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A Bibliometric Analysis of Smart Cities and the Internet of Things

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Abstract: The Internet of things (IoT) is a concept that was introduced into daily life with the Industry 4.0 revolution. It allows for interaction and knowledge sharing not only between humans and between humans and machines, but also between machines themselves. A good example of the IoT is the use of smart appliances: smart appliances create smart homes, and smart homes make smart buildings, resulting in smart cities. Although there is no universally agreed definition of a smart city, it generally means the use of technology and evidence to enhance a city or the services provided to its residents. This study aims identify the trends in global research on the IoT and smart cities through a bibliometric analysis of the scientific publications indexed by Web of Science (WoS) in the years between 2011 and 2021. There are few studies in the literature that have focused on both IoT and smart cities in such a wide variety in addition which makes different kinds of bibliometric analysis. We analyzed the number of documents published, the most highly cited papers, the countries and the authors with the most publications, using the VOSviewer program. This bibliometric analysis of existing work in this area offers valuable insights and a reference for future research for academics and practitioners in the field of IoT and smart cities.

Keywords: Industry 4.0, Internet of Things, Smart City, Bibliometric Analysis.

1 Introduction

The era of Industry 4.0 is a time of great insight and creativity. Industry 4.0 was first proposed in Germany in 2011 at Hannover Messe, the world's largest industry expo [1, 2]. The German government initiated the program, which focused on high-technology strategies. The Fourth Industrial Revolution will be defined by the use of total automation and digitalization processes, as well as the use of electronics and information technology (IT) in production and services. [3]. Cyber-physical networks, the Internet of Things (IoT), the Internet of Services (IoS), augmented reality, cloud information systems and big data analytics are among the topics involved [4 – 6].

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The IoT and IoS are built on the concept of continuous communication across the Internet, which allows for continuous engagement and knowledge sharing not just between humans, but also between machines [7, 8]. Machine-to-machine (M2M) communications and smart products are not considered separate components, and are key aspects of the IoT. In a nutshell, the IoT is relevant where any computer or a living person is linked to the Internet [3]. According to Cisco, 500 billion devices will be connected to the internet by 2030 [9].

Personalization, prediction, energy savings, defect reduction, and quality control are all made possible through the use of IoT appliances. In particular, with the ever-growing trend towards personalization, smart products can answer the needs of individual customers in the age of Industry 4.0. A good example of this is the transformation of traditional homes into smart homes with smart appliances. In practice, the use of these devices kick-starts the development of larger systems such as smart homes and smart building systems, which when combined form smart environments [10]. When these smart environments come together, they create smarter cities. Although there is no universally agreed definition of a smart city (SC), most authors focus on the use of technology and evidence to enhance a city or the services provided to its residents. The term 'smart city' is defined in [11] as "[t]he use of Smart Computing technologies to make the critical infrastructure components and services of a city – which include city administration, education, healthcare, public safety, real estate, transportation, and utilities—more intelligent, interconnected, and efficient".

SCs have received a certain amount of attention in the literature. Similarly, IoT applications are a topic that is very popular within the field of Industry 4.0 and covers many branches of science. Due to the increasing number of scientific studies of SCs and the IoT, there is a need to summarize and interpret the emerging body of knowledge. In the present study, works focusing on IoT technology in terms of the concept of an SC are chosen as our main subject matter, and we aim to identify the relevant publications, and to determine the trends within these studies and the most influential authors. For this purpose, a bibliometric analysis of the studies in the SC-IoT literature is carried out and an evaluation of the results is presented using visual maps. With these methods, the link between a publication and others can be analyzed, or an in-depth analysis of the most important publications, authors and collaborations between authors can be conducted. The recent increase in the number of scientific studies on SC-IoT makes it necessary to interpret and summarize the available knowledge, which indicates the need for bibliometric research on SC-IoT. Although the presentation of bibliometric analyses through visual maps has become widespread, especially in the last few years, it can be seen that research on SC-IoT is limited from the perspective of bibliometric studies. For this reason, it can be concluded that there is a need for research that examines papers on this subject based on various dimensions. The aim of this work is therefore to identify the most relevant and influential studies and scientific networks in the area of SC-IoT and to identify new trends in this field based on the information obtained. In this way, links between publications can be examined, and data showing important publications and authors can be analyzed in depth. In addition, we believe that this research will provide information on the outlook for research on SC-IoT, guide field experts in identifying different topics of study in this field, and prevent repetitive work. In this way, we hope to contribute to a better understanding of the structure and content of SC-IoT. This study aims to answer the following research questions and to represent collaborations between authors, institutions, and countries with the help of visual maps:

1. What is the distribution of SC-IoT publications by year?
2. Which are the most widely cited publications on SC-IoT?
3. What is the collaboration network between co-authors' institutions for SC-IoT publications?
4. What is the cooperation network between co-authors' countries for SC-IoT publications?
5. What is the co-citation–author network for SC-IoT publications?
6. What are the common keywords of SC-IoT publications?

The remainder of the study is organized as follows. A review of the literature will be provided in Section 2. Our methods will be described in Section 3. Section 4 will analyze the findings. Finally, Section 5 will offer a discussion and our conclusions.

2 Literature Review

Many sectors are expected to be transformed by mass digitization and the IoT, a network of physical objects that can communicate with each other over the internet, without the need for human interference [12]. The IoT is a network of physical devices, modern cars, houses, and even basic electrical devices that are used on a daily basis, which are linked to each other via the Internet in order to collect and share data. IoT applications include the transformation of regular household devices to smart appliances, resulting in smart homes that can be combined to make up smart buildings. Finally, when these smart buildings are combined, they form SCs.

With the advent of Industry 4.0 and the use of the IoT, the home appliances industry has embraced innovations such as big data, and has started to collect data from consumers and smart devices. Data collected from individual smart appliances can be used to improve energy efficiency in an SC [13]. A smart home device will optimize energy usage and cut costs, while keeping customers happy [14], resulting in smarter cities with lower energy consumption. The IoT is intended to promote the concept of SCs, with the aim of making city governance and the lives of residents easier by using the most advanced connectivity technologies [15].

There are six aspects to the growth strategy of an SC: smart economics, smart mobility, a smart environment, smart citizens, smart living, and smart governance. This concept is the result of the new age of information technology and the rapid expansion of the knowledge-based economy, which is built on an aggregation of the Internet, telecommunications networks, broadcast networks, wireless networks, and other sensor networks with the IoT as their foundation [3].

High-quality public education, publicly funded scientific research, alluring tax breaks for businesses, and excellent infrastructure, including strong domestic and international connections, widespread broadband, and top-notch public services, especially health care, are the main focuses of the smart economy [16]. The aim of smart mobility is to support the objectives of climate change mitigation and energy security, as well as real-time traffic management, passenger transportation management, parking management, fleet management, bicycle management, toll payments, electric vehicle support, tracking applications and logistics, car sharing services, and so on [16]. By providing complicated control techniques for controlling the many capabilities of a house or building, such as lighting, doors, temperature, electricity and energy, music, and so on, smart settings like homes or domestic systems can help people in a wide range of everyday tasks [17].

In particular, the inclusion of smart citizens is a critical aspect of the development of smarter cities, as such citizens set SMART (specific, measurable, attainable, relevant, and timely) goals and work toward them. Smart living includes smart homes and smart ‘things’. Smart houses will be able to "acquire and apply knowledge about their inhabitants and their surroundings in order to adjust to the residents and accomplish the goals of comfort and efficiency," according to Cook and Youngblood [18]. By making it simple to link the real world to the Internet, smart 'things' enable users to easily access the vast network of connected gadgets. Smart governance is defined as the application of technology to improve planning and decision-making in metropolitan or SCs; it involves enhancing democratic procedures and changing how government services are delivered to make them effective and efficient [16].

An SC contains a variety of electronic components that are used for a wide range of purposes, such as street cameras for surveillance, sensors for transportation networks, and so on. Furthermore, individual mobile device use could spread as a result of this. SCs are those that make use of smart devices to perform a range of tasks such as lighting, traffic control, connecting cities, lowering energy usage, and lowering pollution [15].

SC applications focused on the IoT will function as a personal assistant in the daily routine of each resident, informing them of their next meeting, for example, or optimizing the room temperature based on the outside temperature so that coffee can be made on time. They can detect any problems with a resident's health and inform or alert his or her personal doctor in the event of an emergency [15].

There are many different studies of SCs in the literature. For example, Fernandez- Anez conducted a study of the different definitions of SCs [19]. The link between IoT and SCs was discussed by Arastesh [20], and the design of an SC was examined by Da Silva et al. [21]. Ijaz [22] analyzed SCs from a security perspective, and a study was carried out by El-Baz and Bourgeois [23] that proposed one SC application in particular, which was a logistic mobile application. Pellicer et al. [24] presented a global perspective of SC implementations. Another study by Petroleo et al. [25] involved a survey of the semantics used by cloud sensors for IoT applications, to close the difference between the IoT and the Cloud of Things. Perera et al. [26] analyzed how fog computing could be used in SC applications. In a study by Shuai et al. [27], an analysis of the charging of electric vehicles for SC applications was discussed. Wang and Sng [28] presented a survey of unique in-depth learning algorithms with video analytics as a target SC framework. Talari et al. [29] explored issues related to SCs based on IoT, although bibliometric analysis methods were not used in this study.

There have been several bibliometric analysis studies related to the IoT, but these were not related to SCs. Miskiewicz [30] presented a bibliometric analysis of the IoT from a marketing point of view, while Bouzembrak et al. [31] performed a literature review and bibliometric analysis of relevant articles related to IoT technology in food safety. Rejeb et al. [32] carried out a bibliometric study of the IoT in the field of supply chain management and logistics. Dabbagh et al. [33] presented a bibliometric analysis of the integration of the blockchain with the IoT, and Grooby et al. [34] conducted a bibliometric analysis of authentication and access control in IoT devices. Perez et al. [35] carried out a bibliometric study based on SCs, although this study did not include a point of view related to the IoT. Finally, in another study by Szum [36], IoT-based SCs were examined; however, this study analyzed only 1,019 articles, whereas our study considers 2,104 articles and includes three additional types of bibliometric analysis.

3 Methods

The details of the data collection process are shown in Fig. 1. As can be seen from the figure, preliminary research was initially conducted to determine the search query and databases used in the first stage. As a result, it was observed that the search words that were mainly used in studies of SCs were 'smart city' [37, 38]. In literature studies of the IoT, it has been shown that the primary search term is 'internet of thing' [30, 32]. In the present research, the terms ('smart city'

OR 'smart cities') AND ALL FIELDS: ('IoT' or 'Internet of Things') were used as a search query. Web of Science (WoS) was chosen as a globally accepted database, as it contains high-quality and effective scientific studies [39, 40]. In the second stage, a total of 5,105 studies on SC-IoT were identified by searching the WoS database with the search phrase given above. In the third stage, some necessary filtering was applied to select only articles and to exclude conference papers, book chapters and studies that had not yet been published. In the final stage, all of the data on the 2,104 articles that remained after filtering were downloaded from the WoS platform in .csv format. The data collection process was completed by importing the data into the VOSviewer program, where the analysis was carried out.

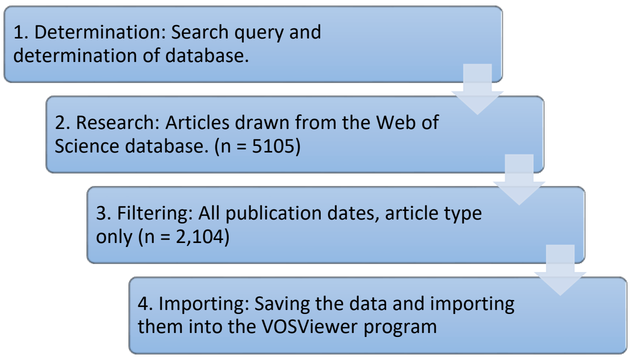

Fig. 1 – *Data collection process used in our research methodology.*

In this study, bibliometric analysis methods were used to examine the articles drawn from SC-IoT. Within the scope of this bibliometric analysis, we carried out a co-author–institution analysis, and a co-author–country analysis of the articles. Following this, a co-citation–author analysis and a common keyword analysis were conducted.

4 Results

The distribution of SC-IoT publications by year is presented in **Table 1** and Fig. 2, and it can be noticed that studies on SC-IoT have been carried out since 2011. This situation is in coordination with the year 2011 when the concept of Industry 4.0 emerged in terms of IoT. We observe that there was a continuous increase in the number of studies until 2020, the year in which most of the publications were produced (n = 790, f = 37.5). Since the data collection process applied in this study included the first quarter of 2021, it was initially striking that there was a decrease in the number of studies for 2021 (n = 222); however, if studies were conducted at the same rate in the remaining quarters of 2021, the number of papers may be higher than in 2020.

Table 1
Distribution of SC– IoT publications by year.

Publication year	Documents	%
2011	2	0.095
2012	2	0.095
2013	9	0.428
2014	22	1.046
2015	37	1.759
2016	86	4.087
2017	191	9.078
2018	332	15.779
2019	411	19.534
2020	790	37.548
2021 (q1)	222	10.551
Sum	**2,104**	**100**

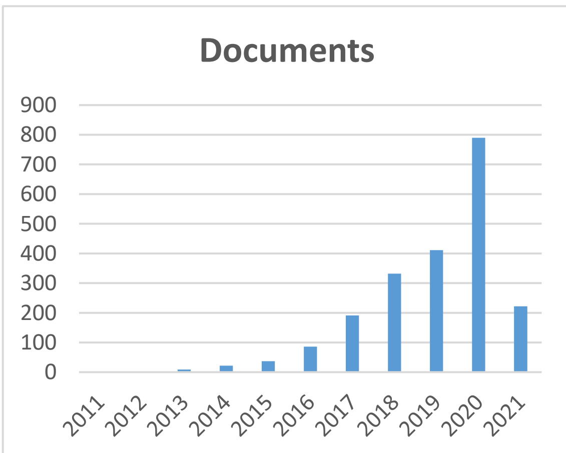

Fig. 2 – *Distribution of SC-IoT publications by year.*

The 10 most widely cited publications on SC-IoT are presented in **Table 2**, including the title of each publication, its authors, the journal in which it was published, the year of publication, the total number of citations, and the average number of citations per year. The most highly cited publication was a 2014 article by Zanella et al. entitled "Internet of Things for smart cities" [41], published in *IEEE Internet of Things Journal*, which received 2,209 citations. The article was also ranked first in terms of the average number of citations per year. In second place was an article entitled "Integration of cloud computing and Internet of Things: A survey" [42], which was published in 2016 by Botta et al.

In third place was a 2017 article by Lin et al. entitled "A survey on Internet of Things: Architecture, enabling technologies, security and privacy, and applications" [43], which was published in the same journal as the first article. This article, with 730 citations, was ranked second in terms of the average number of citations per year. An article published by Sanchez et al. [50] in 2014 was ranked tenth (as shown in **Table 2**), with 318 citations.

When an institutional analysis of the co-authors of the SC-IoT studies was carried out, we found that there were a total of 2,319 institutions to which the authors were affiliated. When the ones with at least 10 publications from these institutions were analyzed, it was concluded that 66 institutions complied with this condition. The results of the analysis, in the form of a collaboration network map of these 66 institutions, are below in Fig. 3.

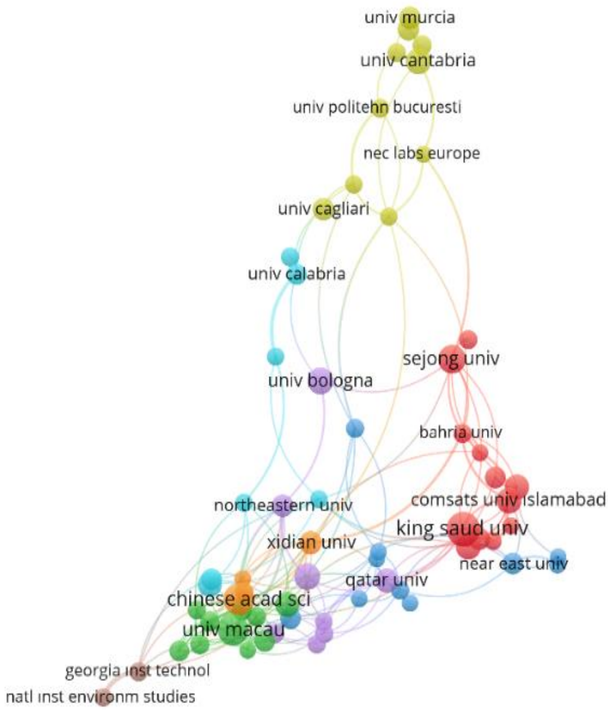

Fig. 3 – *Network map showing co-author–institutional collaborations.*

It can be noticed from the figure that the network of institutions is clustered in seven different colors. The network map shows that the institution with the highest number of publications in terms of co-authors was King Saud University

($n = 40$). The institutions in the red cluster are those with the highest values in terms of connectivity. It was determined from the analysis that there were 180 connections between 66 institutions.

This analysis indicated that the authors of SC-IoT studies came from a total of 90 countries. When the criterion of at least 20 publications was used as the cut-off point, it was seen that 35 countries were represented. A network map of these countries is displayed in Fig. 4; it was found that the country with the highest number of publications and the most dominant among the countries (which are clustered into four different colors) was China, with 519 publications. It was followed by the USA, with 333 publications, and then by the UK, with 169 publications. China, which was ranked first in terms of the number of publications, was also ahead of other countries in terms of the number of citations ($n = 8,324$). When the countries were ranked according to the number of connections, the USA and England were in first place, with 32 links. China was ranked third, with 31 links. It was observed that there were a total of 347 links between countries. From the cooperation map in Fig. 4, it can be seen that the Far Eastern, European and Middle Eastern countries often cooperated with each other.

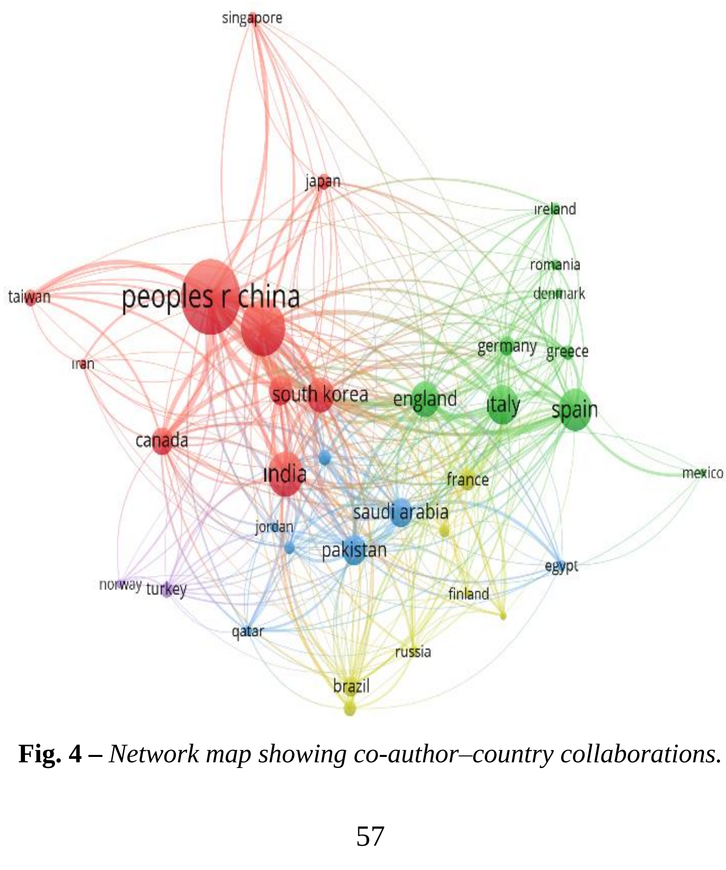

Fig. 4 – *Network map showing co-author–country collaborations.*

Table 2
Top 10 most cited publications on SC-IoT.

No	Title	Authors	Journal title	Year	Total citations	Avg. per year
1	Internet of Things for smart cities [41]	Zanella, Bui, Castellani, Vangelista, Zorzi	*IEEE Internet of Things Journal*	2014	2,209	276.13
2	Integration of cloud computing and Internet of Things: A survey [42]	Botta, de Donato, Persico, Pescape	*Future Generation Computer Systems: The International Journal of eScience*	2016	862	143.67
3	A survey on Internet of Things: Architecture, enabling technologies, security and privacy, and applications [43]	Lin, Yu, Zhang, Yang, Zhang, Zhao	*IEEE Internet of Things Journal*	2017	730	146
4	Low power wide area networks: An overview [44]	Raza, Kulkarni, Sooriyabandara	*IEEE Communications Surveys and Tutorials*	2017	586	117.2
5	An information framework for creating a smart city through Internet of Things [45]	Jin, Gubbi, Marusic, Palaniswami	*IEEE Internet of Things Journal*	2014	573	71.63
6	Sensing as a service model for smart cities supported by Internet of Things [46]	Perera, Zaslavsky, Christen, Georgakopoulos	*Transactions on Emerging Telecommunications Technologies*	2014	448	56
7	Long-range communications in unlicensed bands: The rising stars in the IoT and smart city scenarios [47]	Centenaro, Vangelista, Zanella, Zorzi	*IEEE Wireless Communications*	2016	393	65.5
8	A survey on 5G networks for the Internet of Things: Communication technologies and challenges [48]	Akpakwu, Silva, Hancke, Abu-Mahfouz	*IEEE Access*	2018	365	91.25
9	Multi-sensor fusion in body sensor networks: State-of-the-art and research challenges [49]	Gravina, Alinia, Ghasemzadeh, Fortino	*Information Fusion*	2017	345	69
10	SmartSantander: IoT experimentation over a smart city testbed [50]	Sanchez at al.	*Computer Networks*	2014	318	39.75

In the co-citation–author analysis, we applied a threshold of at least 50 citations. It was determined from the data that 68 authors met this criterion. A visual map of the co-citation–author network is shown in Fig. 5, in which the authors are clustered into three groups. Most co-citations belong to the collaborating authors in the red cluster, which contains 33 authors. There are 21 authors in the green cluster, and 14 in the blue. The order of the authors according to the number of citations is as follows. The author with the most citations (*n* = 273) and highest total link strength (1,455) was L. Atzori, whereas A. Zanella was ranked second in terms of the number of citations (*n* = 240), and J. Gubbi was in third place with 183 citations. C. Perera was in fourth place with 177 citations, and had the second highest total link strength of 1,205.

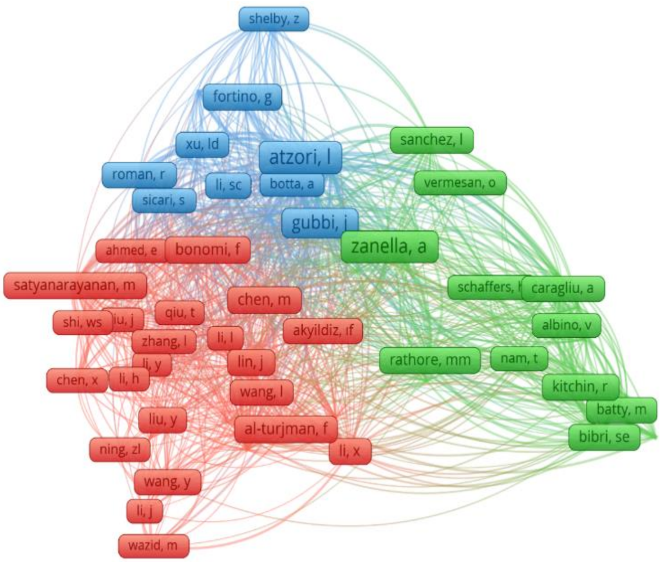

Fig. 5 – *Network map of co-citation–author collaborations.*

From an analysis carried out to determine the most commonly used common keywords in the research data, it was seen that a total of 5,838 keywords were used. A density map of the most frequently used keywords is shown in Fig. 6, based on the condition that they were used at least 10 times.

When the analysis results and Fig. 6 are examined, we see that the ranking of the top 10 keywords in terms of frequency of use was as follows: ‘Internet of Things’ (*n* = 641), ‘smart city’ (*n* = 456), ‘smart cities’ (*n* = 420), ‘IoT’ (*n* = 298), ‘Internet of Things (IoT)’ (*n* = 197), ‘cloud computing’ (*n* = 140), ‘security’ (*n* = 117), ‘big data’ (*n* = 94), ‘edge computing’ (*n* = 84), and ‘wireless sensor networks’ (*n* = 80). The terms ‘blockchain’, ‘deep learning’, ‘machine learning’, and ‘sensors’ were other related keywords used in the studies. A visual map of the keywords used in the studies according to their current status is shown in Fig. 7.

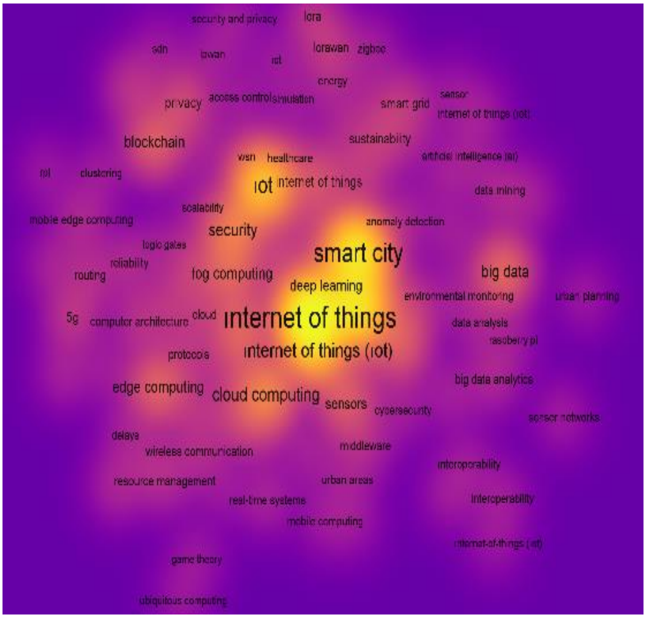

Fig. 6 – *Results of a common keyword analysis showing the most frequently used keywords.*

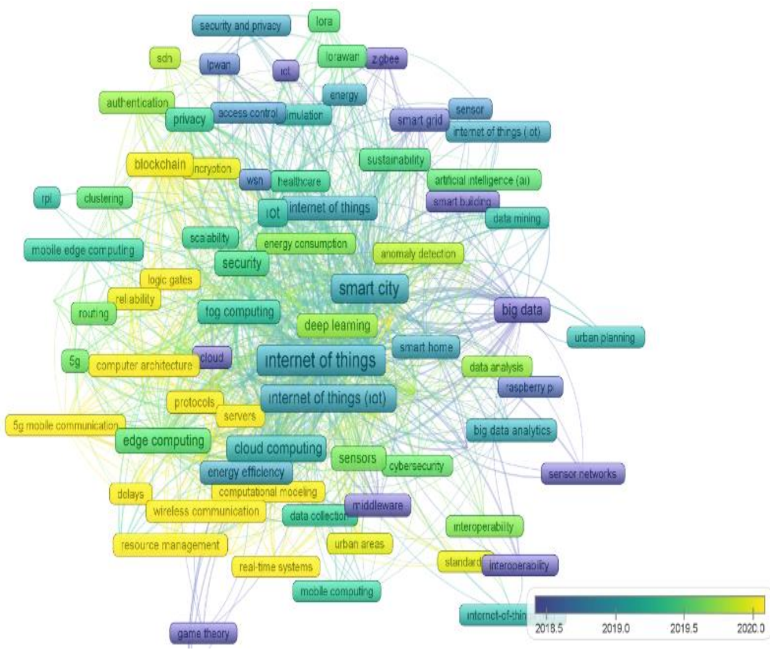

Fig. 7 – *Results of a common word analysis showing the most current keywords.*

In Fig. 7, among the keywords indicated with different colors from 2018 to 2020, the yellow ones are the current keywords on SC-IoT. Terms such as 5G, cloud computing, clustering, blockchain, logic gates, protocols, computational modeling, resource management real-time systems, and wireless communications are examples of keywords used in SC-IoT papers after 2020.

5 Conclusions

A bibliometric approach was used in this study to analyze global research trends in papers using the keywords ‘IoT’ and ‘smart city’ and published between 2011 and 2021. A total of 2,104 articles were identified and examined for this research. Our results showed that the numbers of publications increased each year from 2011 to date. The most widely cited publication was a 2014 article by Zanella et al. entitled “Internet of Things for smart cities”, published in *IEEE Internet of Things Journal*, which received 2,209 citations. The institution with the highest number of publications in terms of co-authors was King Saud University, whereas the country with the highest number of publications was China, with 519 papers. The author with the highest number of citations (n = 273) and highest total link strength (1,455) was L. Atzori. From our analysis, we found that a total of 5,838 keywords were used, with the top 10 being ’Internet of Things’ (n = 641), ‘smart city’ (n = 456), ‘smart cities’ (n = 420), ‘IoT’ (n = 298), ‘Internet of Things (IoT)’ (n = 197), ‘cloud computing’ (n = 140), ‘security’ (n = 117), ‘big data’ (n = 94), ‘edge computing’ (n = 84), and ‘wireless sensor networks’ (n = 80). More recently, keywords such as 5G, cloud computing, blockchain and clustering have started to be used more frequently; this indicates that new research trends involve data storage, data exchange and telecommunications in SCs and the IoT.

As the topic of Industry 4.0 has become widely researched, there has been an increase in the number of bibliometric analyses conducted within the scope of artificial intelligence and other Industry 4.0 topics in recent years. Some of these studies were as follows: Talan (2021) conducted a bibliometric analysis of artificial intelligence in education, and Talan and Demirbilek (2022) presented a bibliometric analysis of learning analytics. When bibliometric analysis studies based on the intersection of the fields of SC and IoT are examined, we see that only five studies have been published on this subject. González-Zamar et al. [53] examined 1,232 documents drawn from studies carried out up to 2019. Researchers have also presented common network analyses in their studies. However, the range of years covered by our study is wider and more up-to-date, and the number of articles that have been reviewed is more comprehensive than in previous works. Szum [36] examined 1,019 publications from WoS, Scopus and IEEE Xplore databases, but analyzed only the keywords in a network analysis. A total of 2,289 publications from the WoS and Scopus databases were examined with R software and analyses of the keywords of these studies were presented in [54]. Rejeb et al. [55] reviewed 1,802 articles from the Scopus database. In [36] and [54], Rejeb et al. focused only on a common word analysis as network analysis. In contrast, in the present study, we present analyses of the co-authors' institutions and countries, a co-citation–author analysis and a common keyword analysis. Choi et al. [56] conducted a content analysis of studies of smart homes and the IoT published between 2015 and 2019, sourced from the Scopus database. These researchers did not perform a co-author or co-citation analysis, did not use software such as VOSviewer, and did not provide visual maps. The range of publication dates was also narrower than in our study, and since we selected the WoS database, our study considered papers that were of higher quality and contributed more to the field. From an examination of the limited existing bibliometric analysis studies of SC-IoT, it can be seen that the articles covered by our study were obtained from a higher quality database (WoS) and our analyses generally involved more articles. In this study, compared to existing works in the literature, a larger number of bibliometric network analyses were undertaken, and the subject was discussed from a more holistic and broader perspective.

There are many papers in the literature that have presented bibliometric analyses of IoT or SCs separately, but very few that have carried out a bibliometric analysis of IoT and SCs together. Ours is one of the few studies that has analyzed these topics together. Compared to other papers, this study analyzes more articles and uses different kinds of bibliometric analysis, and can therefore be considered a new contribution to the literature.

The limitations of our work should be addressed. Firstly, our data were limited to the WoS core collection and published articles. Other international databases (e.g., DOAJ or Scopus) could also be considered; however, the reason for the selection of WoS in this case was that it is one of the largest global databases and includes high-quality scientific publications [29, 30]. In addition, books, book chapters and conference papers could be included in future studies. Moreover, we included only English language publications in our study, and papers in other languages were omitted. In view of these constraints, a more in-depth content analysis is suggested for future researchers undertaking a bibliometric analysis.

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