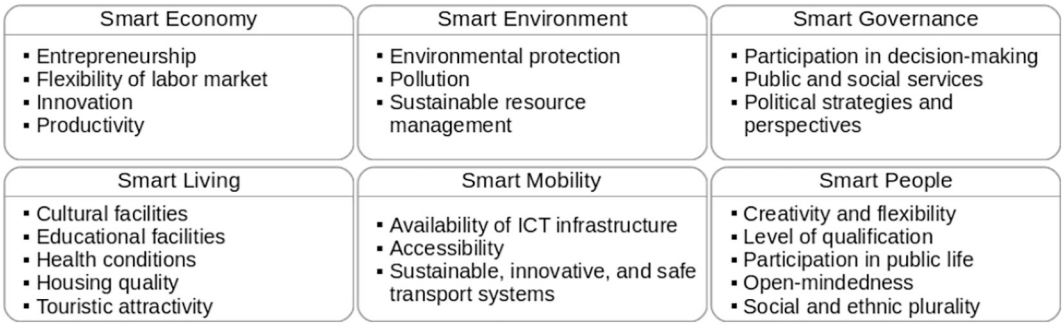


Fig. 1. Smart City initiatives classified by domain.

As a summary, we can see that some of them put the stress on the components and the need to manage them together in an intelligent way, while others focus on their interconnections. Others are more abstract and point to the byproducts of being holistic and smart in the city. CS/IT concepts are explicitly included several times, while in other cases, they are implicitly needed to achieve the goals and to interconnect the elements targeted in them.

In the second part of this section, we address a relevant question: what are the SC domains of work? Nowadays, after years of debate and in spite of some ad-hoc definition, there is a wide consensus at on accepting six domains.

Indeed, SC initiatives are often classified into the following six domains (axes or dimensions) (Manville et al., n.d.; Caragliu et al., 2011): Economy, Environment, Governance, Living, Mobility, and People. Following, we briefly introduce these axes.

Smart Economy refers to e-business and e-commerce, and to economic opportunities that are enabled by CS/IT, including manufacturing and service delivery, innovation, and new products, services or business models.

Smart Environment encompasses smart energy (energy grids, metering, control and monitoring improved by CS/IT, as well as renewable energy sources), water, green buildings, green urban planning, urban services (waste management, drainage systems, public lightning), and efficiency, reuse and substitution of resources to improve environmental conditions.

Smart Governance is concerned with using CS/IT to improve democratic processes and public services (e-government) and to support and facilitate better planning and decision making.

Smart Living refers to initiatives that use CS/IT to enable new (and improved) lifestyles, providing a safe and healthy city, which is attractive to the citizens.

Smart Mobility gathers the group of initiatives that improve transportation and logistics by using CS/IT.

Smart People is concerned with improving creativity and fostering innovation by using CS/IT to enable working (e.g. work-at-home), human resources, capacity management, and having access to education and training.

Note again that all of the above classifications include CS/IT as a fundamental part of their definition. Fig. 1 shows the six domains of SC and a short list of examples (applications).

2.3. Literature search

To select the most representative works, we propose to search for scientific publications indexed in JCR (proposed by Thomson Reuters and presently managed by Clarivate Analytics). Every single existing journal has a good reason to be important and interesting, but JCR indexed journals are worldwide recognized as influential and as top places for modern research. They are also being used by many countries for quality analysis in research, development, and innovation.

Then, we propose to build the citation graph (and the density map) of the selected publications to identify the major trends. We can assume that the densest areas in the map are related to trending topics (major trends) and that the works that have the largest number of citations and relations inside each densest area (i.e., are in the center of the densest areas (van Eck and Waltman, 2010)) are a good source for extracting the *trends*. For convenience, we will use the term *hot spot* to refer to the densest areas in the density map.

3. Literature review

In this section, we present the results of the literature review. Considering the rapid development of the SC literature and to offer an *evolving* perspective of the topic, we performed the literature search for two consecutive years (i.e., we took two snapshots on the same date for two consecutive years). Therefore, in this section we (*i*) introduce the general facts, (*ii*) present the hot spots and the status of research in each of them, plus their evolution, (*iii*) outline the clusters represented by the hot spots, (*iv*) present the *outliers* (highly cited SC works that are not related to the hot spots) detected in the review process, and (*v*) discuss the limitations of this study.

3.1. General facts

We searched in the Web of Science for articles and proceeding papers indexed by JCR with the terms ‘smart city’, ‘smart cities’, ‘digital city’ and ‘digital cities’ in the *title* or in the *topic*. Notice that we included the word ‘cities’ to encompass possible naming variations. Also, note that we will use the term ‘collection’ to refer to the search results.

On Oct 3, 2016, the search returned 2196 hits, where nearly half of the documents (1126 publications) are classified as CS/IT research. Then, on Oct 9, 2017, we repeated the search. The updated results spot 4082 hits in all disciplines and 2067 publications classified as CS/IT. So it seems that CS/IT is quite important for SC as it explicitly appears in half of the existing publications (in a maintained manner).

Fig. 3 shows the number of publications (up to 2017) indexed in JCR per year and field (stacked). Note that the number of publications shown on 2017 only considers the publications indexed up to the date of the snapshot (Oct 9, 2017). Thus, this number is not to be considered as the final result of the year.

From the data shown in Fig. 3, we infer that the interest in SC is increasing rapidly (especially in the last 5 years) and that CS/IT field has a major role in SC research. A remarkable fact is that CS/IT represents 50% of the total research in SC. Besides CS/IT, the most relevant topics according to the number of publications are Engineering (18%), Telecommunications (6%), Science technology other topics (4%), Urban studies (4%), and Business economics (4%).

We analyzed the *origin* of the CS/IT research related to SC, i.e., the country from where the research is done. We computed the count of publications per country using the affiliation of the authors. Particularly, we count the unique occurrence of a country in the

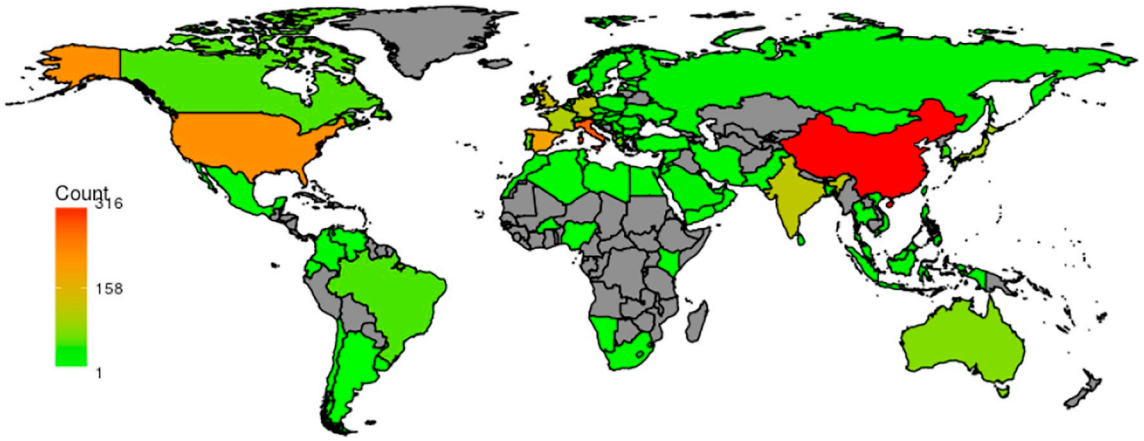


Fig. 2. CS/IT publications related to Smart City per country of affiliation of the authors.

affiliations of each publication. In other words, if a publication has more than one affiliation, we first compute the set of countries (i.e., the list of countries with no repetitions). Then, each occurrence is summed up to the number of publications of each country. Note that a publication might be summed to more than one country and that the proposed method does not take into account intentionally the number of researchers, neither the number of research groups or centers. Thus, we measure the *net contribution* of each country.

Fig. 2 summarizes the accumulated number (*count*) of CS/IT publications related to SC per country of affiliation of the authors (2017 snapshot). The number of contributions increases as the color goes from green to red. The countries shown in gray do not have a publication in the collection.

The accumulated count, i.e., the sum of the publications or net contribution of each country, is equal to 2711 publications. Taking into account that the number of CS/IT publications is equal to 2067 (a publication may *contribute* to the sum of more than one country); we infer that roughly 30% of the publications were done in collaboration between researchers of different countries (according to their affiliation).

The top 10 countries in terms of their net contribution are: China (316 publications), Italy (272), United States (217), Spain (187), India (119), Germany (118), United Kingdom (117), France (104), Japan (97), and Australia (76). It is quite noticeable that their contribution represents nearly 60% of the total.

Furthermore, since half of the top countries belong to Europe and due to the availability of data from European SCs, we compare our findings with the ones presented in (Manville et al., n.d.) by the EU.

Table 3 presents the EU state members alongside with their contributions (*Contrib.*), the number of smart cities (*No. SCs*) reported (available on the page 39, Fig. 11, of the EU report (Manville et al., n.d.)), and the gross domestic product (*GDP*) at purchasing power parity (PPP) per capita in USD reported by the International Monetary Fund in the 2016 report (International Monetary Fund, 2016).

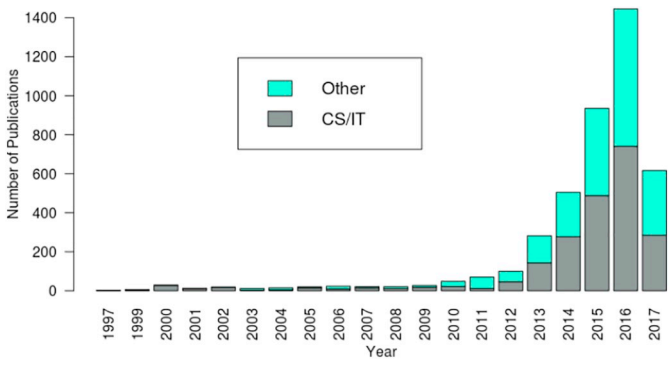


Fig. 3. SC publications indexed by JCR up to Oct 9, 2017.

The results presented in Table 3 show that there is a positive correlation between the number of smart cities and the net contribution of the country. On the other hand, there is no evidence of a correlation between the GDP and the number of smart cities, nor the net contribution of the country. Thus, we conclude that *money* is not the key for a city to become smart.

Another remarkable fact is that Lithuania and Malta are the only EU states that do not *contribute* to the SC research agenda, i.e., there is no publication whose author is affiliated to these countries. While there is one smart city initiative reported in Lithuania, there is none reported in Malta.

However, the most interesting case in our opinion is Luxembourg. There are 8 publications attached to the referred country, but there is no smart city initiative (reported) in practice. Note that in GDP per capita Luxembourg is ranked as the first EU state member (and also second worldwide).

Then, considering that SC research is a useful and important input for policymakers and city managers, we performed a *simple crosscheck validation* to test if researchers are considering urban planning and giving policy recommendations (Neirotti et al., 2014). Particularly, we search for the words 'urban plan'(ning) and 'policy'(ies) in the abstract of all publications.

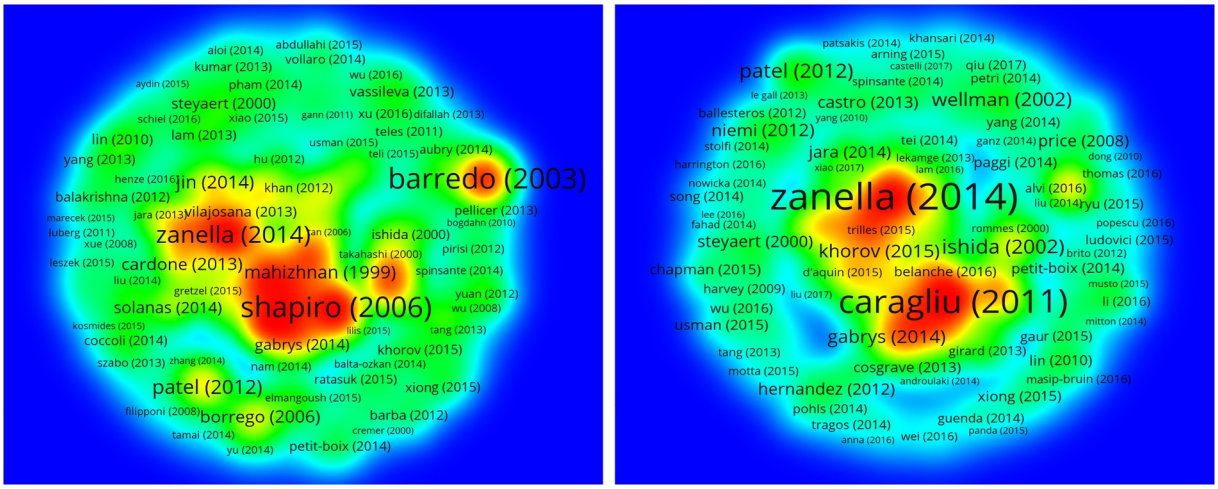
Considering the 2016 snapshot, less than 10% of SC publications (219 out of 2196) mentioned urban planning or policy in the abstract. Moreover, this percentage decreases to 7% (74 out of 1126) when we considered only the publications classified as CS/IT.

On the 2017 snapshot, the situation is quite the same, 390 out of 4082 publications from all disciplines (roughly 10%) mentioned urban planning or policy. While 133 out of 2067 CS/IT publications do it, i.e., less than 7%.

After analyzing the collection in general, we proceed to build the citation graphs (independently for the 2016 and 2017 snapshots) to improve our comprehension of the topic. It is very important to remark that each citation graph only includes the links between publications present in the collection. Therefore, citations to documents that are not part of the collection will not be considered (i.e. no edges will be added to the citation graph). We assume that this situation may lead to underestimating the relevance of a publication because it could be cited by works that were not included in the collection. So, to alleviate this situation, we set the size of each node of the graph to be the number of citations informed by JCR, instead of the number of links. Thus, a publication may be represented by a *big* node, but with no connecting edges in the citation graph.

3.2. Hot spot evolution

Using the citation graph (for all publications, not only CS/IT) we built the *citation density map* for each collection, i.e., a map that is



(a) 2016 (b) 2017

Fig. 4. Density map of JCR publications (all disciplines) related to Smart City.

colored according to the number of publications present in an area (van Eck and Waltman, 2010). The citation graphs and density maps were built using VOS Viewer (van Eck and Waltman, 2010).

Fig. 4 shows the citation density map for all publications included in the working set (all disciplines), using the *jet* colormap (i.e., the density increases from blue to red). It is important to remark that this procedure was repeated for both snapshots (2016 and 2017) independently and that the font size of the publications (name and year in the plot) gets bigger as the number of citations (reported by JCR) increases.

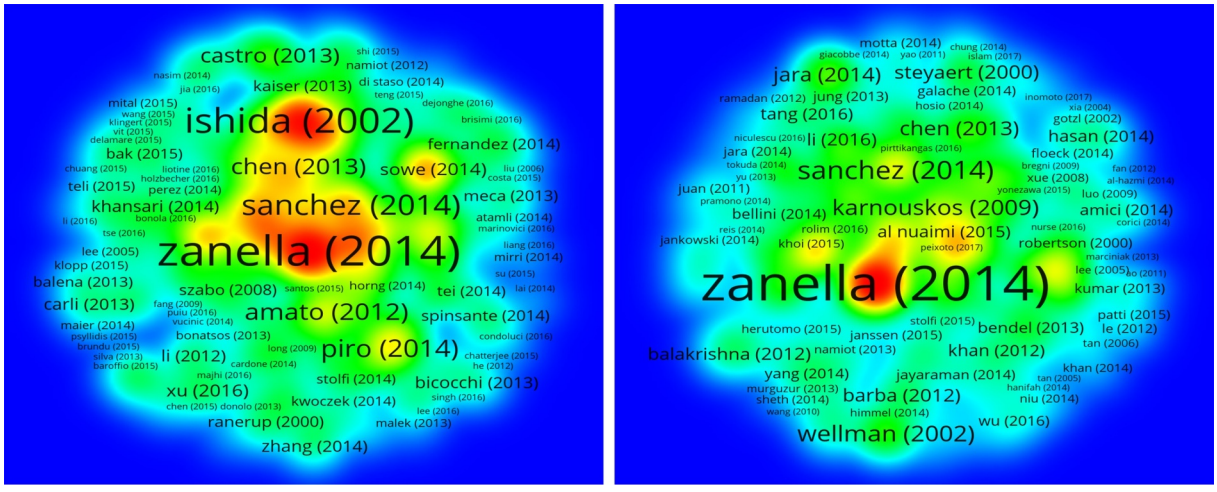
The works attached to the 2016 snapshot hot spot (the zones in red), sorted descending by their number of citations are (Fig. 4a): *Shapiro* (Shapiro, 2006), that outlines the relationship between educated population and employment growth; *Caragliu* (Caragliu et al., 2011), that analyzes the factors that determine the performance of a smart city; *Batty* (Batty et al., 2012), that reviews the state of the art and outlines the future of smart city; *Zanella* (Zanella et al., n.d.), that reviews the currently available technology for implementing urban Internet of Things (IoT) and introduces a use case; *Barredo* (Barredo et al., 2003), that discusses the simulation of urban scenarios through cellular automata; *Ishida* (Ishida, 2002), that presents the use case of digital city Kyoto; and *Mahizhnan* (Mahizhnan, 1999), that presents the use case of turning Singapore into an *Intelligent Island*.

In the 2017 snapshot, the hot spot works, sorted descending by the number of citations are (Fig. 4b): *Zanella* (Zanella et al., n.d.), *Caragliu* (Caragliu et al., 2011), *Batty* (Batty et al., 2012), *Shapiro* (Shapiro, 2006), *Perera* (Perera et al., 2014), that explores the concept of *sensing as a service* and its relation to the IoT; and *Botta* (Botta et al., 2016), that reviews the integration of Cloud and IoT.

Note that the top 4 works from 2016 and 2017 snapshots are the same but in a different order. Also note that the works of *Barredo* (Barredo et al., 2003) and *Ishida* (Ishida, 2002) are still noticeable in the 2017 density map, but they are not anymore in the hot spots and that the work of *Mahizhnan* (Mahizhnan, 1999) is not visible in Fig. 4b (i.e., its size is relatively smaller in 2017 compared to 2016).

Then, we selected the works that are classified as CS/IT, and we repeated the process described above (independently for both snapshots). Fig. 5 shows the corresponding citation density map for works classified as CS/IT. At first glance, we found that two (out of seven) of the 'general' hot spots from 2016 (to know (Zanella et al., n.d.; Ishida, 2002)) are also present in Fig. 5a. Moreover, two (out of six) of the 'general' hot spots from 2017 are present in the corresponding density map (Fig. 5b).

Then, considering the number of CS/IT publications related to SC (Section 3.1) and the relative importance of these publications to the hot spots, we infer that CS/IT has a major role in SC research. The rest of the analysis is presented in the next section.



(a) 2016 (b) 2017

Fig. 5. Density map of JCR publications classified as CS/IT related to Smart City.

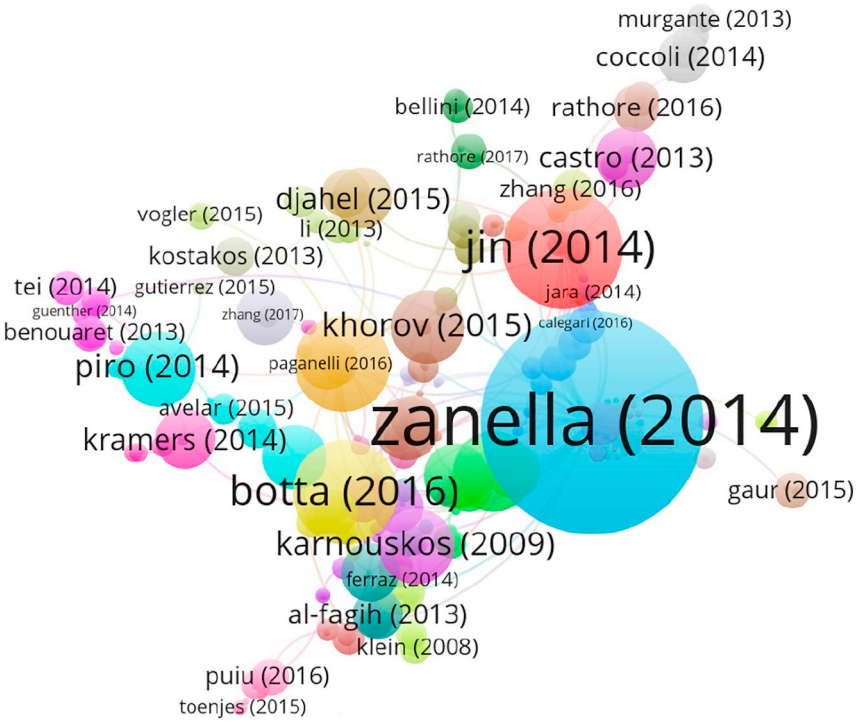


Fig. 6. CS/IT publications related to Smart City that are strongly related to the main hot spot shown in Fig. 5b.

3.3. Hot spot relations

To offer a broader view of the hot spot we analyzed the citation graph (2017 snapshot). It is important to note that the *strength* of the relation between the two publications is reflected by the distance in the representation, where a smaller distance indicates a stronger relationship. The distance between publications is calculated using the association strength method (van Eck and Waltman, 2010).

Considering the size (and spatial distribution) of the publications in the citation graph, we decided to split it into three figures (Fig. 6, 7a and b). The criteria used to divide the graph was the distance between publications, i.e., each figure contains a group of publications that are strongly related, but have a weaker connection (just one link) to another group of publications. Note that this is just a visualization issue.

Fig. 6 presents the citation graph of the works that are strongly related to the densest part of Fig. 5b, the 'main hot spot'. The nodes of the graph represent the publications, while the edges represent the citation (link) from one publication to another. As said before, the size of the node is relative to the number of citations informed by JCR (not to the number of links to publications in the collection).

We notice that there is some consistency regarding the most notable work, to know the publication of Zanella et al. (n.d.) (refer to Figs. 4, 5 and 6), a "survey of the enabling technologies, protocols, and architecture for an urban IoT". Also, we found that there are several subgroups (or clusters) of publications that share a major number of links between them and are close to each other. These subgroups of publications are plotted with different colors in Fig. 6. Due to 'technical' restrictions (the size of the image), the works that have a smaller number of citations may not be visible in the referred figure. Also, note that there are works that are *hidden* under other publications, i.e., publications that are very close to a highly cited work, but do not have a large number of citations.

Fig. 7 presents the groups of publications that are weakly related to the main hot spot presented in Fig. 6. Note that there is one link from these secondary spots to the main hot spot (pointed out in each figure) and that some links are shortened to facilitate the visualization.

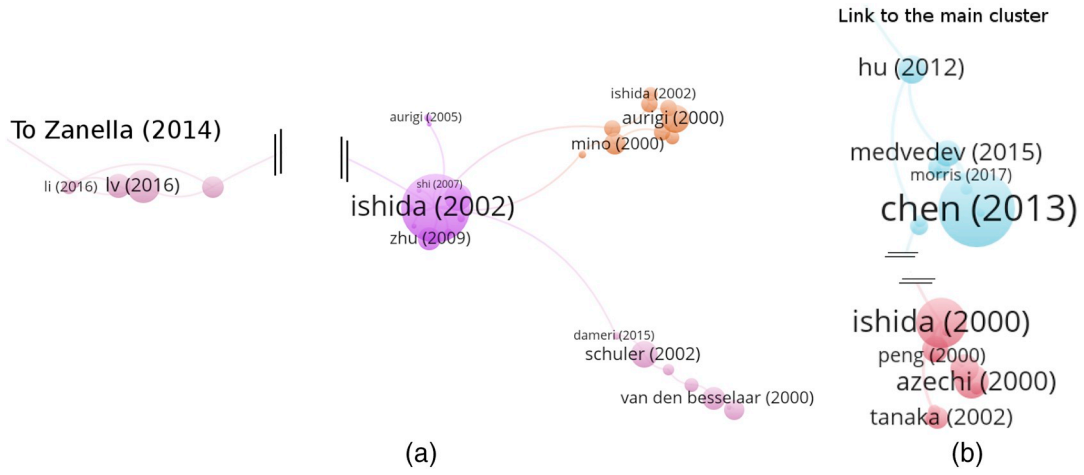


Fig. 7. JCR publications classified as CS/IT related to Smart City that are far away from the 'main hot spot'.

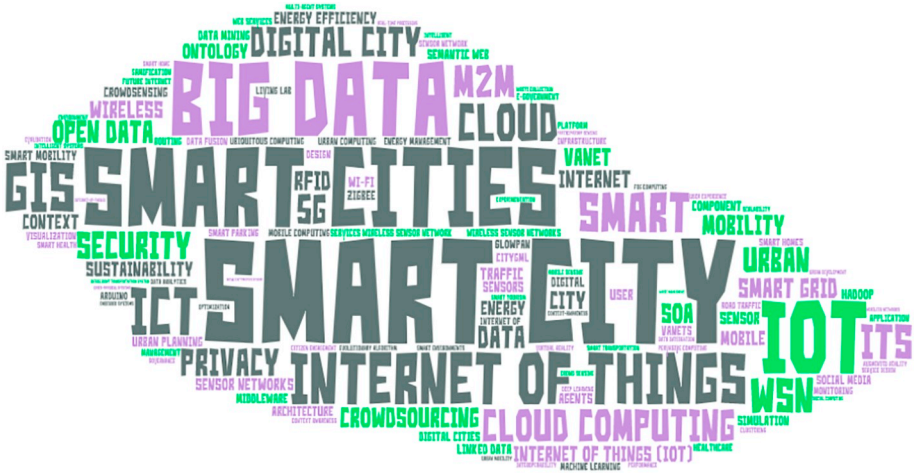


Fig. 8. Smart City word cloud based on author keywords extracted from CS/IT publications indexed by JCR.

Table 3
EU members, CS/IT publications related to Smart city by country (affiliation) and number of smart cities per country.

Country	No. SCs	Contrib.	GDP	Country	No. SCs	Contrib.	GDP
Austria	4	43	47,856	Italy	31	272	36,313
Belgium	4	21	44,881	Latvia	4	3	25,740
Bulgaria	1	1	20,116	Lithuania	1	NA	29,882
Croatia	1	9	22,415	Luxembourg	0	8	101,936
Cyprus	1	3	34,387	Malta	0	NA	37,891
Czech Republic	1	20	33,223	Netherlands	11	41	50,846
Denmark	4	15	46,603	Poland	4	27	27,715
Estonia	1	1	29,502	Portugal	1	56	28,515
Finland	4	30	41,813	Romania	4	29	22,319
France	11	104	42,384	Slovakia	1	8	31,182
Germany	11	118	48,190	Slovenia	1	5	32,028
Greece	1	67	26,809	Spain	31	187	36,451
Hungary	1	6	27,211	Sweden	11	37	49,678
Ireland	1	52	69,375	UK	31	135	42,514

Specifically, the link from the subgroup of Ishida (2002) to the subgroup of Lv (Lv et al., 2016) in Fig. 7a, and the one from the subgroup of Chen (2013) to the one of Ishida (2000) in Fig. 7b.

Table 4 briefly summarizes the top 1% cited publications (according to the JCR) that have at least one link to another publication in the collection related to the hot spot (Figs. 6 and 7). In this particular case, the top 1% corresponds to publications that have at least 30 citations. Therefore, this is a summary of the more influential works in the domain of SC from a CS/IT point of view and offers a unique and fast approach for beginners, general guidelines, and future consults.

All publications listed in Table 4 are *visible* in the main hot spot *neighborhood* (Fig. 6), except for the works of Chen (2013) and Ishida (2002). Both works are *out of the scope* of Fig. 6, due to their relative (long) distance to the rest of publications (van Eck and Waltman, 2010), but are included in Fig. 7.

Table 5 briefly describes the most cited works presented in Fig. 7 that are not introduced in Table 4. Note that none of these belong to the top 1% cited publications (though they belong to the top 5% of most cited CS/IT articles).

At first glance, based on our analysis of the works listed in Tables 4 and 5, we found that most works focus on developing or improving the base technology for SC, especially in IoT. Regarding the domain of application (refer to Fig. 1), most efforts are placed in Smart Environment and Mobility; while Governance and Living are relegated to secondary; and the rest of the domains (Economy and People) are barely mentioned.

Then, we reviewed in detail the most cited works (Table 4) looking for policy and urban planning recommendations. The first thing that gained our attention and concern is the lack of policy or urban planning recommendations in the literature.

For example, considering the top cited publications (Table 4), only 5 out of 16 (i.e., nearly 30%) explicitly gave a policy or urban planning advice (Ishida, 2002; Jin et al., 2014; Kramers et al., 2014; Piro et al., 2014; Sun et al., 2016). While 4 out of 16 give some attention or at least mention the words policy and urban planning (Zanella et al., n.d.; Castro et al., 2013; Djahel et al., 2015; Sanchez et al., 2014). But the most *frightening* thing is that nearly half of the top publications, i.e. 7 out of 16, do not even mention policy or urban planning (Amato et al., 2012; Botta et al., 2016; Chen, 2013; Dobre and Xhafa, 2014; Hu et al., 2013; Karnouskos and De Holanda, 2009; Khorov et al., 2015).

This insight suggests an issue: researchers are not considering the whole context of SC problems. Moreover, researchers might not be considering the real potential of their research, as it can aid policy-makers to improve their work.

We also performed an analysis of the *author keywords* on the 2017 CS/IT snapshot. Specifically, we counted the occurrence of each author keyword (informed by JCR) as is, i.e., without performing any preprocessing. We found that 3560 keywords were used, but only 658 keywords were used more than once. Table 6 shows the top 1% keywords in terms of occurrence and Fig. 8 shows the word cloud[1] of the author keywords.

The domain has started to converge, as we can infer by the use of the keywords 'smart city(ies)' in the vast majority of works (721 times,

[1] Created using https://wordart.com [Accessed: Jan, 2018].

Table 4
CS/IT most cited scientific publications related to Smart City according to JCR.

Reference	Overview	#Cites	Reference	Overview	#Cites
Zanella et al., (n.d.)	Reviews the current available technology for implementing urban IoT and introduces a use case in Italy (collecting environmental data and monitoring the public street lighting)	398	Khorov et al. (2015)	Reviews the Wi-Fi protocol IEEE 802.11ah and its use in smart city context (smart sensors and meters)	44
Jin et al. (2014)	Presents an IoT framework and a case study in Melbourne, Australia (noise mapping)	114	Chen (2013)	Outlines an intelligent system for M2M (machine to machine) communications (for context-aware communication), based on RFID and a IoT architecture	35
Botta et al. (2016)	Reviews the integration of Cloud and IoT	88	Dobre and Xhafa (2014)	Introduces a platform for collecting and aggregating context information on a large scale and a transportation system designed using this platform	35
Sanchez et al. (2014)	Introduces an IoT architecture and tests it in Spain (environmental monitoring, outdoor parking management, parks and garden precision irrigation, augmented reality)	74	Sun et al. (2016)	Promotes the concept of smart and connected communities SCC, where IoT is a key enabler	35
Ishida (2002)	Presents the use case of digital city Kyoto	69	Amato et al. (2012)	Introduces recommendation service integrated with an IoT platform for creating personalized tourist paths within cultural heritage sites	33
Hu et al. (2013)	Introduces a novel mobile cyber-physical system for crowd-sensing applications	53	Castro et al. (2013)	Reviews on the use of GPS information from taxis to understand social and community dynamics	31
Piro et al. (2014)	Presents an "information centric platform for supporting the typical ICT services of a Smart City"	46	Djahel et al. (2015)	Reviews and discusses the future of road traffic management systems	30
Karnouskos and De Holanda (2009)	Creates infrastructure to simulate a smart grid city	45	Kramers et al. (2014)	Discusses about the use of ICT to reduce energy consumption in cities	30

Table 5
Most cited documents related to the secondary spots.

Reference	Overview	#Cites
Lv et al. (2016)	Presents a 3-D virtual representation of Shenzhen City	16
Ishida (2000)	Compares digital city initiatives	15
Aurigi (2000)	Reviews the state-of-the-art of digital city	12
Schuler (2001)	Explores the social presence (particularly the citizenship) within digital cities	11
Van Den Besselaar et al. (2000)	Present reviews of the state of the art in digital cities	8

nearly 11% of all author keywords). On the other hand, it is quite noticeable that the third most frequently used keyword (*internet of things*) is found in three different versions (‘*internet of things*’, ‘*iot*’ and ‘*internet of things (iot)*’). By the distance to the first term(s) it is clear that researchers do not consider this to be a synonym of SC, what is common sense if one analyzes the (narrower) focus on devices of the IoT concept. In the same line, the concept *wireless sensor network* is found in three versions (‘*wireless sensor network*’, ‘*wsn*’ and ‘*wireless sensor networks*’), plus a look-alike keyword (*sensor network*). These lack of consensus impose a challenge to researchers, who have to struggle to include all relevant keywords to perform a complete search. Thus, we envision the importance of having and using an up-to-date common keywords framework, to ease future classification and search.

In line with our previous finding (Section 3.1), just a few publications (15) are tagged explicitly as ‘urban planning’. On the other hand, ‘policy’ is not even a top keyword (Table 6). We dived into all author keywords looking for keywords containing a reference to policy, and we found that 13 publications mentioned the term in some way (policy making, smart city policy, economic policy, among others). Therefore, we conclude that policy recommendation and urban planning are not an actual priority for SC researchers in the CS/IT field.

We also analyze the author keywords of the top publications (refer to Table 4). There are 84 unique keywords. However, only 6 are present in more than one work (Table 7 shows these keywords). Note that we *reduce* similar keywords, e.g., *smart city* and *smart cities*.

At first glance, we notice that there is a strong relation (number and order) between the keywords used both in the top publications and the whole SC literature (maybe the top publications are a proxy of the field). And again, we observed that IoT and Big Data are major players in SC research and that the *experimentation* (Castro et al., 2013; Sanchez et al., 2014) in the real world is of the utmost importance.

To continue our analysis, we measured the *distance* between the most cited publications, i.e., the number of edges in the shortest path of the citation graph (without considering the direction of the edges). Table 8 presents the minimum distance between each pair of publications included in Table 4. The table also presents the **mean** distance from a publication to the rest of the set and the **adj. mean**, which represents the mean distance from each publication excluding the works of *Chen* (Chen, 2013) and *Ishida* (Ishida, 2002) (due to their relative disconnection).

The results presented in Table 8 and Fig. 6 can be interpreted as that there is a strong relationship between the most cited publications, or (in other words) that the leading researchers are *reading* each other and taking into account their ideas and results.

However, when we look at the full picture, i.e., when we consider the whole collection, there is a remarkable fact (that gained our concern): there is a relatively small connection between works. Considering the works classified as CS/IT from the snapshot of 2016 (1126 publications), only 241 publications have a connection with another work in the collection; while 885 works do not have a link (in the collection). Considering the 2017 snapshot, only 726 out of 2067 CS/IT publications have one or more citations (according to JCR), and 416 works have a link within the collection. As a conclusion, there might be a problem in the way that modern research is being done in this domain

Table 6
Most frequently used author keywords in literature regarding Smart City.

Keyword	Count	Keyword	Count	Keyword	Count	Keyword	Count
Smart city	416	Open data	22	Internet	15	Social media	12
Smart cities	305	Smart grid	22	Wireless sensor network	15	Data	11
Internet of things	183	Sustainability	19	Ontology	14	Component	11
Big data	91	Energy efficiency	17	Smart mobility	14	Mobile	11
Iot	82	Gis	17	Context	13	Linked data	11
Cloud computing	75	Ict	17	Semantic web	13	Energy management	11
Smart	54	Wsn	17	Architecture	13	Smart homes	10
Digital city	38	Mobility	16	Urban planning	13	Sensors	10
Security	31	Wireless sensor networks	16	Machine learning	12	Urban computing	10
Cloud	30	M2m	16	Crowdsensing	12	Traffic	10
Crowdsourcing	29	Urban	15	Its	12	Mobile computing	10
Internet of things (iot)	29	Sensor networks	15	Vanet	12	Ubiquitous computing	10
Privacy	25	Wireless	15	Digital cities	12	Simulation	10

Table 7
Hot spot most referenced author keywords.

Keyword	Count	Keyword	Count
Smart city	12	Experimentation	2
Internet of things	8	Mobile agent	2
Big data	2	Network architecture	2

(as in others, by the way), because there is not enough communication or contact between working groups and researchers are not using the published knowledge.

3.4. Outliers

So far we have considered publications with a great number of links in the citation graph to be the hot spots (refer to Table 4). However, there are works that have a large number of citations (in the snapshots) but do not have links (in the data set). Then, we consider that those works might be influential to some given group(s) of interest. We call them *outliers*.

To identify these outliers, we selected the works categorized as CS/IT from both snapshots that belong to the top 1% cited works, in this particular case that have at least 30 citations. Then, we looked for the works that do not have a link to another work in the entire data set (including all categories). In other words, we will look for works that are highly cited but are still not so influential to the SC community.

We found two publications that met the outlier criteria (please refer to Table 9). Both works are SC related studies. However, none of them are cited by works in the collection. Moreover, there is no relation in the topic between these two works and the hot spots (refer to Tables 4 and 5). Many scenarios might have led to this situation. For example, the journals that published these works are not usually read by the SC research community or the topic is in the frontier and there are no works related yet, among others.

An interesting case found in the top 1% is the publication of *Jara* (Jara et al., 2014) (34 cites). It introduces an IoT framework for integrating user sensors into a common infrastructure. This work has no links into the CS/IT collection, but it has links to the rest of the collection (publications that are not classified as CS/IT). This phenomenon might be interpreted as that this work is providing the technical foundations to SC works that are not CS/IT-centric, or that the journal where the work was published is still not very relevant to the CS/IT community working in SC.

Finally, considering that the outliers represent a small percentage of the total number of publications analyzed, we think that our results are valid and representative. Moreover, we believe that they are a good approximation to the major trends in SC research from the CS/IT perspective.

3.5. Limitations of our study

It is clear that every method has its limitations and this study is not an exception. From the reviewing methodology (Vom Brocke et al.,

Table 8
Distance between the CS/IT most cited works regarding Smart City.

First author	Z	J	B	Sa	I	H	P	Ka	Kh	Ch	D	Su	A	Ca	Kr	D
Zanella	0	2	2	2	3	3	6	2	2	8	3	4	6	5	4	2
Jin	2	0	3	2	5	4	7	4	3	11	4	2	3	5	6	4
Botta	2	3	0	4	5	4	5	4	6	7	1	5	6	6	3	4
Sanchez	2	2	4	0	5	5	6	2	2	8	6	5	5	7	6	3
Ishida (2002)	3	5	5	5	0	6	9	5	5	11	6	7	9	8	7	5
Hu	3	4	4	5	6	0	9	6	5	10	5	2	7	8	7	5
Piro	6	7	5	6	9	9	0	8	8	10	4	9	5	11	2	4
Karnouskos	2	4	4	2	5	6	8	0	4	6	5	6	7	7	3	5
Khorov	2	3	6	2	5	5	8	4	0	10	5	5	6	5	6	2
Chen	8	11	7	8	11	10	10	6	10	0	9	12	13	13	9	10
Dobre	3	4	1	6	6	5	4	5	5	9	0	6	5	7	2	5
Sun	4	2	5	5	7	2	9	6	5	12	6	0	3	7	6	6
Amato	6	3	6	5	9	7	5	7	6	13	5	3	0	8	3	7
Castro	5	5	6	7	8	7	11	7	5	13	7	7	8	0	9	5
Kramers	4	6	3	6	7	7	2	3	6	9	2	6	3	9	0	6
Djahel	2	4	4	3	5	5	4	5	2	10	5	6	7	5	6	0
Mean	3.6	4.3	4.3	4.5	6,4	5.7	6.9	4.9	4.9	9.8	4.9	5.7	6.2	7.4	5.3	4.9
Adj. mean	2.9	3.3	3.5	3.7	NA	4.6	5.6	4.2	3.9	NA	3.9	4.4	4.7	6.0	4.2	3.9

Table 9
Publications classified as outlier during the analysis.

Reference	Overview	#Cites
Wellman (2001)	Analyzes how social relations have changed over time and the effects of these changes on the future design of the digital cities	52
Ratasuk et al. (2015)	Outlines the requirements for M2M fifth generation (5G) communication systems	36

2009) to the summarizing technique, every decision made change the outcome of the analysis. However, by doing the review in a structured and documented way, we try to alleviate this problem or at least ease the reproducibility of the study.

Among the decisions made in this survey, maybe the most noticeable one is the selection of the search keywords. For example, if we search for articles indexed by JCR that were published before 2016 and include the terms 'smart city' or 'smart cities' in the topic or title, there are 797 hits. If we add the terms 'digital city' and 'digital cities' to the search query, there are 996 hits. Then, by adding the terms 'intelligent city' and 'intelligent cities' we get 1042 articles. Finally, we included the terms 'eco city' and 'eco cities' and we obtain 1164 hits.

As expected, as we add search terms, the number of articles increases. On the other hand, not all the keywords have the same importance, i.e., some of them are used more often than others. Taking into account the relative importance of each term and the consensus among SC literature of treating 'smart' and 'digital' city as synonyms (Manville et al., n.d.; Cocchia, 2014), we think that the bias introduced by our decision does not significantly alter the outcome of the analysis.

Another important decision made was to use the density map and the citation graph to derive the major trends. This issue recalls to the definition of the scope 2.1 and the taxonomy of Cooper (1988). We might have chosen to present the results historically. Then, we might have used a tree to organize the publications, where the root could have been the first SC work. Surely, the result in this scenario is very different, but again, this difference does not invalidate the point of view of our study.

In spite of these limitations, the results presented in the study still constitute a broad and objective approach to the SC research literature from CS/IT perspective. Moreover, the insights of the analysis are useful for highlighting trends and areas that need *attention* (i.e., domains of SC that might need a deeper study).

4. Conclusions

In this work, we have presented a systematic analysis of the state-of-the-art of SC from the perspective of CS/IT. Particularly, we used a methodology that enables the reproduction and (partial) automation of the analysis, and we repeated the analysis over two consecutive years (2016 and 2017).

We analyzed all SC publications (articles and proceeding papers) indexed by JCR related to SC and identified the major trends in the study of the field by analyzing the density map and the citation graph. The results showed that CS/IT is a major contributor to SC research and that SC research is rapidly gaining attention worldwide.

Like the majority of SC reviews highlight, the results of this work showed that there is no consensus in the definition of SC; indeed, there are many working definitions. There are multiple explanations for this, maybe a Smart City is not a conceptual object, a goal or a status. Or maybe it is an iterative procedure where cities get smarter in time. Whatever it might be, most definitions encompass the same concepts of a holistic vision of subfields, importance of CS/IT, citizens as the main target, open data, and sustainability.

The analysis of the citation graph shows that the majority of the publications in the collection do not have citations (according to the statistics of JCR), neither references (links) to the rest of the works in the same field (considering the publications in the same snapshot). Therefore, we might consider SC itself to be still work-in-progress, and with our survey, we hope to contribute to help convergence.

As part of this work, we analyzed the economic, practical and research perspective of the SC in EU (Manville et al., n.d.; International Monetary Fund, 2016). The results showed that the wealthiness of a country is not directly related to the development of the SC and, as pointed out by other studies (Manville et al., n.d.; Neirotti et al., 2014), it seems to be a context-dependent issue. However, further study has to be carried out to reveal the key factors.

We studied the inclusion of policy and urban planning recommendations in the CS/IT literature. The results showed that only a few publications explicitly tackle this issue, while the majority of them do not even consider it. Therefore, we encourage the research community to face SC problems as a whole and to consider that their research can (and should) be input for policymakers and city authorities. On the other hand, as other SC reviews state (Cocchia, 2014; Neirotti et al., 2014), we urge the city policymakers to use SC research output to adapt the actual policies.

The analysis of the major trends showed that most of the work done could be classified as Environment and Mobility applications, while Governance and Living are relegated to a secondary place. The rest of the SC domains (People and Economy) are barely mentioned, even if they have paramount importance. The results also showed that the technological focus is at present on enabling technologies, like the Internet of Things and Big Data. We believe that in the future the cyber-physical systems and the intelligent applications will give a meaning to the smart part in SC.

Finally, in this study, we present a comprehensive perspective of SC from CS/IT point of view, based on data and calculated metrics. Therefore, we believe that this study constitutes a useful single entry point for everyone who wants to introduce in the topic.

As future work, to alleviate the frontier bias, we propose to broaden the search to Google Scholar or other databases. And even more important, we propose to repeat this analysis but considering all SC disciplines, aiming to obtain a holistic approach of the domain.

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