Studies on Smart Cities

Subjects: Management
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The concept of smart cities has gained significant momentum in science and policy circles over the past decade. This study aims to provide an overview of the structure and trends in the literature on smart cities. Bibliometric analysis and science mapping techniques using VOSviewer and CiteSpace are used to identify the thematic focus of over 5000 articles indexed in the Web of Science since 1991. In addition to providing insights into the thematic evolution of the field, the three-decade study period is divided into two sub-periods (1991–2015 and 2016–2021). While splitting the dataset into more sub-periods would have been desirable, we decided to only examine two sub-periods as only very few papers have been published until 2010. The annual number of publications has progressively increased since then, with a surge in the annual number of publications observable from 2015 onwards. The thematic analysis showed that the intellectual base of the field has been very limited during the first period, but has expanded significantly since 2015. Over time, some thematic evolutions, such as further attention to linkages to climate change and resilience, and more emphasis on security and privacy issues, have been made. The thematic analysis shows that existing research on smart cities is dominated by either conceptual issues or underlying technical aspects. It is, therefore, essential to do more research on the implementation of smart cities and actual and/or potential contributions of smart cities to solving societal issues. In addition to elaborating on thematic focus, the study also highlights major authors, journals, references, countries, and institutions that have contributed to the development of the smart cities literature.

Keywords: smart city ; internet of things

1. Introduction

There are indications that the concept of smart cities emerged as early as 1974, when the city of Los Angeles attempted to create the world's first urban big data project [1]. However, it is after 20 years (1994) that a major milestone in the smart sities pursuit occurred in Amsterdam, when a virtual 'digital city' was created with the purpose of promoting internet usage among local populations [2]. Since then, there have been extensive research and attempts to create smart city digital infrastructures, with large ICT corporations, such as Cisco and IBM, taking the lead [3][4], especially in research and development. For instance, in 2008, IBM launched the 'IBM Smarter Planet', with an aim to investigate and test how applying sensors, networks, and analytics to different urban fabrics can render more performance and, as a result, identify business opportunities. The success of this program led to the corporation unveiling the USD 50 million smart cities campaign in 2009, aimed at helping cities reach efficiency and performance, while overcoming some contextualized urban challenges [5]. After the widespread application of technology in diverse urban spheres, this concept, in 2011, gained ground in acceptability with different cities in developed economies, with the city of Barcelona leading the way [6]. While the smart cities program today (2021) is still gaining a rapid adoption rate, there is no universally agreed definition as to what constitutes a smart city [4][7][8]. However, one agreed commonality is the ability to assist planners and municipal authorities in taking more effective actions towards achieving higher efficiencies and performance in different frontiers, with the expected outcome being improved liveability status, increased inclusivity, and fostering of sustainability agendas, amongst others [9][10]. It is, therefore, obvious that smartness is a multi-dimensional concept and a combination of both hard infrastructure (i.e., technology-based) and soft infrastructure (i.e., regulations, knowledge economy, citizen participation, social and institutional innovation, data management, etc.) is essential for building smart cities.

The increasing acknowledgement of the multi-dimensional nature of the smart city concept has led to a paradigm shift from a technology-based approach to more holistic approaches that recognize the central role of social, economic, and institutional forces. Indeed, the impacts of the smart city concept in different urban dimensions have been mainly viewed positively, especially in prompting transformative changes in urban infrastructures such as institutional, physical, social, and economic infrastructures. The groundbreaking outcomes of the smart city concept have led to the emergence of other concepts such as the 'Safe City' concept [11], and the latest one being the '15-Minute City' concept [12], which are seen to utilize the foundation of smart city concept in varying ways. The emergence of these technology-based planning concepts has in turn led to a boom in software and hardware products that aim to tap into an emerging digitally inspired market

estimated to be between USD 83.9 billion [13] and USD 410.8 billion [14], according to different market research firms. However, due to increasing demand for different digital products, the market is expected to expand to reach over $297.7 billion [13] and USD 820.7 billion by 2026 [14]. Other market research firms, such as Mordor Intelligence, value the smart cities market even higher at USD 739.78 billion as of 2020 and expect it to experience a Compound Annual Growth Rate (CAGR) of approximately 18.22%, to reach a market value of approximately USD 2.0361 trillion by 2026 [15]. This showcases that, even though there are discrepancies on the expected value of smart cities, there are commonalities on their substantial worth and shared trust on their growth potential.

As with the smart cities market increase, the market for technology products, especially relating to the Internet of Things (IoT) based devices has also been seen to increase. It is reported to have reached approximately USD 250.7 billion by 2019, but due to market developments, the market size is projected to expand to above USD 1.46319 trillion by 2027; a 24.9% CARG during the projected period [16]. While these market figures are encouraging, especially from an economic point of view, they also raise alarms, especially on the observable and perceived trends where the urban areas are morphing into cold mechanical elements, thus undermining humanistic and liveability aspects in cities [9]. Such urban characteristics have been argued to being driven by profit-oriented agendas by different companies: both small and big, eyeing the expanding market. The mechanical nature of how cities are turning has not gone unnoticed, as already, there is an increasing pool of literature that is focusing on the need to have cities include ‘soft’ approaches as a core dimension of the urban planning concept. Such calls even emanate from UN-Habitat, that, despite supporting new urban planning models, advocates for ‘People-Centered Smart Cities’ [17], which would ultimately lead to a win-win situation where both companies and corporations are able to benefit, just as well as urban dwellers- from improvements in different urban fabrics.

Such benefits are already being enjoyed by residents and companies that have invested in cities such as Barcelona [6], London [18], Amsterdam [19], Songdo [20], Hangzhou [21], and numerous others in varying geographies, which have already embraced and implemented some aspects of smart cities concept. Coupled with the development of new technologies supporting the concept, it is expected that more smart cities will continue to emerge in the coming years. In the academic sphere, both existing and emerging smart cities are spurring a surge in literature touching on the global discussion on smart cities across a range of themes including governance [22][23], liveability [24][25], safety [26][27][28], economic performance [29], mobility [30][31], health [32], culture [4], education [33], communication infrastructures [34], energy [35], and others.

Along with the increasing interest in smart city development, the number of academic articles published on smart cities has also grown rapidly over the past two decades. In the past few years, several review articles have been published that have improved our understanding of the state of development of the smart cities field and have highlighted key successes and challenges. According to these studies, while the smart city concept is hailed for its transformative prospects on the urban planning sphere, there are notable issues that must be streamlined. Camero and Alba [36] note that one such issue is the lack of a universally agreed definition and the scope of the same. They argue that the lack of unanimity in the definition has led to research on the concept being built in a wide array of silos depending on the understanding of those conducting the research. This argument is affirmed by Cocchia [37] who highlights that a number of terminologies such as the Intelligent City and Digital City have been used to depict the technological foundations of urban concepts, without properly linking them to the broader smart city concept. The point by Camero and Alba [36], on creation of application silos, is seen to align with the proposition by Ruhlandt [38], supporting that research on smart cities is hampered by lack of understanding of various components such as smart governance, technological application, and the metrics adopted as yardsticks for those components. Without any explicit understanding of the components and metrics, it becomes problematic in determining the expected outcomes, and, as is expressed by Pereira et al. [39], this leads to researchers concentrating on specific components rather than generally focusing on the entirety of the smart city concept. To overcome these challenges, several efforts have been made to provide metrics for assessment of different smart city aspects and dimensions [40][41]. On their end, Talari et al. [42] note that concentrating on specific aspects of the smart city concept would have far reaching implications in respect to philosophical approaches and perspectives about the concept’s implementation, especially in different regions and in different sectors. Focusing on specifics in the smart city concept would also be impacted by time as already technological advancements are emerging fast and in diverse sectors. This, then, has a bearing on the research in the present paper, especially in relation to increasing publications, covering a diverse set smart city dimensions, raising the challenge and need for regular reviews.

While traditional reviews are essential for detailed understanding of research fields, they are not always suitable to keep up with the rapid pace of scientific publishing, especially in popular fields such as sustainability or smart city development. This issue can be partially solved by using science mapping and bibliometric analysis techniques that allow the collection of overall understanding of knowledge structure and trends using advanced text-mining methods [43]. In this way,

bibliometric analysis studies can complement traditional systematic reviews. There are several generic bibliometric studies on smart cities research [44][45][46][47][48][49][50][51]. These studies have improved our understanding of the overall landscape of the field, and interestingly point out similarities between some concepts, particularly regarding the 'intelligent city', and the 'smart city'; where the former focusses on systems design, without necessarily engaging in heavy utilization of technology. Smart cities, on the other hand, approach systemic design by supporting a technological foundation. In addition, smart cities follow a more comprehensive approach that, in addition to technological focus, acknowledges the significance of people, economy, and institutions. There are also several bibliometric studies focused on specific issues such as governance of smart cities [52], smart city applications in the building and construction sectors [53], relationship between smart cities and migration [54], and smart city indicators [55].

2. Three Decades of Research on Smart Cities: Mapping Knowledge Structure and Trends

2.1. Publications Trends

Figure 1 displays the distribution of the 5722 publications over the study period (1991–2021). The results show that there is an overall growth in the number of publications per year. It is clear that this is still a young field, as most papers have been published over the past 10 years or so. In fact, only 17 papers have been published between 1991–2010, accounting for less than 1% of the documents in the database. In the following 5 years, 429 papers have been published, indicating that 'smart cities' has become a mainstream research topic since 2010. From 2015, however, a rapid growth pattern can be observed. In particular, the growth pattern has been exponential since 2018. Interestingly, the number of articles published over the past three years is greater than the cumulative number of articles published between 1991 and 2018. As explained in the Introduction, this is a clear indication of the increasing recognition of the significance of smart cities for dealing with multiple challenges that cities around the world are facing and have been highlighted in major policy documents such as the New Urban Agenda and the Sustainable Development Goals (SDGs). Based on this, an upward trend in publications on smart cities is expected for the coming years.

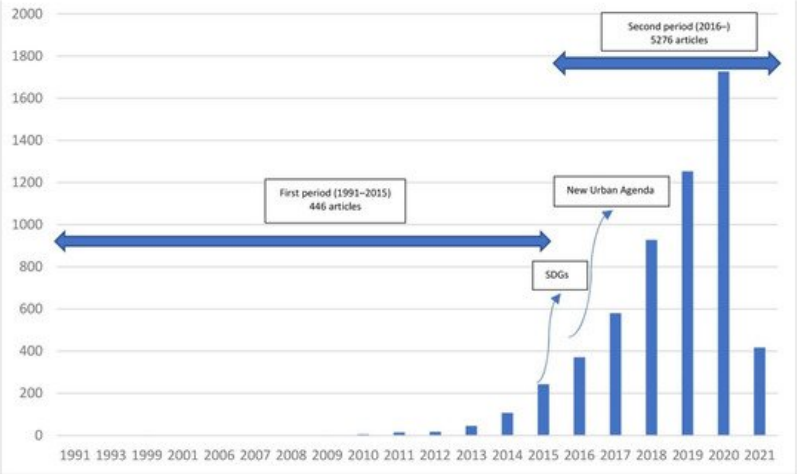

Figure 1. The number of articles published per year. Note that the lower number of articles in 2021 is as the literature search for the purpose of this paper was done in early 2021. An upward trend is expected for 2021 and the following years.

2.2. Thematic Focus Areas and Their Transition

2.2.1. Thematic Clusters

The output of the term co-occurrence analysis for the entire dataset is shown in **Figure 2**. Three major clusters can be identified from this figure. These are: (1) the smart city concept, depicted by the color red, (2) big data analytics, represented by the color blue, and (3) the technological aspects, especially in relation to Internet of Things, depicted by the color green. The link's thickness between nodes indicates strength of connection, while the size of the node is directly proportional to the term frequency. Therefore, as is clearly depicted in the diagram, the most dominant clusters were the smart city and the IoT. The other cluster that is mainly focused on the application of big data analytics and other smart solutions (e.g., machine learning, deep learning, etc.) in the energy sector has received relatively less attention.

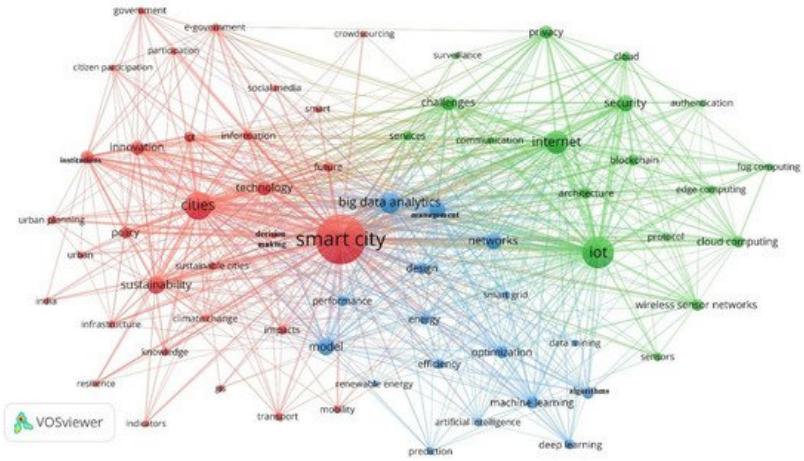

Figure 2. The output of the term co-occurrence analysis for the whole study period (1991–2021).

The Smart City Concept Cluster

This co-occurrence analysis, shown in **Figure 2**, showcases that most of the literature in respect to the smart city is centered around the concept itself, with much attention given to the broader urban context [32][33][36][38][56] and how those have been influenced by technology application and adoption (red cluster). The literature on this concept also centered on how cities have been striving to achieve sustainability [25], more so after the high level global meetings that culminated in diverse accords and agreements such as the Paris Agreement, SDGs, the New Urban Agenda, and others. The dominance of the term ‘sustainability’ in this cluster is not surprising considering that a lot of research on smart and sustainable cities has been published in the past few years, demonstrating how smart solutions can contribute to solving issues related to various social, economic, and environmental dimensions of sustainability (e.g., see [57][58]). The analysis also shows that, in the smart cities literature, the term ‘cities’ has been frequently used in conjunction with other terms such as ‘innovation’ [59][60][61], which relates closely with the application of technology, and in the pursuit of sustainability [8][12]. Other terms that were researched in conjunction with cities include ‘policy’, showcasing a drive from researchers in understanding how policy frameworks impact on issues such as urban planning, infrastructure development, initialization of innovative programs, and others. Other terms that occurred in this cluster include ‘mobility’ and ‘transport’, showing that the transport sector is crucial in the whole agenda of making cities smarter. In fact, along with the energy sector, transportation has been one of the major sectors in which applications of smart city technologies have been studied [62]. Further, terms such as ‘e-government’ and ‘citizen participation’ have also appeared, especially in relation to ‘innovation’ and ‘information’, showing that researchers are keen to understand governance dimensions of smart cities, though not many recognize and appreciate the intricate roles and the dynamics of governments and citizens in the actualization of smart city agendas [63][64][65][66][67][68]. There are also some other terms, such as ‘indicators’ and ‘Geographic Information System’ (GIS) that, comparatively, have occurred less frequently. In the recent years there has been an increasing focus on developing and implementing smart city assessment tools and indicator sets. Among other things, such tools and indicators contribute to better informed decision making regarding smart cities and evaluate their contributions to other societal goals, such as sustainability and resilience [69]. Similarly, it is increasingly recognized that GIS technologies are essential for effective development and implementation of smart cities and, generally, for better-informed urban planning [70]. For instance, platforms enabled by real-time GIS enable acquiring, storing, processing, and visualizing large amounts of geospatial data in an efficient manner [71]. Such platforms can facilitate enhanced modeling of urban operations, enable better informed and more timely decision making, and improve the efficiency and safety of various sectors such as urban transportation [71].

The Internet of Things Cluster

This cluster (depicted in **Figure 2** in green) showcases a drive by researchers to understand the influence of technology at varying levels of the smart city concept. From **Figure 2**, it is clear that that most of the research has been on the topic of ‘IoT’ [72][73][74], with most of the articles being centered on the influence of the ‘internet’ on the concept. The research on ‘IoT’ is interestingly seen to touch on different aspects of a city, such as financials [75][76], smart devices [77], the security of such devices [78][79][80], and many others. As far as the internet is concerned, it is clear that this term had two major thematic focus areas. One focuses on ‘security’ aspects and how they impact on the adoption of smart devices in cities. Associated research is seen to be closely related to terms such as ‘authentication’ and ‘surveillance’. It is apparent that there are notable ‘security’ concerns in regard to IoT, with themes linking to the issue of ‘privacy’ surging [66][68], generating substantial attention in terms of number of publication and citations.

The second thematic focus area that attracted some publication traffic, as shown in **Figure 2**, is ‘challenges’, in the application of internet aspects in smart cities. This is particularly seen to have been researched in conjunction with internet security and privacy, indicating that it is a main concern, and part of the obstacles that researchers perceive to have the potential to derail the successful implementation of smart city concepts. The term ‘infrastructure’ also appears in this cluster, depicting that researchers were interested in understanding the intricate matters of how the internet infrastructure was rendered to facilitate application of IoT technology [81][82][83]. Another term that is seen to have received considerable attention is ‘blockchain’, especially in regard to security [84]. The presence of this term in this cluster is timely, as this technology is seen as the future of security [85][86], especially in regard to issues such as contracts [87][88], computing [85][89], and in enhancing privacy [85][90]. Other terms that appear in this cluster but seem to have received, relatively, less attention include ‘sensors’, ‘fog-computing’, ‘authentication’, and ‘edge computing’, among others.

The Big Data Analytics

This cluster (indicated by blue in **Figure 2**) is seen to be less dominant in respect to the smart city concept as per this co-occurrence analysis. The term ‘big data analytics’, however, has co-occurred frequently with other terms and has a central position in the figure. This is not surprising considering the significance of big data analytics for smart city operations [91]. This cluster seems to be specifically focused on the applications of smart city products in the energy sector. In conjunction with the term ‘big data analytics’, are terms such as ‘networks’, ‘models’, and ‘design’ that appear to have been frequently researched in respect to this topic. These terms are also seen to appear in the edges of both the smart city cluster and the IoT cluster, highlighting their nature as overarching terms [92][93]. Among the terms that appear to have been researched in respect to big data analytics also include ‘smart grid’, ‘optimization’, ‘efficiency’, and ‘renewable energy’. These are not surprising, as the current, and probably future debate and trends in the energy sector are expected to be on renewable energies [94][95], and how those can be enhanced through the use of technology to increase efficiency. In respect to ‘optimization’, terms such as ‘machine learning’, ‘deep learning’, ‘data mining’, and ‘artificial intelligence’ are seen to have received some search attention, but in a relatively limited way. While these are at the edges of the three clusters, the, relatively, limited research and literature on them is surprising, as they are among some of the enablers of IoT technologies [96][97], showcasing a gap in the literature.

3.2.2. Thematic Focus Transition over Time

To explore the thematic focus transition, we divided the dataset into two sub-periods and conducted separate term co-occurrence analyses for each period.

First Period (1991–2015)

Although the concept of ‘smart cities’ can be noted as early as the 1980s, it did not gain considerable attention until after the fourth revolution (early 2000). This is evident in the co-occurrence analysis map (**Figure 3**) for the period between 1991 and 2015, where the frequency of many terms relevant to the smart city concept is seen to be low. Additionally, the list of keywords with citation bursts (**Figure 4**) shows that during this period, topics related to precedent concepts such as ‘intelligent city’ have still been dominant. This indicates that, though there have been some interests by researchers, the level of understanding of smart cities was still in its infancy stage. During this period, the main focus and publications were on general application of smart technologies in cities, with most of the literature touching on issues such as policies, transport, innovation, performance, model, growth, institutions, and knowledge. Other terms appearing in respect to cities include climate change, and Information and Communications Technology (ICT). This is understandable, especially in relation to climate change, as the importance of urban actions for tacking climate change was widely recognized in this period, following the publication of the 4th and 5th assessment reports of the Intergovernmental Panel on Climate Change (IPCC), in 2007 and 2014, respectively [98][99]. The importance of cities was further recognized with the ratification of the Paris Agreement [100] and the birth of the Sustainable Development Goals (SDGs) towards the end of this period [101]. In conjunction with climate change, it is evident that research attention and publications were drawn to the issue of ICT and innovation as some of the possible dimensions where solutions, especially in regard to sustainability, could be drawn; hence, publications on these topics started to gain some prominence.

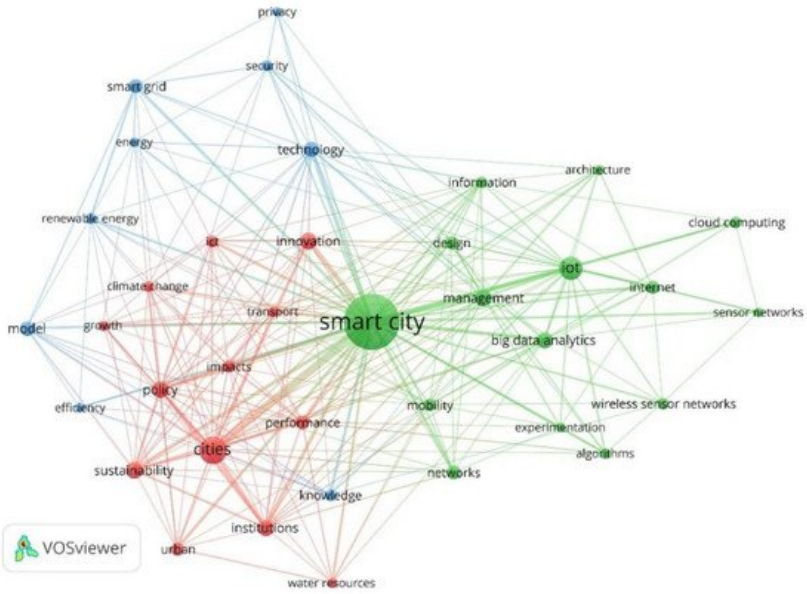

Figure 3. The output of the term co-occurrence analysis for the first period (1991–2015).

Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	1991–2015
intelligent city	1991	0.87	**2009**	2015	
access control	1991	1.07	**2012**	2013	
cloud computing	1991	0.86	**2012**	2012	
cities and town	1991	2.39	**2013**	2013	
internet	1991	1.79	**2013**	2013	
road	1991	1.19	**2013**	2013	
human factor	1991	1.19	**2013**	2013	
sensor network	1991	1.19	**2013**	2013	
data model	1991	1.19	**2013**	2013	
sensor	1991	1.07	**2013**	2015	
design	1991	0.99	**2013**	2013	
wireless sensor network	1991	0.99	**2013**	2013	
privacy	1991	0.89	**2013**	2013	
crowdsourcing	1991	0.89	**2013**	2013	
security	1991	0.78	**2013**	2015	
experimentation	1991	1.53	**2014**	2015	
smart environment	1991	1.02	**2014**	2015	
mapreduce	1991	1.02	**2014**	2015	
strategy	1991	1.02	**2014**	2015	
network architecture	1991	1.02	**2014**	2015	
context-awareness	1991	1.02	**2014**	2015	
citizen sensing	1991	1.02	**2014**	2015	
case study	1991	1.02	**2014**	2015	
intelligent service	1991	1.02	**2014**	2015	
smart grid	1991	0.75	**2014**	2015	

Figure 4. Top 25 keywords with the strongest citation bursts in the first period. Bold format represent the year.

In respect to technology as an enabler of smart cities, it is evident that attention was consolidated on issues such as security, innovation, and policies. It is evident that within the period 1991–2015, the concept of smart city started to attract attention in many intellectual quarters, though the internet employment in different urban fabric was still in infancy. Therefore, considerations to issues of security, especially in regard to data and surveillance, is noted to be prevalent in the civic realm. In addition, it is evident from the analysis that most technologies were being directly focused on the energy sector, though the number of publications in regard to the same are still limited, and key words such as ‘smart grid’ and ‘renewable energy’ were not attracting much attention from academia. Another area of noted interest during this period is the Internet of Things. This topic was very relevant during this period, as most of the emerging technologies that could help actualize the smart city concept were hinged on it. For this reason, most of the publications on IoT are seen to have focused on other sub-cluster terms such as ‘big data analytics’, ‘internet’, ‘management’, and ‘design’. During this period, considering that smart devices need to communicate with each other, terms such as ‘information’, ‘architecture’, and ‘sensor network’ were seen to have started gaining some consideration amongst researchers, but in limited scale. For instance, there were very few publications and interest on issues such as ‘cloud computing’, ‘sensors’, and ‘wireless

sensors networks', and this could be attributed to the fact that those technologies had not gained substantial traction by then.

Second Period (2016–2021)

This period, as depicted in **Figure 5**, has witnessed an explosion of publications on all the three main clusters. As explained earlier, publication of international policy frameworks and their emphasis on smart solutions may have contributed to this increased attention to smart cities research. The IoT cluster has seemingly gained more attention in this period. Attention in this cluster is seen to have focused especially on the sub-cluster 'internet', which is seen to have attracted further research in new terms such as 'challenges, 'protocol', and 'cloud'. These terminologies may have emerged with the realization that IoT enabled devices need to communicate in a standardized protocol to aid in the seamless collection of data, and further, relaying back the insights after analysis of data to relevant parties for better urban management [92]. During this period, it is observable that the term 'energy' is still a key term that is strongly connected to the term 'optimization'. This may indicate the increasing use of smart solutions for enhancing operational efficiency of energy systems. Attention to energy is not surprising, given that energy sector plays an essential role in addressing key challenges highlighted in policy documents such as SDGs and the New Urban Agenda. In addition, several other key terms such as 'machine learning' and 'deep learning' have appeared in this cluster and gained even a stronger position than 'energy'. This may indicate that, though energy-related issues are dominant in the global agenda, they have been overtaken by other research areas in respect to IoT technologies, leading to the understanding that research interests and global conversations moved towards how to utilize the concept across an array of other fields, hence leading to the need for the development and deployment of the data and technology infrastructure.

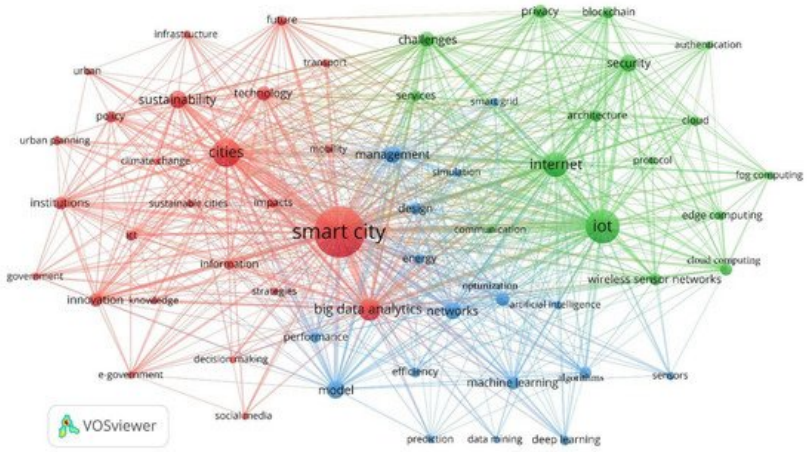

Figure 5. The output of the term co-occurrence analysis for the second period (2016–2021).

In respect to data management, it is clear that during the second period (**Figure 5**), there has been increased attention on areas such as big data [35][102][103] and computation, especially in relation to climate change [104][105] and others become apparent. Interestingly, there is a perceived focus on addressing to climate change [8][10][104][105][106]. The significance of 'big data' in the second period is also evident from the citation burst analysis (Figure S1 of the Supplementary Materials). The importance of data in the management of the smart city may also have triggered the explosion of research and publications in this cluster, with new terminologies such as 'artificial intelligence', 'optimization', 'simulation', 'efficiency', 'prediction', 'deep learning', 'machine learning', and 'performance' gaining traction. The emergence of these new terms shows how much attention has been given to data management, and the advancement in technology regarding the analysis of data that is continuously being produced in, and by, smart cities. Data management and big data analytics are expected to gain further momentum in the post-COVID era. In fact, there are arguments that the recent pandemic has increased interest in big data analytics and smart city development [107].

In respect to the smart city cluster, this second period is observed to have experienced numerous publications, not only touching on cities, but also on the relationship between cities, data, and IoT. However, in respect to cities, and with the growing number of smart cities [108][109][110], it is evident that researchers were and continue to be interested in areas such as sustainability, governance, technology, policies, and the impacts of the same. Those areas of interest are some of the new emerging frontiers that the literature has gained during this timeline. However, some topics, such as institutions and their influence in achieving 'smartness', are seen to continue attracting more attention, even in the second period. Further, other areas that seem to have remained pertinent since the emergence of the smart city concept, as captured in **Figure 4** and **Figure 5** above, include the transport sector where, in the second period (**Figure 4**), researchers are seen to have concentrated more on mobility, especially due to emergence of technology-enabled services such as ridesourcing [111],

smart cars [31][111][112], and new concepts such as the 15-min concept [12] which emphasizes the reducing of vehicular use by giving precedence to cycling and walking due to reduced proximity between different urban essentials.

2.3. Influential Sources

The co-citation analysis was used to find out which journals have had the highest impact in the development of the field. Again, the size of the nodes is proportional to the number of citations, and link width is proportional to the strength of connection between two nodes. Quantitative details related to the citation count and total link strengths of the top 20 journals can be found in Table S1 of the Supplementary Materials. Results show that journals such as IEEE Access, Cities, IEEE Internet of Things, Lecture Notes in Computer Science, IEEE Communications Magazine, Future Generation Computer Systems, and Journal of Urban Technology have had higher influence. Three major clusters can be identified from the results of the co-citation sources analysis, as shown in **Figure 6**. The largest cluster (green) includes journals that are mainly focused on Internet of Things (IoT) and other technical issues (e.g., related to internet, cloud computing, architecture of smart cities, and wireless networks, etc.). This relates to the green cluster (The Internet of Things cluster) in **Figure 2**. As expected, electrical engineering journals and in particular those published by Institute of Electrical and Electronics Engineers (IEEE) have played a significant role in advancing the underlying technical issues of smart cities. The most prominent journals of this cluster are IEEE Access, IEEE Internet of Things Journal, Lecture Notes in Computer Science, IEEE Communications Magazine, Future Generation Computer Systems, and Sensors.

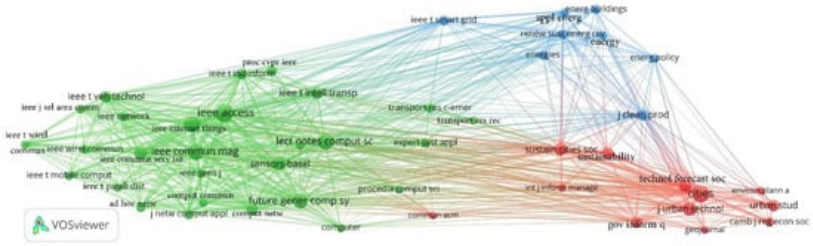

Figure 6. The most influential journals contributing to the development of smart cities literature.

The second largest cluster (red in **Figure 6**) is primarily composed of urban planning and policy journals. This cluster relates to the red cluster (the smart cities topic cluster) in the thematic cluster analysis (**Figure 2**). Results show that urban planning and policy issues have mainly been addressed by journals such as Cities, Journal of Urban Technology, Sustainable Cities and Society, Sustainability, and Urban Studies.

The third cluster (depicted in blue in **Figure 6**) is dominated by journals focused on energy-related issues. This corresponds to the blue cluster in **Figure 2** that is focused on topics such as ‘energy’, smart grid’, ‘optimization’, ‘efficiency’, and ‘renewable energies’. Once again, this shows the specific attention of the smart cities literature to energy-related applications. The most influential journals of this cluster include Journal of Cleaner Production, IEEE Transactions on Smart Grid, Renewable & Sustainable Energy Reviews, and Energy and Buildings.

2.4. Major Contributing Countries and Institutions

In order to identify the most prominent countries that have contributed the most to the knowledge in the field, a bibliographic coupling analysis was conducted. The results are shown in **Figure 7**. The list of the top 20 most prominent countries with the number of documents, number of citations, and total link strength is presented in Table S2 of the Supplementary Materials.

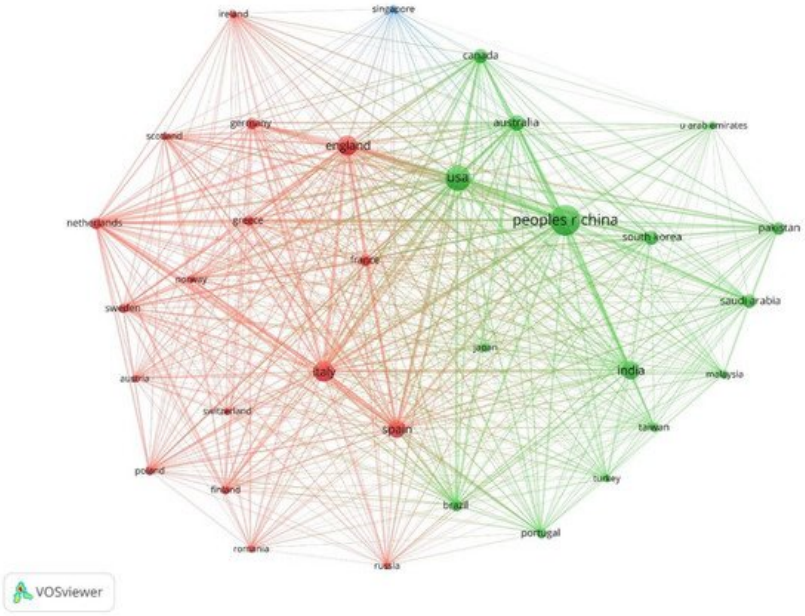

Figure 7. Countries that have made significant contribution to the development of the smart cities literature.

It is noted that countries such as China, USA, Italy, England, India, Spain, Australia, South Korea, and Canada have published more on this topic. These countries also rank high in terms of the total number of citations. Examples of highly cited papers from the top 10 countries are shown in **Table 1**. Interestingly, while developed countries have contributed more, several developing countries have also been highlighted in the figure, showcasing that there is a global adoption of the concept, irrespective of GDP and development status.

Table 1. The top-10 countries contributing to smart cities research and examples of their highly cited publications.

Country	Affiliation of the First/Corresponding Author	Example of Highly Cited Publication
USA	**University of Chicago**	[113]
Italy	**University of Padova**	[114]
China	**Dalian University of Technology**	[115]
England	**University of Westminster**	[116]
Spain	**University of Cantabria**	[117]
Australia	**Swinburne University of Technology**	[118]
Canada	**Ryerson University**	[119]
The Netherlands	**Vrije Universiteit Amsterdam**	[120]
South Korea	**Yonsei University**	[121]
India	**National Institute of Technology Allahabad**	[122]

However, there are many countries, particularly from Africa and Asia that are missing. The clusters shown in **Figure 7** indicate that there is a close collaboration among countries that are geographically proximate. For instance, the red cluster primarily includes European countries (England, France, Italy, Spain, Germany, and Greece), while the green cluster includes a broader range of countries from Northern America (USA, Canada) to Asia (China, South Korea, India, Japan, Saudi Arabia, and Pakistan).

The bibliographic coupling analysis was also used to find out which countries are in the forefront of the field. **Figure 8** shows that universities from Italy, the US, China, and Saudi Arabia have contributed more to the development of the discourses in the field. Those are universities such as Polytechnic University of Milan, University of Naples Federico II, King Saud University, MIT, Chinese Academy of Sciences, and Huazhong University of Science and Technology. The list of the most prominent organizations with the number of documents, number of citations, and total link strength is presented in Table S3 of the Supplementary Materials.

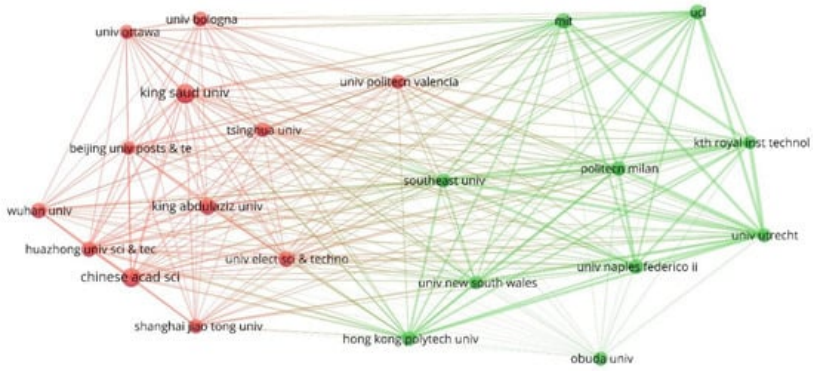

Figure 8. Organizations that have made significant contributions to the advancement of the field.

2.5. Influential Documents

The co-citation analysis was also used to identify the most prominent publications in this field. The output of co-citation analysis by cited references is shown in **Figure 9**. The top 20 most cited references are shown in Table S4 of the Supplementary Materials. It should be noted that this list is not exhaustive, and other influential documents also exist that have not been included in order to ensure readability of the figure (e.g., [123]). This analysis shows that there are three clusters of the most prominent publications (red, green, and blue). The red cluster includes studies primarily focusing on the main core concepts, definitions, and trends of smart cities (e.g., [119][120][124][125][126][127][128]). This cluster associates with the red cluster (the smart city concept cluster), identified in Thematic analysis in Section 3.2. The majority of the influential documents in this cluster include studies that are primary resources of the smart cities literature in the first period (1991–2015). Obviously, given their focus on fundamental smart city concepts, they have played important roles in guiding smart city research. The second largest cluster depicted by blue color, is mainly comprised of studies focused on the implementation and realization of smart cities. These cover various issues such as success of smart city programs in achieving their (utopian) goals [129][130][131], utilities of big data analytics for improving socio-economic and governance mechanisms in cities and enhancing operational efficiency [132][133], weaknesses that need to be addressed [130], corporate smart cities [129][131], smart mentality [133], and roles of different stakeholders and actors in the management and realization of smart cities [133]. This cluster is in close relationship with the blue cluster in **Figure 2** that is focused on the applications of smart cities. The third largest cluster (green) primarily addresses issues related to the underlying technological foundations of smart cities. These include issues related to the IoT, cloud computing, internet algorithms, wireless networks, etc. [114][134][135]. This cluster is closely associated with the Internet of Things cluster identified in the thematic cluster analysis in **Figure 2**.

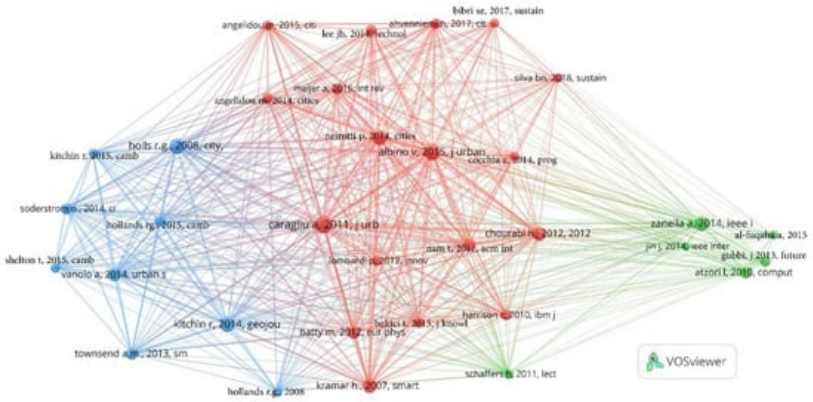

Figure 9. The most influential documents contributing the development of the field.

The results of citation burst analysis also confirm those of the co-citation analysis and show that works such as [120][124][130][136] have been very influential in advancing smart city discourse in the literature (Figure S2 of the Supplementary Materials).

2.6. Influential Authors

To identify the most influential authors it is also possible to set ‘cited authors’ as the unit of analysis in the co-citation analysis. Details related to the top 20 most prominent authors (in terms of citation) is shown in Table S5 of the Supplementary Materials. As shown in **Figure 10**, three major clusters of influential authors can be identified that are, to a great extent, consistent with the results of the analysis in the previous sections (prominent publications and thematic

cluster analysis). The red cluster includes authors that have mainly worked on the core concepts and definition of smart cities (such as Tan Yigitcanlar, Andrea Caragliu, Nicos Komninos, Taewoo Nam, Margarita Angelidou, Vito Albino, and Michael Batty, etc.). In other words, the authors of this cluster have primarily contributed to topics included in the smart city concept cluster of **Figure 2**.

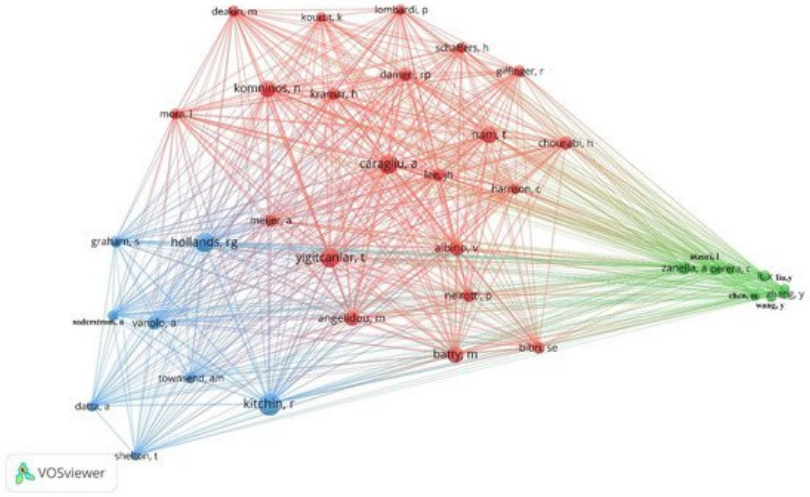

Figure 10. The most influential authors.

The second important cluster (blue) includes the authors that have expertise in big data and have worked on issues related to the implementation and the future of smart cities (e.g., Rob Kitchin, Anthony Townsend, Robert Hollands, and Alberto Vanolo). This cluster also associates with the big data analytics and smart city applications cluster identified in thematic analyses (blue cluster in **Figure 2**) and blue cluster identified in previous section (influential documents in **Figure 9**).

The third cluster (green) includes authors whose expertise revolve around the Internet of Things and the underlying technical issues related to smart cities. Key authors in this cluster are Andrea Zanella and Luigi Atzori. This cluster is also in close connections with the green cluster (Internet of Things) identified in **Figure 2** and the green cluster in the most influential documents (**Figure 9**).

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