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Guiding Urban Decision-Making: A Study on Recommender Systems in Smart Cities

Andra Sandu [1], Liviu-Adrian Cotfas [1,*], Aurelia Stănescu [2] and Camelia Delcea [1]

[1] Department of Economic Informatics and Cybernetics, Bucharest University of Economic Studies, 010552 Bucharest, Romania
[2] Department of Management, Bucharest University of Economic Studies, 010552 Bucharest, Romania
* Correspondence: liviu.cotfas@ase.ro; Tel.: +40-771269599

Abstract: In recent years, the research community has increasingly embraced topics related to smart cities, recognizing their potential to enhance residents' quality of life and create sustainable, efficient urban environments through the integration of diverse systems and services. Concurrently, recommender systems have demonstrated continued improvement in accuracy, delivering more precise recommendations for items or content and aiding users in decision-making processes. This paper explores the utilization of recommender systems in the context of smart cities by analyzing a dataset comprised of papers indexed in the ISI Web of Science database. Through bibliometric analysis, key themes, trends, prominent authors and institutions, preferred journals, and collaboration networks among authors were extracted. The findings revealed an average annual scientific production growth of 25.85%. Additionally, an n-gram analysis across keywords, abstracts, titles, and keywords plus, along with a review of selected papers, enriched the analysis. The insights gained from these efforts offer valuable perspectives, contribute to identifying pertinent issues, and provide guidance on trends in this evolving field. The importance of recommender systems in the context of smart cities lies in their ability to enhance urban living by providing personalized and efficient recommendations, optimizing resource utilization, improving decision-making processes, and ultimately contributing to a more sustainable and intelligent urban environment.

Keywords: smart cities; recommender systems; bibliometric analysis; Biblioshiny

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1. Introduction

The 21st century has been marked by drastic shifts and remarkable technological progress. As a result, in order to adjust to this rapidly changing world, people must come up with creative solutions and actions that will make their lives easier while taking advantage of the benefits that are associated with rapid digitization and technological advancement.

People have been more likely to settle in urban areas, especially within the last century. There are many reasons for this trend, including the availability of various jobs, chances for career advancement, closer proximity to prestigious educational institutions, better access to health services, cultural diversity, and many other advantages. This aspect has gained the attention of multiple scientists who offered more insight into this subject matter, including both advantages and disadvantages of living in urban areas, such as in the papers authored by Thomas et al. [1] on the topic of determining why people leave particular places, Kuddus et al. [2] on urbanization seen as a problem for the rich and poor, Zhang [3] on premises and challenges of urbanization around the world, Kundu et al. [4] on the trends and patterns in worldwide urbanization, and Kwilinski et al. [5] on the effects of urbanization on green growth. Furthermore, in a recent paper, Andrade-Ruiz et al. [6] discussed the emerging perspectives of the application of recommender systems in smart cities, highlighting the occurrence of different processes by which recommendations are filtered in areas such as tourism, health, mobility, and transport.

The concept of "smart city" appeared in the last decades as a result of technological, social, and even economic developments, being a consequence of the urban environment's expansion and the integration of technology within it. These so-called "smart cities" are based on an evolution of the traditional way in which cities were conceived and managed.

The "smart cities" concept incorporates digital technology into a variety of sectors, including communications, transportation, energy, water, and others, with the goal of protecting the environment, enhancing the quality of life for people, and increasing the productivity of daily operations. Therefore, via modernizing the infrastructure and linking all activities together, they contribute to improving people's quality of life and meeting modern society's needs.

Although at first glance, some may wonder about the connection between smart cities and recommender systems, it has been determined that the two have an interdependent relationship, the latter being the basis of the former. In other words, the concept of a "smart city" would not be possible without highly effective recommendation systems that employ cutting-edge techniques and algorithms, such as content-based filtering, user/item-based collaborative filtering, sentiment analysis algorithms, location/context-based recommendation algorithms, machine learning algorithms, clustering or classification algorithms, etc. By making use of these advanced techniques, it is possible to offer personalized services according to the current needs and efficiency in resource management, significantly influencing the evolution of the urban environment in a beneficial manner.

By analyzing the specialized literature, the success experienced by urban areas through the implementation and use of recommender systems can be easily observed. Academics published their works related to this subject matter within the scientific literature and highlighted the measurable and significant impact that recommender systems had on the evolution of smart cities, improving the quality of citizens' lives, as well as ensuring a healthier and sustainable environment. As a result, articles that address various topics, such as smart mobility, e.g., traffic intelligence [7], bicycle road systems [8], sustainable energy production [9], healthcare monitoring systems [10], solutions for voltage issues [11], irrigation systems in urban parks [12], and vehicle charging stations [13], have been encountered in the scientific literature.

In these papers, noteworthy details are brought to the fore, while some of them provide and examine the results through analyzing various real-data scenarios. For instance, the article by Wolniak [8] focused on smart mobility, more specifically on bicycle road systems, found associations within gross domestic product, bicycle roads' length, and geographical patterns, and examined the results on real datasets from Poland's provinces. The author stated that institutions should speed up the process of building special roads for bicycles because they will have a good impact on the environment, people's quality of life, traffic issues, and improvement of smart cities.

Another relevant example that has to be mentioned here is the paper written by Cano et al. [12]. This study focused on a significant issue in smart cities, especially in desert areas, namely, water consumption. The authors come up with an innovative smart decision support system, using four variables (land, temperature, humidity, and weather forecast), with the main purpose of improving irrigation systems, so as to reduce the unnecessary consumption. This system was applied in a case study from a park in Lima City, and the results highlighted its feasibility.

Moreover, readers who want to explore even more into the recommender systems and techniques can refer to the following articles from the specialized literature that address some challenges and opportunities from different perspectives: Gonçalves et al. [14], Kamilin and Yamaguchi [15], Ferreira et al. [16], Moolikagedara et al. [17], Kim and Shon [18], and Alzahrani et al. [19]. Based on these research findings, the following benefits offered by recommender systems in smart cities can be considered [14–19]:

- Offering alternative routes for avoiding traffic in order to facilitate mobility in urban areas.

- Reducing problems related to parking spaces, offering suggestions for drivers (e.g., free parking spaces).
- Promoting the use of public transport, ride sharing, and electric scooters or bikes in order to help reduce pollution.
- Promoting and educating people on responsible waste management as well as how to use resources, such as gas, water, etc., with the intention to protect the environment.
- Increasing the safety of residents by offering suggestions regarding emergency situations, safe routes, etc.
- Supporting and promoting culture by offering recommendations on cultural events held in the area.
- Encouraging a healthy lifestyle by providing ideas for outdoor activities and time spent in parks/nature.

All the aforementioned aspects provide further proof for the significance and applicability of this study, based on real-world scenarios from daily life.

Therefore, the current article aims to elucidate the importance and the crucial impact that recommendation systems have in smart cities, together with highlighting the urgent need to implement all these effective solutions in the urban environment.

Nowadays, apart from the imperative necessity of integrating these recommender systems in smart cities, it should be similarly underlined here that the implementation of these advanced technologies still presents many challenges and barriers, such as high costs, issues associated with security, outdated infrastructure, the community's hesitancy in adopting new technologies, and many more. The significance of strong communication between institutions, decision-makers, and researchers should also be carefully considered, as should the technological obstacles. All parties interested in this area must cooperate and assist one another for this domain to evolve.

That being stated, this study aims—through this bibliometric investigation—to analyze the extracted manuscripts that were previously published in the scientific literature around the area of recommender systems in smart cities, shedding light on emerging trends and subjects addressed, valuable insights, challenges, and future areas that require improvements, by carefully exploring various perspectives, including and not limited to authors, sources, affiliations, countries, keywords, production over time, collaborations, and connections between categories. To better understand all the hidden substrates of this domain, a large variety of graphs, tables, and suggestive and pleasant visual representations are also provided, with the intention of laying the foundation for potential future research routes and approaches, contributing to a better world, a balanced and healthy environment, along with developing urban areas with educated and informed citizens.

Through the analysis conducted in this paper, we aim to answer the following questions:

- Q1. Which are the most esteemed journals and the most prolific authors that were oriented to the area of recommender systems in smart cities?
- Q2. How can the production over time in this revolutionary domain be characterized?
- Q3. What observations should be outlined regarding the collaboration in the creation of manuscripts that address the domain of recommender systems in smart cities?
- Q4. What hidden insights come to light by performing the word analysis and what can be said about the niche, motor, basic, emerging, or declining themes in terms of authors' keywords?
- Q5. What crucial information should be highlighted about citations?

The next sections refer to the following aspects: Section 2 deals with describing the materials and methods used, namely the data extraction and the analysis indicators, Section 3 is dedicated to the dataset analysis, while Sections 4 and 5 provide discussions and limitations of the study. The paper ends with concluding remarks.

2. Materials and Methods

As broadly recognized, each bibliometric analysis begins with the meticulous documentation of the potential sources, optimal methods, and appropriate materials. Therefore,

the primary objective of the current section is to shed light on the previously listed aspects, in an objective manner, giving readers a broader understanding of the steps followed for gathering and analyzing the dataset associated with papers in the area of recommender systems in smart cities.

Figure 1 acts as the initial foundation for the indicated discussion, highlighting two primary phases, dataset extraction and bibliometric analysis. This methodological approach is similar to the one suggested in the scientific literature for conducting a bibliometric analysis [20,21].

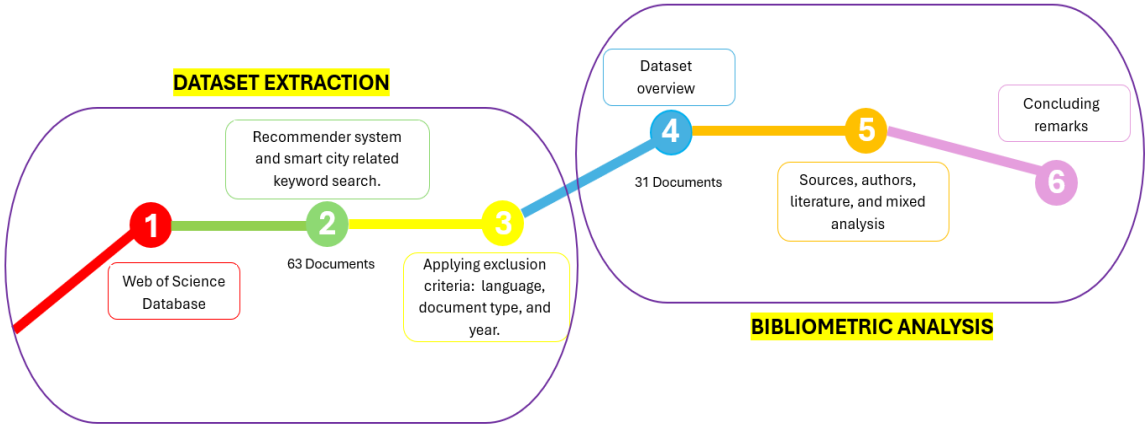


Figure 1. Analysis steps.

The first part refers to the stages followed by the authors in order to generate the relevant dataset for the present analysis. As depicted in the Figure 1, the papers were collected from the Web of Science database, and then filtered based on keywords and other significant criteria (language, document type, and year).

The second part was focused on the bibliometric analysis performed. More specifically it started from the dataset overview, then delved even deeper into the subject matter, investigating it from various perspectives (sources, authors, literature, and mixed analysis), and finished with underling the concluding remarks, crucial for the development of the domain, possible enhanced strategies, and future works for interested researchers or institutions.

Each stage presented subordinate steps, rigorously elaborated on below in the corresponding sections.

2.1. Dataset Extraction

The first step, known as dataset extraction, represents a crucial phase for each bibliometric analysis, regardless of the domain addressed, that requires an extensive investigation of the available and suitable tools used for the extraction, along with proper selection of papers from the scientific literature. Obtaining a relevant dataset, closely linked to the field of interest, directly impacts the results derived from the performed study. In other words, the more accurate the data, the more precise and valuable the results, which will contribute to specialized literature.

Within the present manuscript, the focus was on one of the broadly esteemed and appreciated databases, known as Clarivate Analytics' Web of Science Core Collection, or Web of Science [22], which allowed effortless access to a multitude of scientific papers from various fields, covering different topics.

The decision of using exclusively a single database, and not a combination of two or more options, was based on a comprehensive investigation, from which a series of solid arguments were derived, guided by the desire to obtain the most appropriate set of data for the study conducted in this article.

First, it was noticed that Web of Science is significantly appreciated among the scientific community, compared to other existing databases, such as Scopus or even IEEE. The studies performed by Cobo et al. [23] and Bakir et al. [24] served as solid proof for this statement,

highlighting the huge collection of papers included, published by a multitude of authors from all over the world, in various sources and covering different topics.

The interface is intuitive and easy to use, and it offers users the possibility to import data in row format in the frequently utilized R tool, Biblioshiny, which places Web of Science in the top of authors' preferences [25,26]. These aspects are further supported by the fact that many researchers who have conducted bibliometric studies have exclusively used the Web of Science database to extract the dataset (interested readers can refer to [25,27–31]), to the detriment of other competitors, which once again underlines its prominent position within the scientific community.

Furthermore, the users benefit from personalized access to sources through a subscription-oriented system, an aspect that attracts the attention of some scientists. For example, some studies (Liu [32] and Liu [33]) familiarize and bring to the readers' attention how important it is for an author to benefit from full access in terms of sources in order to perform a bibliometric analysis as accurately as possible. In this context, it must be specified that for the current article, we had full access to all 10 indexes offered by the Web of Science platform, as follows:

- Science Citation Index Expanded (SCIE)—1900-present.
- Social Sciences Citation Index (SSCI) 1975-present.
- Arts and Humanities Citation Index (A&HCI)—1975-present.
- Emerging Sources Citation Index (ESCI)—2005-present.
- Conference Proceedings Citation Index—Science (CPCI-S)—1990-present.
- Conference Proceedings Citation Index—Social Sciences and Humanities (CPCI-SSH)—1990-present.
- Book Citation Index—Science (BKCI-S)—2010-present.
- Book Citation Index—Social Sciences and Humanities (BKCI-SSH)—2010-present.
- Current Chemical Reactions (CCR-Expanded)—2010-present.
- Index Chemicus (IC)—2010-present.

Another justification for the preference of employing a singular database for data collection stems from the individualized analyses undertaken in this bibliometric inquiry. The utilization of multiple databases would have introduced challenges regarding the determination of primary sources, among other considerations.

It is imperative to underscore the authors' commitment to furnishing an unbiased portrayal of the data collection process. Hence, it is essential to note that the inclusion of additional databases for paper retrieval could have potentially influenced the outcomes, resulting in minor discrepancies compared to those yielded by the current methodology.

As anticipated, following the selection of the data collection tool, a process of paper filtration ensued. Table 1 provides more insights into this procedure, succinctly encapsulating all exploratory steps executed within the Web of Science database. Included are details regarding the employed queries and the resultant findings. It shall be noted that we have performed the search both for the singular and the plural form of the keywords, which has been ensured by adding a "*" at the end of the keyword.

The first exploratory step, perhaps the most important one, involved the exclusive selection of papers that address the topic studied in the current bibliometric analysis, namely, recommender systems in smart cities. In the initial phases, specific keywords ("recommender system" and "smart city") were searched for in either titles, abstracts, or even authors' keywords, and then the obtained results were intersected so as to include only papers with both keywords found in at least one of the sections. Hence, after these actions, a relatively small number of 63 documents was obtained, compared to other bibliometric studies performed on different topics [34–36]. This suggests the novelty of the field within the scientific community, underlining the potential for deeper exploration.

The next exploratory step focused on applying the language exclusion criterion. Starting from the premise that English is the most popular and used language in writing scientific papers, it was decided to eliminate articles written in any language other than English. This decision was in line with other works from the field, such as studies by Fatma

and Haleem [37], Stefanis et al. [38], and Gorski et al. [39]. Upon the execution of the query, it was found that all the papers were written in English, and no paper was excluded from the analysis.

The third exploratory step involved limiting the dataset solely to documents that were marked as "articles". This option is supported by the study conducted by Fatma and Haleem [37], while Donner [40] stated the importance of properly differentiating across various types of papers when conducting a bibliometric analysis due to their specific content and purpose, which might affect the number of citations. Furthermore, the Web of Science includes under the "article" umbrella all the papers that are considered to bring new and original works [41]. Therefore, in the Web of Science, proceedings papers will have a dual document type, both "article" and "proceedings paper" [41]. The document type exclusion criterion seemed to have major consequences for the dataset, reducing the number of works by almost half (33 papers).

The last exploratory step restricted the presence of the articles written in 2024. Bearing in mind that this bibliometric analysis took place during the month of April 2024, it was thought as beneficial to exclude an ongoing year, so as not to affect the results of the investigation. Consequently, two articles were removed, further reducing the dataset to 31 articles.

Therefore, the final dataset, collected and filtered, consisted of 31 articles, as presented and analyzed from various perspectives in the upcoming sections of the paper.

Besides the limitations highlighted in Section 5 of the paper, it should be noted that the extracted dataset represents a niche theme within the broad topic of smart cities. This can be observed from the data provided in Table 1, showing that more than 26,000 papers have addressed themes related to smart cities.

Table 1. Data selection steps.

Exploration Steps	Filters on Web of Science	Description	Query	Query Number	Count
1	Title/Abstract/ Authors' Keywords	Contains specific keywords related to recommender system in title/abstract/ authors' keywords	((TI = (recommender_system*)) OR AB = (recommender_system*)) OR AK = (recommender_system*)	#1	19,129
		Contains specific keywords related to smart city in title/abstract/authors' keywords	(((((TI = (smart_city)) OR TI = (smart_cities)) OR AB = (smart_city)) OR AB = (smart_cities)) OR AK = (smart_city)) OR AK = (smart_cities)	#2	26,293
		Contains specific keywords related to recommender systems and smart city in title/abstract/authors' keywords	#2 AND #1	#3	63
2	Language	Limit to English	(#3) AND LA = (English)	#4	63
3	Document Type	Limit to Article	(#4) AND DT = (Article)	#5	33
4	Year published	Exclude 2024	(#5) NOT PY = (2024)	#6	31

2.2. Bibliometric Analysis

This section outlines the bibliometric analysis performed on the dataset.

All the images presented on the subsequent pages were created using Biblioshiny [42], a highly esteemed R tool widely embraced within the scientific community [43–45]. This tool is distinguished by its expansive array of functionalities, captivating visual design of figures and graphs, as well as its advanced and innovative features. It effectively illuminates

valuable insights from imported data, thereby streamlining the creation of invaluable manuscripts within the scientific realm and beyond. Consequently, Biblioshiny stands out as a preferred choice among academics, particularly in the domain of bibliometric analysis.

With the aid of this robust tool, the present article unveiled significant insights, encompassing the addressed topics, latent themes, perspectives, potential strategies, areas necessitating improvement, future trajectories, and numerous additional considerations pertaining to recommender systems in smart cities.

Figure 2 provides a visual depiction of the five facets of the bibliometric analysis.



Figure 2. Bibliometric analysis facets.

The initial facet shed light on overarching details regarding the dataset, encompassing particulars such as timestamps, sources, document counts, citations, scientific output, references, and author demographics.

As anticipated, the analysis of sources predominantly focused on journals, examining them from various perspectives and employing relevant metrics.

Subsequently, attention shifted toward authors, elucidating their productivity trends over time, institutional affiliations, geographic distributions, scientific output, and collaborative endeavors within the realm of recommender systems in smart cities.

The fourth facet entailed a comprehensive exploration of papers and their associated terminologies, encompassing co-occurrence networks and thematic mappings.

The last one consisted of a mixed analysis, making use of three-field plots.

3. Dataset Analysis

In the forthcoming sections, a comprehensive analysis will be conducted on the dataset pertaining to recommender systems in smart cities. This examination will encompass all five

previously outlined facets: dataset overview, sources, authors, papers, and mixed analysis. Emphasis will be placed on employing relevant indicators and visual representations, including graphs, tables, and figures, to facilitate clear elucidation.

3.1. Dataset Overview

Upon initial inspection, Table 2 presents an overview of the dataset comprising 31 documents, disseminated across 26 distinct sources, spanning a decade from 2014 to 2023. The modest number of publications juxtaposed with the expansive timeframe suggests ongoing analysis and inquiry within the field. Despite the prolonged attention of scientific researchers, the domain of recommender systems in smart cities remains intricate and evolving, fraught with diverse challenges, including financial and legal considerations. Consequently, scholarly contributions in this area are relatively sparse and demand considerable dedication.

Table 2. Main information about the dataset.

Indicator	Value
Timespan	2014:2023
Sources	26
Documents	31
Average years from publication	3.71
Average citations per documents	16.03
Average citations per year per document	3.153
References	1760

Examining the average publication year, a modest value of 3.71 emerged, underscoring the contemporary nature of the study and signaling the prevalence of recent scholarly output. Furthermore, the calculated averages for citations per document and citations per year per document underscored the academic significance of the literature surrounding recommender systems in smart cities. This observation was reinforced by the substantial number of references, totaling 1760, affirming the scholarly depth and breadth of the field.

Figure 3 distinctly illustrates the upward trajectory of published papers in the realm of recommender systems in smart cities, with an average annual scientific production growth of 25.85%. It should be noted that for the annual growth rate, the value is offered by Biblioshiny [42]—part of the Bibliometrix-R package 4.0.0. The value can also be computed through the use of the following formula:

$$Annual\ Growth\ Rate = \left(\frac{Final\ Year\ Production}{Initial\ Year\ Production}\right)^{\frac{1}{Time\ Span}} - 1$$

Here, it should be noted that the initial and final years used by Biblioshiny for determining the initial and final years' production refers to the initial and the final years for the latest period of the timespan in which all years had at least one publication, while the timespan refers to the period between the initial and final years of the latest period of the timespan in which all years had at least one publication. Thus, in our case, the annual growth rate was determined as:

$$\begin{aligned} Annual\ Growth\ Rate &= \left(\frac{2023\ Year\ Production}{2017\ Year\ Production}\right)^{\frac{1}{Time\ Span\ between\ 2017\ and\ 2013}} - 1 \\ &= \left(\frac{5}{1}\right)^{\frac{1}{7}} - 1 = 1.2585 - 1 = 0.2585 = 25.85\% \end{aligned}$$

The field exhibited a modest inception, as evidenced by the limited number of publications. Among the 31 articles analyzed, only 1 was published in 2014, with subsequent years displaying sparse publication activity, including 2 years with no recorded publications. Notably, 2017 saw the emergence of a single publication. However, academic interest ap-

pears to have intensified starting from 2018, culminating in a peak of six articles published in 2021.

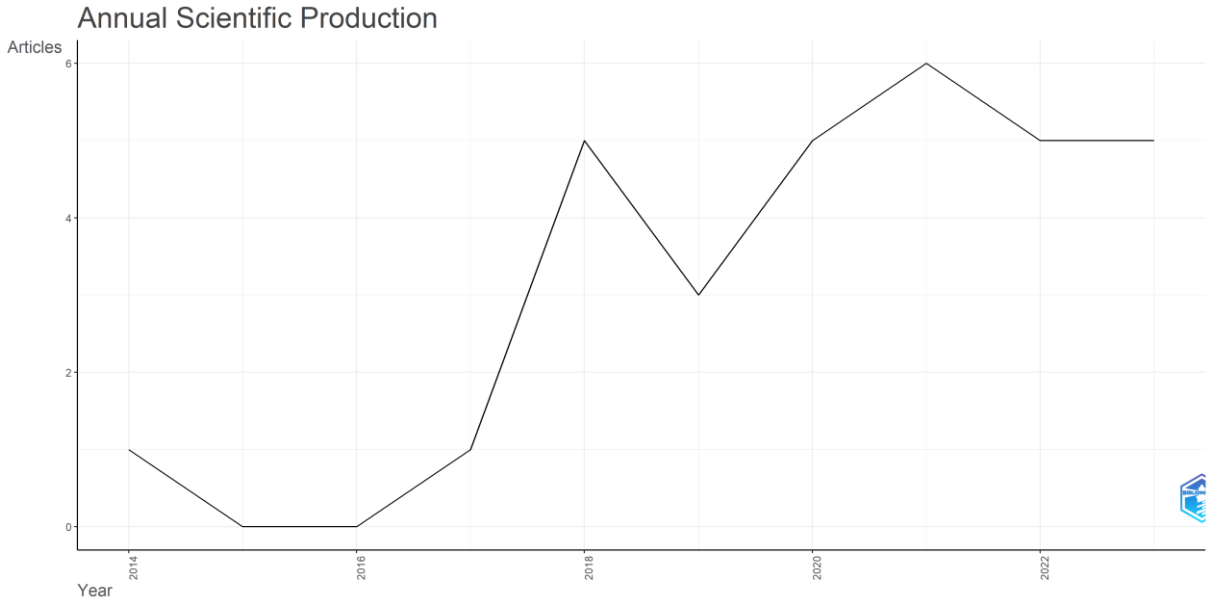


Figure 3. Annual scientific production evolution.

The surge in publication output may be attributed to various factors. One plausible explanation is the onset of the COVID-19 pandemic, which prompted global concern and accentuated the imperative for optimal, innovative, and efficient solutions to crisis scenarios. This urgency, encompassing the optimization of resource utilization, enhancement of decision-making processes, and cultivation of a more sustainable and intelligent urban environment, likely spurred increased scholarly activity in the field.

Figure 4 illustrates the evolution of average citations per year, showcasing an erratic and fluctuating pattern characterized by values ranging from 0.67 to 5.40. This variability serves as compelling evidence for the moderate to high visibility of the papers within the academic sphere.

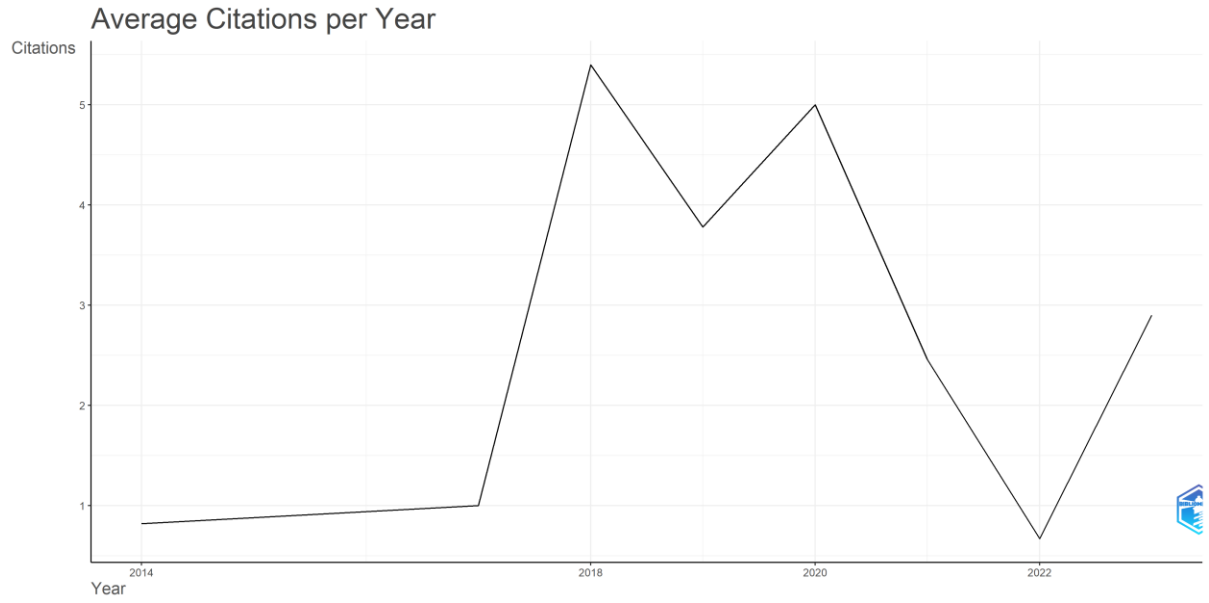


Figure 4. Evolution of annual average article citations per year.

Table 3 sheds light on document contents by underling two main indicators: keywords plus (knows as index terms) and authors' keywords.

Table 3. Document contents.

Indicator	Value
Keywords plus	57
Authors' keywords	137

There were 57 keywords plus registered, and the use of a concentrated vocabulary was evidenced by the obtained average of 1.84 such terms per document (value resulted from the division of keywords plus and number of documents included in the bibliometric analysis).

Regarding authors' keywords, a value of 137 was recorded, with an average of 4.42 such terms per document (division between authors' keywords and total number of documents).

Table 4 brings to light intriguing insights concerning authors in the domain of recommender systems in smart cities. Notably, there was a conspicuous disjunction between the total count of authors and the quantity of articles pertaining to this subject matter. The disparity, with nearly five times as many authors as articles, underscores a prevalent trend of collaboration among academics within this field.

Table 4. Authors.

Indicator	Value
Authors	138
Author appearances	141
Authors of single-authored documents	3
Authors of multi-authored documents	135

Additionally, a nuanced observation arose from the frequency of authors' appearances. It becomes apparent that certain authors contributed to multiple papers, as indicated by the discrepancy between the number of authors' appearances (141) and the total count of unique authors (138).

The heightened degree of collaboration within this research domain is further underscored by the prevalence of multi-authored documents, totaling 137. It is noteworthy to mention that while collaboration is prevalent, three single-authored papers were also included in the analyzed collection of articles.

Table 5 further elucidates the discourse surrounding authors and provides additional evidence regarding collaborations within the domain of recommender systems in smart cities. Building upon the previously highlighted increased degree of collaboration among academics, the values presented in this table serve to reinforce the initial hypotheses and furnish additional substantiation on this topic.

Table 5. Authors' collaboration.

Indicator	Value
Single-authored documents	3
Documents per author	0.225
Authors per document	4.45
Co-authors per document	4.55
Collaboration index	4.82

Authors who contributed monographic papers were found to have done so with an average of precisely one document. This calculation was derived by dividing the total

count of authors of single-authored documents (3) by the number of single-authored documents (3).

Moreover, the reduced value recorded for the documents per author indicator (0.225) lends further credence to the aforementioned assumptions. Predictably, numerical measurements for authors per document (4.45), co-authors per document (4.55), and collaboration index (4.82) followed suit, offering insights into the collaborative dynamics prevalent within this academic sphere.

3.2. Sources

Figure 5 directs attention to the most relevant sources. The top tier showcases journals that have published at least two articles pertaining to recommender systems in smart cities.

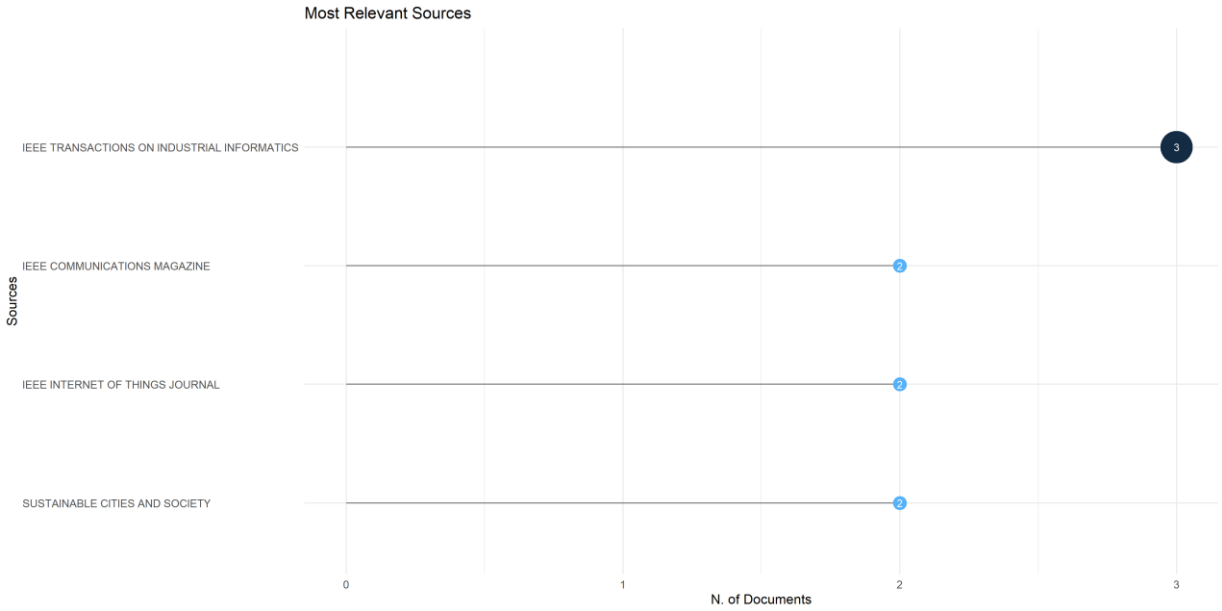


Figure 5. Top four most relevant journals.

At the forefront stands the *IEEE Transactions on Industrial Informatics* journal, with three papers, immediately succeeded by *IEEE Communications Magazine*, *IEEE Internet of Things Journal*, and *Sustainable Cities and Society*, each with two published papers.

It is not a surprise that the specified journals occupy the foremost positions, based on the number of published documents in the studied area. All are very popular within the scientific community, highly esteemed, and oriented toward technological innovations, considered by many academics a good choice for publishing the findings associated with the emerging domain of smart cities.

Figure 6 focuses on core sources by Bradford's law. The specified principle divided three distinct zones based on the sources' significance: core—Zone 1 (significant and highly cited journals), center—Zone 2 (journals with moderate productivity), and external—Zone 3 (less influential journals) [46,47].

As expected, the journals that placed as the top four most relevant sources were also found among Zone 1, categorized as influential and widely cited, including *IEEE Transactions on Industrial Informatics*, *IEEE Communications Magazine*, *IEEE Internet of Things Journal*, *Sustainable Cities and Society*, *ACM Transactions on Intelligent Systems and Technology*, and *AI and Society*.

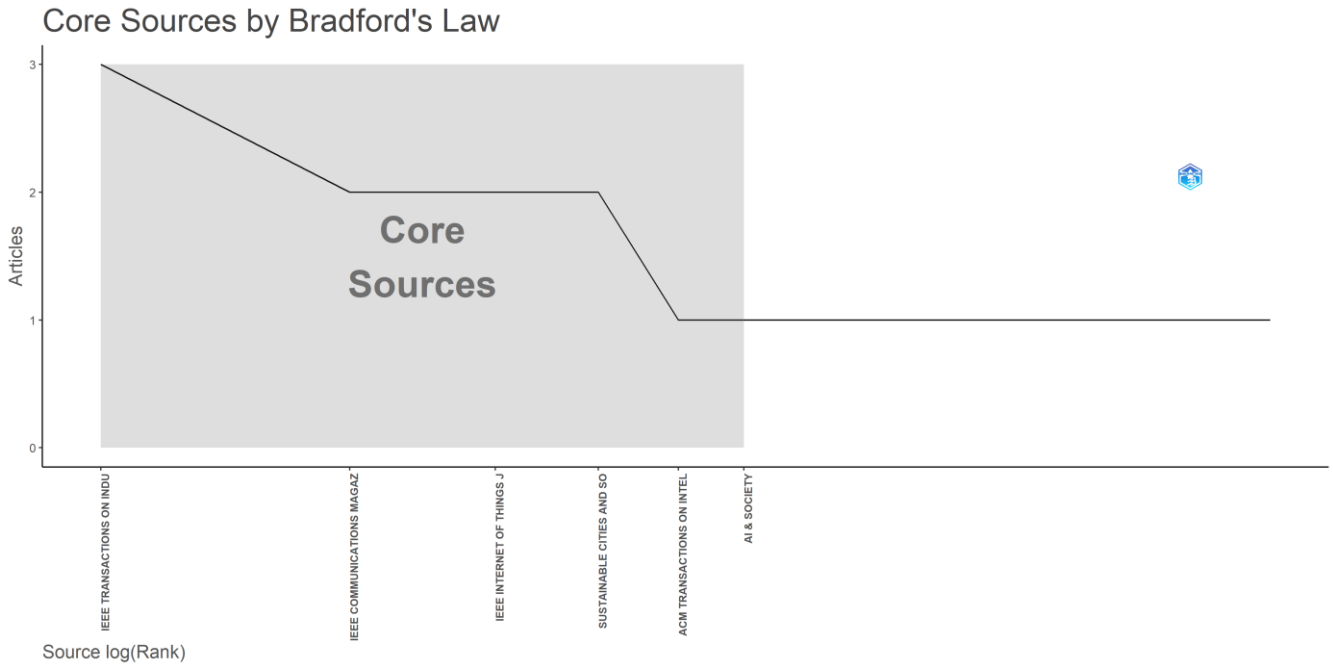


Figure 6. Bradford's law on source clustering.

This again proves the assumption underlined above: the specified journals are truly relevant within the scientific community, placing them as key contributors for the development of the domain. The authors' decision of publishing their papers within one of the specified journals, along with the significant number of citations gathered by the journals in different works associated with the field of smart cities, further highlights their importance, increased productivity, and influence among academics, being considered valuable weapons for understanding the subject matter.

Figure 7 provides insight into sources' local impact according to the H-index, a crucial metric used to determine how significant a journal is. From a theoretical point of view, the greater the value of the indicator, the greater the impact, influence, and productivity of the journal within the scientific community.

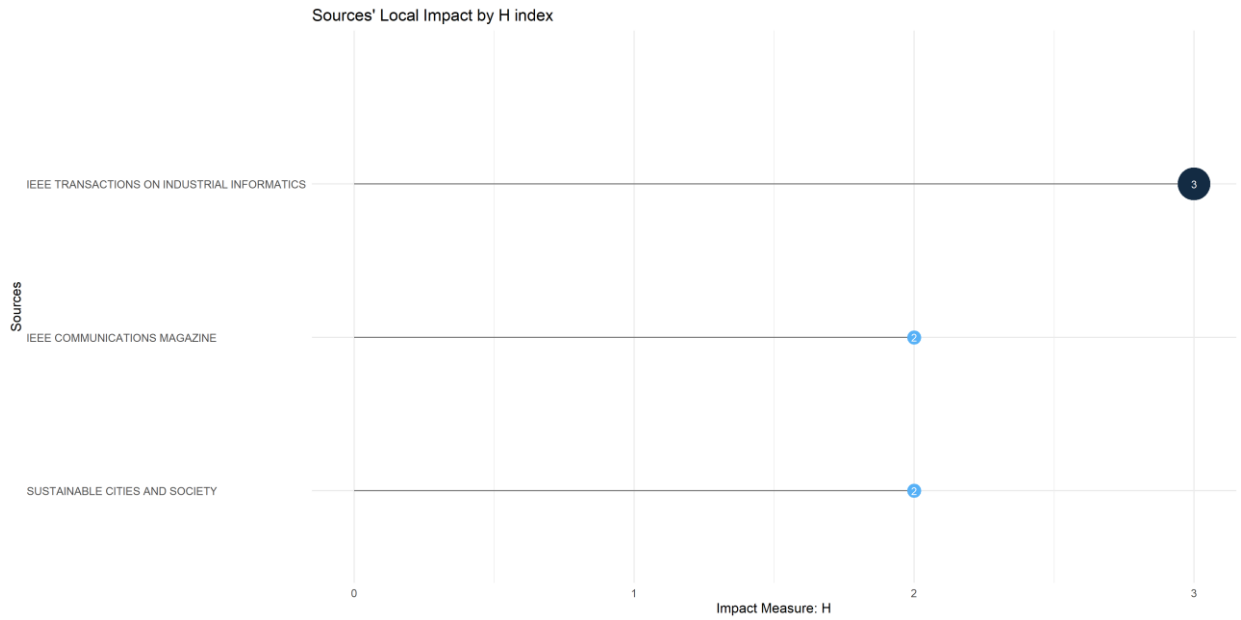


Figure 7. Journals' impact based on the H-index.

As expected, *IEEE Transactions on Industrial Informatics* held the leader position, with three citations. To be more precise, in this journal, at least three papers associated with the area of smart cities were published, and each had at least three citations.

The next place was occupied by other noteworthy and popular journals, more specifically, *IEEE Communications Magazine* and *Sustainable Cities and Society*, each with a recorded value of two for the H-index indicator (at least two papers with at least two citations).

To further explore the dataset, Figure 8 brings to fore the journals' growth (cumulative) based on the number of papers. By analyzing the below snapshot, one can easily notice a user-friendly graph, presenting two main axes: the x-coordinate incorporates chronological years involved in the analysis, more specifically, the period between 2014 and 2023, while the y-coordinate suggests the cumulate occurrences. Situated beneath the illustration, the reader can examine an intuitive legend, in which each journal is associated with a unique color. In this manner, the production over time for each journal is effortlessly depicted in the graph for the desired period.

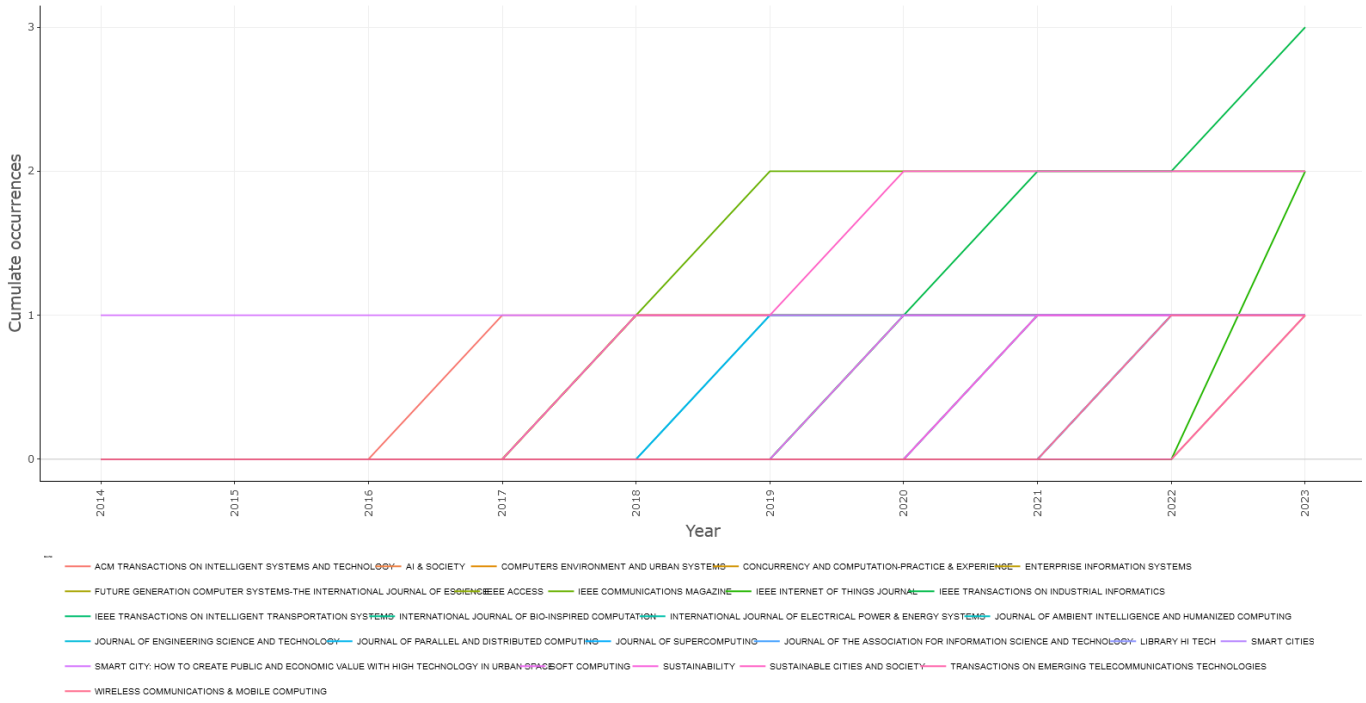


Figure 8. Journals' growth (cumulative) based on the number of papers.

The details revealed from the figure were not surprising, again confirming that the journals with notable growth were *IEEE Communications Magazine*, *Sustainable Cities and Society*, *Smart City: How to Create Public and Economic Value with High Technology in Urban Space*, *IEEE Transactions on Industrial Informatics*, and *ACM Transactions on Intelligent Systems and Technology*.

This figure further emphasized and proved the significance and influential contribution of the journals classified as key contributors within the area of recommender systems in smart cities, assumptions also underlined in the previous pages.

3.3. Authors

Figure 9 directs the attention to the most relevant authors, taking into consideration a predefined rule that restricts the presence at the top for the academics with less than two published articles relevant to the recommender systems in smart cities domain.

Consequently, a particularly uncommon situation can be observed, in which each of the three scientists in the hierarchy recorded an equal number of manuscripts, more specifically, two, that were written and published in Web of Sciences indexed journals. Thus, we

provide the names of the three authors, in alphabetical order: Gao XZ, Subramaniyaswamy V, and Vijayakumar V.

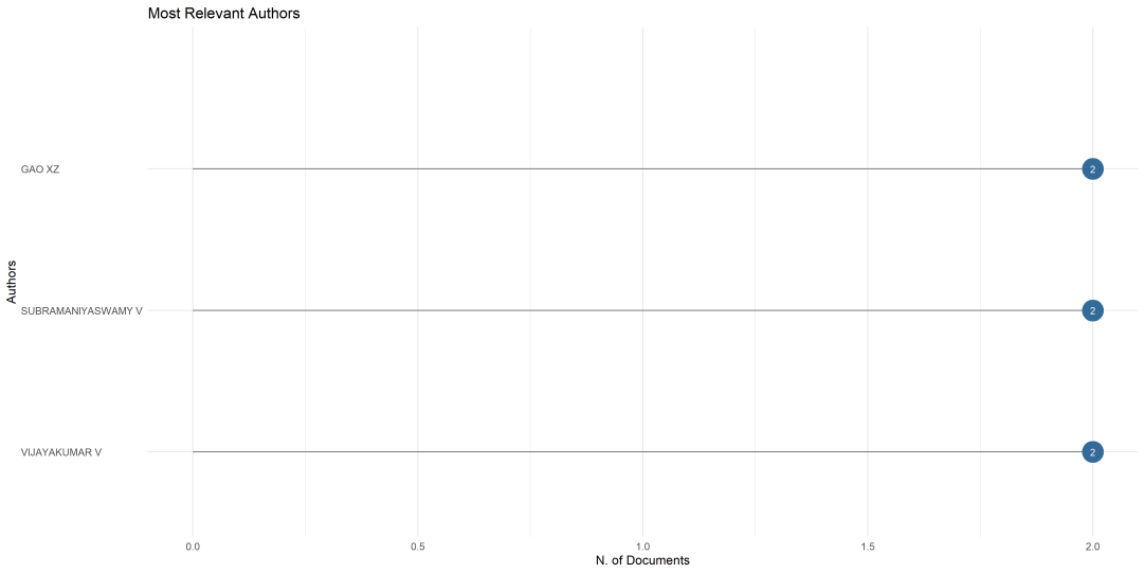


Figure 9. Top three authors based on number of documents.

This graphical illustration proved the significant involvement of the three authors in the examined field and their increased interest in studying and enhancing the citizens' life, as well as investigating possible strategies for improving urban environments. They are considered key contributors in this area, and their papers are valuable assets for the scientific community and beyond.

Figure 10 depicts the top 10 authors' production over time. As already discussed above, the area of recommender systems in smart cities had a slow evolution in terms of publications within the scientific community. This field is still under development and, possibly, this could be associated with the fact that the development of smart cities is not only from a theoretical point of view, but also requires a lot of resources, costs, and data for testing. This represents the need for both institutions and people oriented toward this field to allocate greater importance to academics to support and provide them with the necessary resources, so as to encourage them to continue the development of this area. The teamwork in this domain is crucial and the evolution of urban regions will not be possible if people involved in this process do not communicate and support each other.

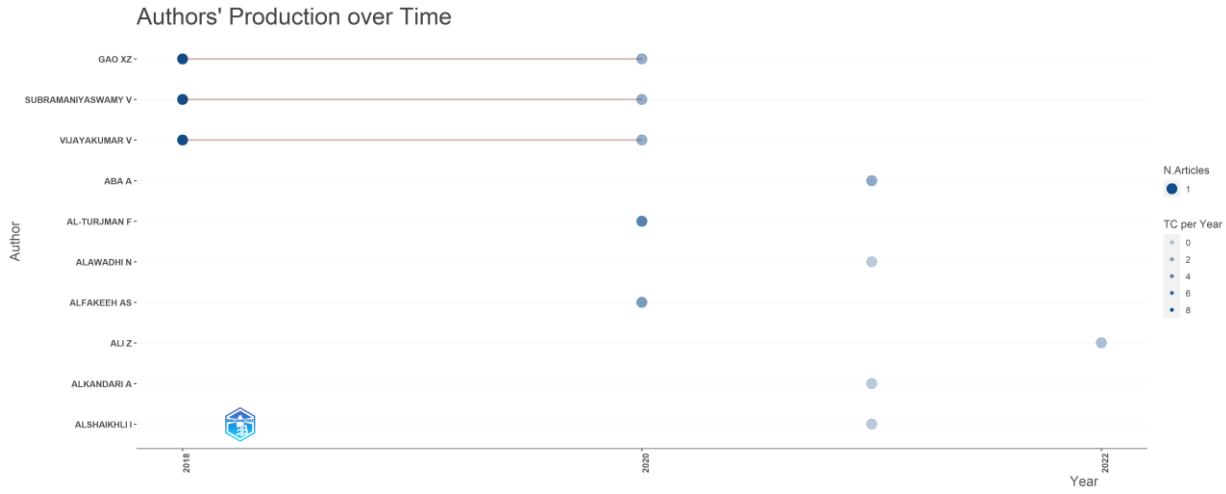


Figure 10. Top 10 authors' production over time.

One can easily notice that the most prolific authors in this domain are Gao XZ, Subramaniyaswamy V, and Vijayakumar V, each with two published articles within 2018–2020, and the list is completed by other scientists that published at most one article in this area during the analyzed timespan.

In terms of universities, Figure 11 classifies the top 12 most relevant affiliations that recorded at least two published manuscripts in the domain of recommender systems in smart cities.

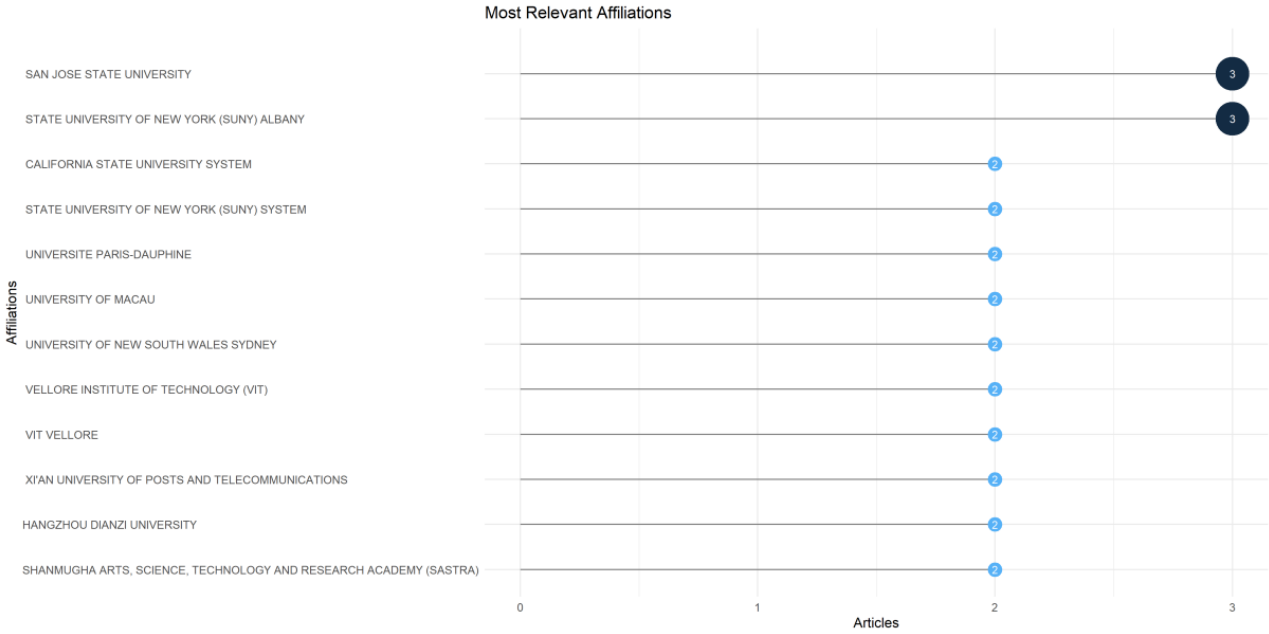


Figure 11. Top 12 most relevant affiliations.

This figure shows the universities that had a remarkable contribution in this field, suggesting that their students benefited from exemplary academic guidance, with a focus on technological innovation. All these assumptions are highlighted in the published papers, which represent valuable weapons for the development of this domain.

The foremost positions are held by two universities, both with three published articles: San Jose State University and State University of New York (Suny), Albany.

Other affiliations, each with two published articles, are listed in alphabetical order, as follows: California State University System, State University of New York (Suny) System, Universite Paris-Dauphine, University of Macau, University of New South Wales, Sydney, Vellore Institute of Technology (Vit), Vit Vellore, Xi'an University of Posts and Telecommunications, Hangzhou Dianzi University, and Shanmugha Arts, Science, Technology, and Research Academy (Sastra).

Figure 12 provides the top 15 most relevant corresponding authors' countries.

Through a rigorous investigation of the below visual representation, it can be noted that China sits atop the hierarchy, with seven papers, recording high values for both examined indicators: single and multiple country publications (the red segment—MCP = 2 and the green segment—SCP = 5).

India placed second, with five published articles (MCP = 3 and SCP = 2), followed closely by the USA with three scientific works (MCP = 1 and SCP = 2). For the entire list, please refer to Figure 12.

This analysis is truly relevant to the studied area, since it highlights hidden factors and trends, such as authors' collaborations and the global impact of the subject matter and offers a comprehensive understanding of the international academic landscape. This may help institutions to develop enhanced strategies, best practices, and appropriate decisions for the research domain.

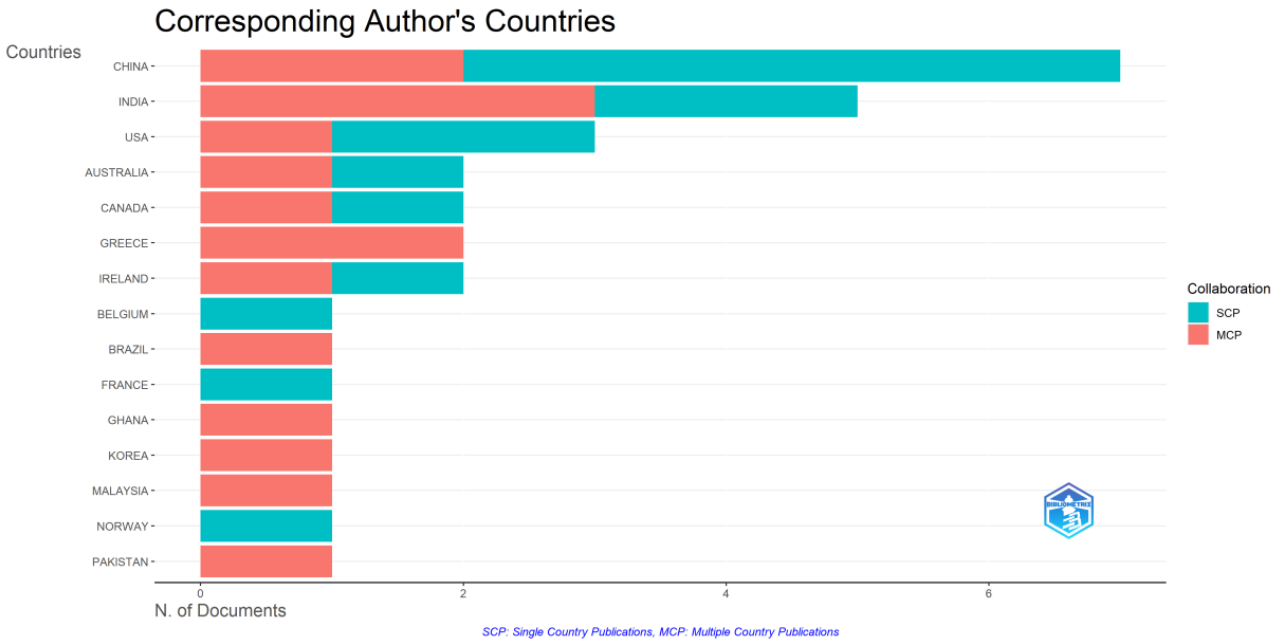


Figure 12. Top 15 most relevant corresponding authors' countries.

Figure 13 illustrates the scientific production based on country via a colored representation of the globe, in which the more pronounced the blue color, the greater the productivity of papers written in the area of recommender systems in smart cities.

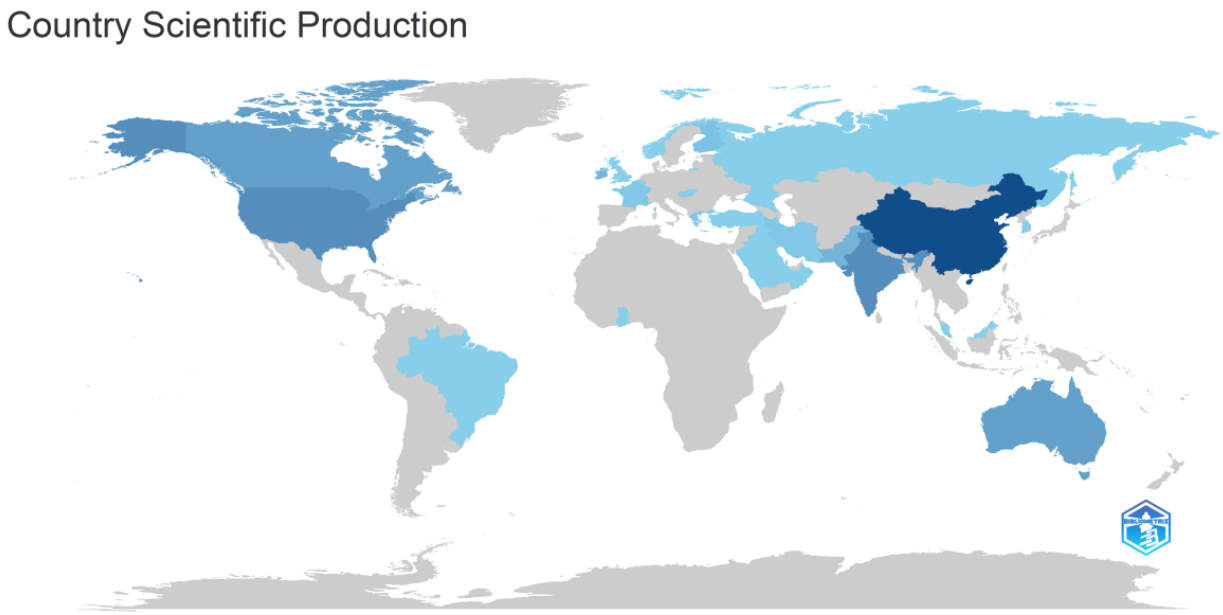


Figure 13. Scientific production based on country.

For instance, as expected based on the above discussions, China reflects a boost in productivity, while other countries, such as Russia, Turkey, and the UK, are experiencing a low productivity.

The top 15 countries according to the number of citations are depicted in Figure 14. As expected, the first position is held by China, which recorded an impressive value of 202 citations, followed thereafter, at a substantial difference, by India with 91 citations, and the USA with 62 citations.

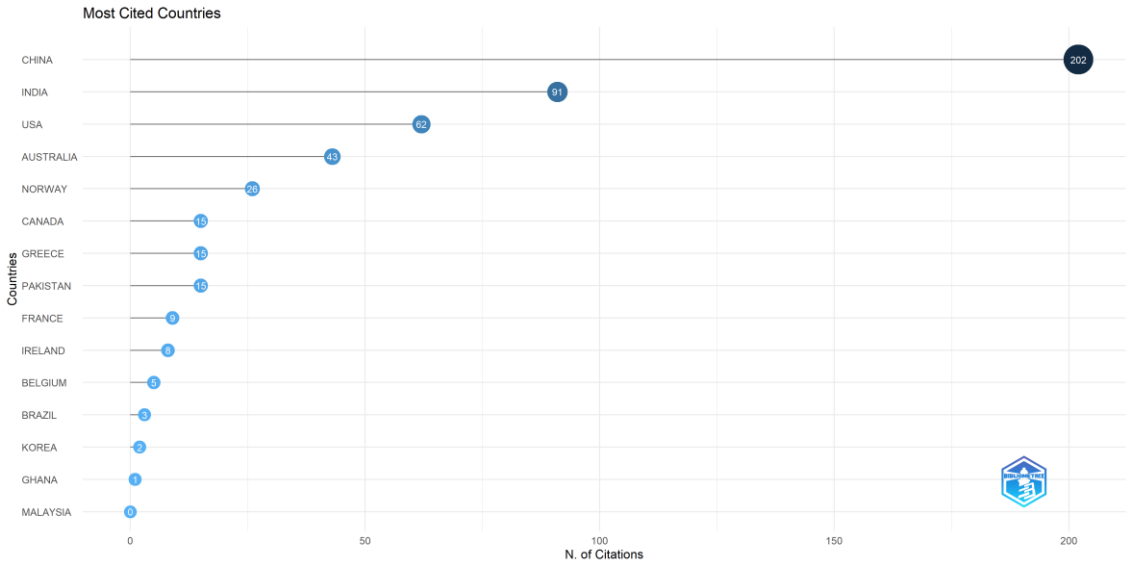


Figure 14. Top 15 countries with the most citations.

For the entire hierarchy, please consider the information in Figure 14.

In contrast to other analogous studies encompassing a diverse array of topics and involving a substantial number of authors from various nations, Figure 15 underscores a markedly restrained and diminished level of international collaboration in the present bibliometric analysis. Specifically, only 15 countries globally have contributed articles within the realm of recommender systems in smart cities. This constrained international collaboration could potentially be attributed to the limitations of the database employed.

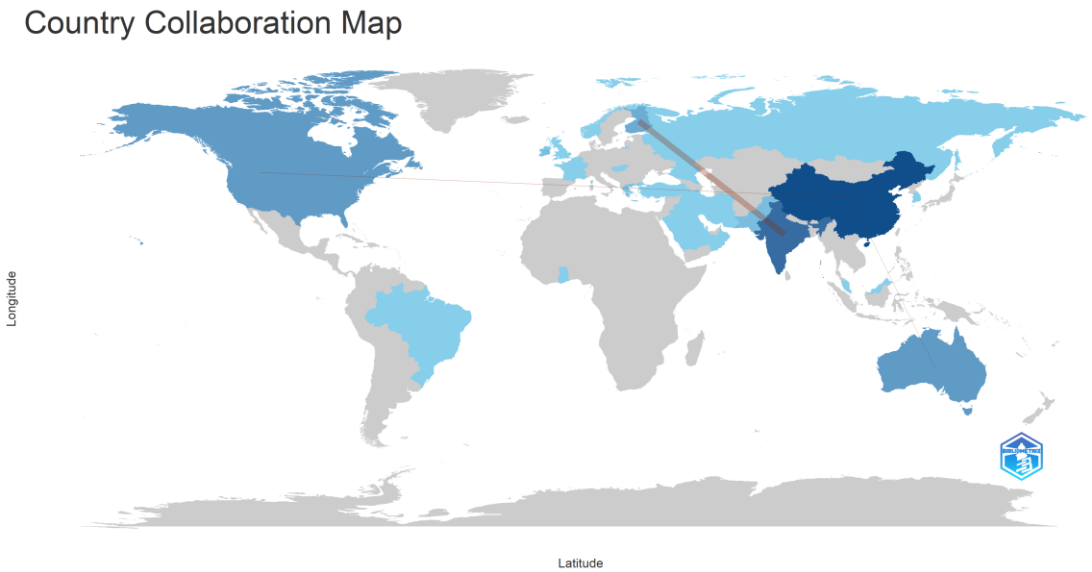


Figure 15. Country collaboration map.

Nevertheless, among the countries exhibiting the highest degree of collaboration, China prominently occupies the top position. China has fostered collaborative partnerships in manuscript authorship with several other countries, including Australia, Canada, Finland, India, Iran, Iraq, and the USA.

Figure 16 offers a graphical representation of the collaboration networks among the top 50 authors, employing color coding to denote their affiliations with different research groups.

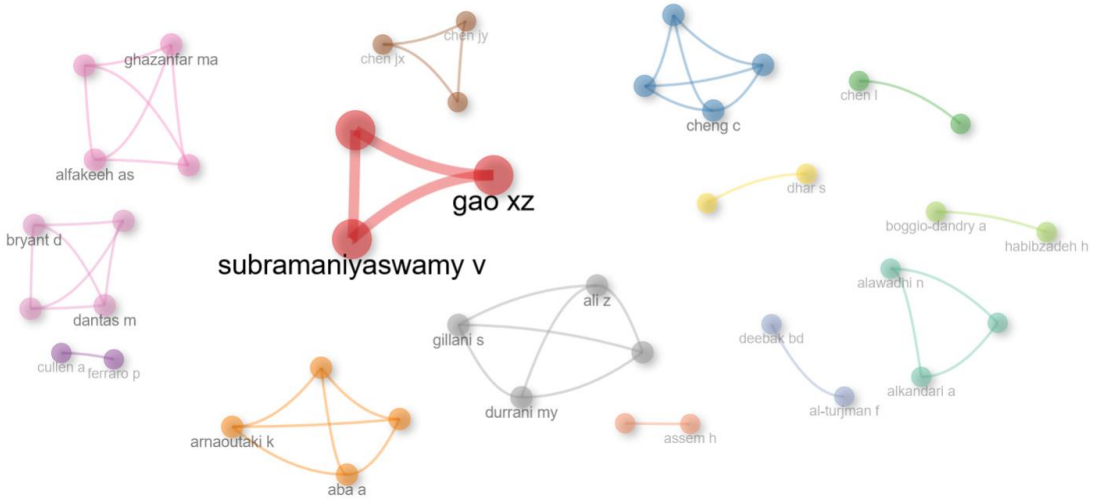


Figure 16. Top 50 authors collaboration network.

3.4. Analysis of Literature

The main purpose of this section is to explore the existing literature published within the scientific community in the area of recommender systems in smart cities.

The first subsection provides an overview of the documents, including general details about the paper (author name, year of publication, journal in which it was published, and references), along with the number of authors who collaborated in writing the manuscript, their region of provenance, and some crucial indicators (total citations, total citations per year, and normalized total citations), relevant for understanding the paper's significance within academics.

In order to fulfil the initial goal of obtaining a comprehensive picture of the literature around this interesting topic, the dataset consisting of 31 articles was split in the second subsection, into 4 distinct categories, based on the approach followed in the investigation:

- Papers that incorporate collaborative filtering.
- Papers that incorporate recommender systems.
- Papers that incorporate other approaches.
- Review papers.

Utilizing this categorization, the papers were scrutinized and succinctly summarized to underscore the primary themes addressed within the domain investigated in this paper. This analysis involved delineating the purpose, methodologies employed, challenges encountered, results obtained, and prospective areas necessitating further exploration or improvement.

The last subsection offers a broad examination of the words, focusing on keywords plus, authors' keywords, bigrams, and trigrams, offering visual representation for a better understanding of the subject matter, including word clouds, a co-occurrence network for the terms in authors' keywords, and a thematic map based on authors' keywords.

3.4.1. Papers Included in the Bibliometric Analysis—Overview

Table 6 brings to the foreground general details about the 31 papers included in the bibliometric analysis. While the descriptions for the TC and TCY indicators are comprehensive considering their extended names, further information should be provided on the calculus of the NTC indicator. Therefore, the NTC value was obtained by dividing the value of the TC for a specific paper by the average citations per document recorded in the database for the year in which the paper was published [48]. Also, it should be noted that the NTC gives equal credit to all the authors of a publication; thus, it is not sensitive to the number of authors of a publication.

Table 6. The 31 papers included in the dataset—overview.

No.	Paper (First Author, Year, Journal, Reference)	Number of Authors	Region	Total Citations (TC)	Total Citations per Year (TCY)	Normalized TC (NTC)
1	Wang W, 2020, IEEE Transactions on Industrial Informatics, [49]	6	China, Macao	75	15.00	3.00
2	Ng CK, 2018, Enterprise Information Systems, [50]	5	China	59	8.43	1.56
3	Logesh R, 2018, Future Generation Computer Systems, [51]	5	India, Finland	56	8.00	1.48
4	Habibzadeh H, 2018, IEEE Communications Magazine, [52]	6	Albany, China, Canada	39	5.57	1.03
5	Anthony B, 2021, AI & Society, [53]	1	Norway	26	6.50	2.64
6	Zhang F, 2019, Journal of Parallel and Distributed Computing, [54]	8	China, USA, Australia	25	4.17	1.10
7	Liu YW, 2023, IEEE Transactions on Industrial Informatics, [55]	8	China, Iran, Iraq, Finland, India	25	12.50	4.31
8	Nassar MA, 2019, IEEE Communications Magazine, [56]	5	Australia	23	3.83	1.01
9	Deebak BD, 2020, Sustainable Cities and Society, [57]	2	India, Turkey	23	4.60	0.92
10	Eirinaki M, 2018, Computers, Environment and Urban Systems, [58]	7	USA	21	3.00	0.56
11	Li S, 2019, International Journal of Electrical Power & Energy Systems, [59]	5	China, Australia	20	3.33	0.88
12	Xu C, 2021, IEEE Transactions on Industrial Informatics, [60]	7	China	16	4.00	1.63
13	Ayub M, 2020, Soft computing, [61]	5	Pakistan, Saudi Arabia,	15	3.00	0.60
14	Kinawy SN, 2018, Sustainable Cities and Society, [62]	3	Canada	14	2.00	0.37
15	Negre E, 2014, Progress in IS, [63]	2	Paris	9	0.82	1.00
16	Sivaramakrishnan N, 2020, International Journal of Bio-Inspired Computation, [64]	6	India, Australia, Finland	9	1.80	0.36
17	Arnaoutaki K, 2021, Sustainability-Basel, [65]	6	Greece, Hungary	8	2.00	0.81
18	Assem H, 2017, ACM Transactions on Intelligent Systems and Technology, [66]	3	Ireland	8	1.00	1.00
19	Anagnostopoulos T, 2021, Smart Cities-Basel, [67]	3	Greece	7	1.75	0.71
20	Smets A, 2022, Journal of the Association for Information Science and Technology, [68]	3	Belgium	5	1.67	2.50
21	Neves F, 2020, IEEE Access, [69]	7	Brazil, Canada	3	0.60	0.12
22	Rahim A, 2022, The Journal of Supercomputing, [70]	6	Pakistan, Oman, Korea	2	0.67	1.00
23	Gill HK, 2022, Library Hi Tech, [71]	3	India	2	0.67	1.00
24	Narman HS, 2021, Journal of Ambient Intelligence and Humanized Computing, [72]	3	USA	2	0.50	0.20
25	Rafique W, 2023, Transactions on Emerging Telecommunications Technologies, [73]	3	Canada, Qatar	1	0.50	0.17
26	Li YHZ, 2023, IEEE Internet of Things Journal, [74]	4	China	1	0.50	0.17
27	Katarya R, 2023, Concurrency and Computation: Practice and Experience, [75]	1	India	1	0.50	0.17
28	Li Y, 2023, IEEE Internet of Things Journal, [76]	8	China	1	0.50	0.17
29	Sharma R, 2022, Wireless Communications and Mobile Computing, [77]	3	India, Ghana	1	0.33	0.50
30	Alawadhi N, 2021, Journal of Engineering Science and Technology, [78]	3	Malaysia, Kuwait	0	0.00	0.00
31	Overko R, 2022, IEEE Transactions on Intelligent Transportation Systems, [79]	6	Ireland, UK	0	0.00	0.00

Upon initial examination, as elucidated and explored in the preceding section, it became evident that collaboration among academics within the realm of recommender systems in smart cities has notably intensified. Further investigation into the number of authors for each paper revealed that 29 out of 31 articles were the product of collaborative endeavors.

Additionally, it was unsurprising that among the most prominent countries contributing to the publication of articles in this domain were China, the USA, and India.

In terms of accumulated citations over time, the leading position was occupied by the manuscript authored by Wang et al. [49], boasting top values across all three indicators: total citations (TC) = 75, total citations per year (TCY) = 15.00, and normalized total citations (NTC) = 3.00.

Following closely was the article authored by Ng et al. [50] (TC = 59, TCY = 8.43, and NTC = 8.00), with Logesh et al. [51] trailing behind (TC = 56, TCY = 8.00, and NTC = 1.48).

Moreover, it is noteworthy that the recorded values for total citations fell within the range of 0 to 75, while TCY spanned from 0 to 15.00, and NTC varied between 0 and 3.00. These figures underscore the moderate to high visibility and relevance of papers addressing recommender systems in smart cities within the scientific community.

3.4.2. Papers Included in the Bibliometric Analysis—Review

As already mentioned above, in this subsection, the dataset collected for the present bibliometric analysis will be divided and examined based on the approaches/techniques used.

Considering the 31 articles extracted from the Web of Science platform, we decided to divide them into 4 main categories: papers that incorporate collaborative filtering, recommender systems, other approaches, and review papers—please refer to Table 7.

According to this assessment, the content of the articles will be briefly summarized, with the purpose of highlighting the key aspects.

Papers That Incorporate Collaborative Filtering

By investigating Table 7, one can observe that 8 out of the total 31 articles included in the analysis incorporated a collaborative filtering approach in their content.

The study conducted by Wang et al. [49] placed first based on the number of citations, proving its significance and relevance within the scientific community by addressing an emerging topic, namely, the recommendation of a personalized point of interest, using collaborative filtering in the context of smart cities. The authors started from the premise that the level of trust between two people is directly influenced by analogous preferences or even personality characteristics, and examined the similarities, also including relevant factors, such as spatial temporal factors (geographic–temporal influence). In the analysis, two popular real-world datasets were involved, referred to as Gowalla and Foursquare, associated with information related to places visited by the users, preferences, activities, reviews, social interactions, etc. In terms of evaluation, the outcome was assessed using two significant metrics: 'precision@k' (computed as the division between the amount of true POIs found in the recommended list and recommendation list k) and 'recall@k' (computed as the amount of true POIs in the recommended list and the number of newly visited POIs), with k being replaced during the tests by five values, namely, 1, 5, 10, 15, and 20. For the Gowalla dataset, precision registered values between 21.65 and 37.25, while recall registered values between 20.24 and 44.44. In the case of the Foursquare dataset, the model performed even better: precision was between 22.12 and 39.21, while recall was between 20.55 and 47.35. It was noticed that if k increased, consequently, the recall curve increased, while the precision curve decreased. The results revealed that the suggested trust-enhanced collaborative filtering technique performed significantly better than other existing alternatives [49].

Table 7. The approaches used in the 31 papers included in the bibliometric analysis.

No.	Paper (First Author, Year, Journal, Reference)	Type of Papers						
		Application-Oriented Papers						Review Papers
		Recommendation Approach			Context-Aware Recommender Systems	Evaluation Criteria	Case Study	
		Collaborative Filtering	Content-Based Recommender Systems	Other Approaches				
1	Wang W, 2020, IEEE Transactions on Industrial Informatics, [49]	✔			✔	Precision, recall	Points of interest (geolocation)	
2	Ng CK, 2018, Enterprise Information Systems, [50]					-	-	✔
3	Logesh R, 2018, Future Generation Computer Systems, [51]	✔			✔	Hit-rate, precision, recall, F-measure, accuracy	Urban trip	
4	Habibzadeh H, 2018, IEEE Communications Magazine, [52]		✔			-	-	
5	Anthony B, 2021, AI & Society, [53]		✔			Based on a questionnaire with 8 components: recommendation content, recommendation presentation, system quality, information quality, service quality, CBR search, security and trust, system support	Dataset containing smart city initiatives	
6	Zhang F, 2019, Journal of Parallel and Distributed Computing, [54]	✔				Root-mean-square error (RMSE), scale-up, size-up, speed-up	MovieLens I, MovieLens II, Epinions, Netflix datasets.	
7	Liu YW, 2023, IEEE Transactions on Industrial Informatics, [55]			✔		Recall, normalized discounted cumulative gain	Foursquare, Gowalla, NYC, and TKY datasets.	
8	Nassar MA, 2019, IEEE Communications Magazine, [56]					-	-	✔

Table 7. *Cont.*

No.	Paper (First Author, Year, Journal, Reference)	Type of Papers						
		Application-Oriented Papers						Review Papers
		Recommendation Approach			Context-Aware Recommender Systems	Evaluation Criteria	Case Study	
		Collaborative Filtering	Content-Based Recommender Systems	Other Approaches				
9	Deebak BD, 2020, Sustainable Cities and Society, [57]		✔			Mean absolute error, rate coverage, root-mean-square error (RMSE), F-measure	Epinions, FilmTrust, Ciao datasets.	
10	Eirinaki M, 2018, Computers, Environment and Urban Systems, [58]	✔			✔	-	Real permit data from New York City.	
11	Li S, 2019, International Journal of Electrical Power & Energy Systems, [59]	✔			✔	Prediction accuracy (mean absolute error, root-mean-square error (RMSE)).	Electricity Tariff using an Australian dataset.	
12	Xu C, 2021, IEEE Transactions on Industrial Informatics, [60]		✔			Matrix factorization (MF), neural matrix factorization (NeuMF), dual-attention mutual leaning (DAML), visual Bayesian personalized ranking (VBPR), multi-view visual Bayesian personalized ranking (MVBPR), visually explainable collaborative filtering (VECF), multi-modal aspect-aware latent factor model (MMALFM)	Restaurants and products datasets.	

Table 7. *Cont.*

No.	Paper (First Author, Year, Journal, Reference)	Type of Papers						
		Application-Oriented Papers						Review Papers
		Recommendation Approach			Context-Aware Recommender Systems	Evaluation Criteria	Case Study	
		Collaborative Filtering	Content-Based Recommender Systems	Other Approaches				
13	Ayub M, 2020, Soft computing, [61]	✔			✔	Mean absolute error (MAE), root-mean-square error (RMSE), rating coverage (RC), inverse MAE (iMAE), F1-score	Epinions, FilmTrust, CiaoDVD.	
14	Kinawy SN, 2018, Sustainable Cities and Society, [62]		✔		✔	Usability evaluation through a focus group approach	Ontology with limited synthetic data.	
15	Negre E, 2014, Progress in IS, [63]		✔		✔	Utility matrix	Toy example with synthetic data.	
16	Sivaramakrishnan N, 2020, International Journal of Bio-Inspired Computation, [64]	✔				Accuracy, precision, recall, F-measure	Yelp and TripAdvisor datasets.	
17	Arnaoutaki K, 2021, Sustainability-Basel, [65]		✔			User perception evaluated using a questionnaire	Dataset with the travel plans available in the city of Budapest.	
18	Assem H, 2017, ACM Transactions on Intelligent Systems and Technology, [66]			✔		-	Manhattan area data.	
19	Anagnostopoulos T, 2021, Smart Cities-Basel, [67]		✔		✔	Accuracy	Real data from New Philadelphia associated with vehicle ride sharing.	

Table 7. *Cont.*

No.	Paper (First Author, Year, Journal, Reference)	Type of Papers						
		Application-Oriented Papers						Review Papers
		Recommendation Approach			Context-Aware Recommender Systems	Evaluation Criteria	Case Study	
		Collaborative Filtering	Content-Based Recommender Systems	Other Approaches				
20	Smets A, 2022, Journal of the Association for Information Science and Technology, [68]			✔		Questionnaire evaluating relevance, novelty, diversity, serendipity, satisfaction	Dataset with 1641 questionnaire responses.	
21	Neves F, 2020, IEEE Access, [69]		✔		✔	Precision, recall, F-measure, mean absolute error (MAE), root-mean-square error (RMSE)	Multiple case studies associated with different health domains (chronic kidney disease, wound healing control).	
22	Rahim A, 2022, The Journal of Supercomputing, [70]	✔			-	Precision, recall, F-measure, mean absolute error (MAE), root-mean-square error (RMSE)	Epinions, FilmTrust, and Ciao datasets.	
23	Gill HK, 2022, Library Hi Tech, [71]			✔	✔	Accuracy	Synthetic dataset generated for Zika epidemic in Brazil in 2016.	
24	Narman HS, 2021, Journal of Ambient Intelligence and Humanized Computing, [72]		✔		✔	F1-score, precision, recall, confusion matrix	Real-time traffic information from New York.	
25	Rafique W, 2023, Transactions on Emerging Telecommunications Technologies, [73]					-	-	✔

Table 7. *Cont.*

No.	Paper (First Author, Year, Journal, Reference)	Type of Papers						
		Application-Oriented Papers						Review Papers
		Recommendation Approach			Context-Aware Recommender Systems	Evaluation Criteria	Case Study	
		Collaborative Filtering	Content-Based Recommender Systems	Other Approaches				
26	Li YHZ, 2023, IEEE Internet of Things Journal, [74]		✔			Accuracy, training time	-	
27	Katarya R, 2023, Concurrency and Computation: Practice and Experience, [75]					-	-	✔
28	Li Y, 2023, IEEE Internet of Things Journal, [76]			✔				
29	Sharma R, 2022, Wireless Communications and Mobile Computing, [77]					-	-	✔
30	Alawadhi N, 2021, Journal of Engineering Science and Technology, [78]			✔	✔	-	Finding nearby locations.	
31	Overko R, 2022, IEEE Transactions on Intelligent Transportation Systems, [79]			✔		Travel duration, travel distance	Road network in the city of Dublin.	

The manuscript of Logesh et al. [51] focused on urban trip recommendations in the context of smart cities, proposing a new approach of user clustering that employs the utilization of Quantum-behaved Particle Swarm Optimization (QPSO). The recommender system based on collaborative filtering was assessed using real datasets from two popular online platforms relevant for this area, more specifically, Yelp and TripAdvisor. Apart from this, the authors also provided a new framework for urban trip recommendations, called XplorerVU. For the evaluation, the scientists used relevant metrics for proving the suitability of the model: hit-rate, precision, recall, accuracy, and F-measure. The formula for each indicator, along with visual representations and comparisons, are presented in the manuscript. As for the first dataset, Yelp, according to the recommendation approach, precision ranged from 0.6255 to 0.7653, recall from 0.5834 to 0.6692, F-measure from 0.6037 to 0.7140, accuracy from 80.65 to 96.54, and hit-rate from 55.34 to 79.36. In the case of the TripAdvisor dataset, precision ranged from 0.5967 to 0.7124, recall from 0.5808 to 0.6832, F-measure from 0.5886 to 0.6975, accuracy from 80.21 to 96.12, and hit-rate from 54.42 to 78.49. The results seem satisfactory and demonstrated high effectiveness.

In the study conducted by Zhang et al. [54], a very interesting and crucial issue in today's technological era was brought to light—privacy in recommender systems, in the context of smart cities. The scientists investigated the recommender system based on collaborative filtering for privacy awareness via a rating matrix, proving the significance of their work.

The next article, written by Eirinaki et al. [58], addressed another critical challenge for smart cities, namely, a system for building permits using collaborative filtering. The system proposed by the writers is fully based on the cloud, making it easy and cheap to implement, being a valuable weapon for both citizens and institutions involved in this complex process, saving time, and providing efficiency in multiple areas (decision workflows, planning processes, data analytics, etc.). The study considered factors such as time, location, and even request type, associated with the users. The relevance of the framework was further proven using real data from a popular and crowded city (New York). By using the graphical user interface of the permit system, exploratory data analysis was performed, shedding light on interesting aspects for city officials (seasonal/quarterly permit trends, expiration analysis, geolocation, decision process flow, and recommendations).

The paper by Li et al. [59] addressed a key topic in today's technological world, focused on a novel electricity tariff generation, which aims to be personalized for each individual. They started by collecting a relevant dataset for electricity consumption and examined it using an innovative matrix-factorization approach, based on collaborative filtering, with the main purpose of coming up with an original and efficient recommendation system for this subject matter. Throughout the use of 90 power consumption profiles of Australian users, the scientists presented relevant graphs, such as power consumption distribution across time or electricity price based on time. For evaluating the matrix, the mean absolute error (MAE) and root-mean-square error (RMSE) were computed. In the case of MAE, the presented method registered a value of 0.2361, while RMSE was 1.0134, highlighting that the prediction accuracy of the method recorded satisfactory results, in comparison to other approaches (for Item-Based CF, MAE = 0.4321 and RMSE = 1.2547; for User-Based CF, MAE = 0.4873 and RMSE = 1.3491).

The study by Ayub et al. [61] was centered around the collaborative filtering method engaged in offering individually tailored services for citizens in the context of smart cities. Guided by the desire to improve the level of satisfaction and the quality of life for citizens, the authors included implicit and explicit trust as well as the similarity of user preferences in their analysis, so as to produce an efficient recommendation for any individual. For conducting the experiments, three online datasets were used: FilmTrust, CiaoDVD, and Epinions. The evaluation metrics used in this paper included mean absolute error (MAE), root-mean-square error (RMSE), rating coverage (RC), inverse MAE (iMAE), and F1-score. All the computed values were nicely presented by the authors using suggestive graphs

and tables. The results demonstrated the study's effectiveness, representing a valuable and powerful resource for the scientific community.

Sivaramakrishnan et al. [64] focused on another relevant topic for the analyzed area, namely, proposing an innovative recommender system employing collaborative filtering based on user clusters. The main purpose of the manuscript was to provide individuals with relevant suggestions for locations. The scientists utilized the grey wolf optimization algorithm, Pearson correlation coefficient, and cosine similarity, and evaluated the accuracy of the system using real-world datasets, also used by other researchers in previous studies: TripAdvisor and Yelp. In terms of evaluation metrics, the authors considered four main relevant indicators: accuracy, precision, recall, and F-measure. In the case of the cosine prediction model for different recommendation approaches, the Yelp dataset registered the following intervals for the indicators: $78.38 \leq$ accuracy ≤ 81.98, $53.65 \leq$ precision ≤ 57.42, and $11.38 \leq$ recall ≤ 17.82, while for the TripAdvisor dataset: $78.28 \leq$ accuracy ≤ 81.92, $53.57 \leq$ precision ≤ 57.34, and $11.27 \leq$ recall ≤ 17.74. On the other hand, for the Pearson prediction model, the following values were recorded for the Yelp dataset: $78.44 \leq$ accuracy ≤ 82.05, $53.75 \leq$ precision ≤ 57.49, and $11.44 \leq$ recall ≤ 17.93, while for Trip Advisor: $78.37 \leq$ accuracy ≤ 81.99, $53.66 \leq$ precision ≤ 57.42, and $11.36 \leq$ recall ≤ 17.81. The graphs associated with the analysis of the F-measure can be observed in the manuscript, with interesting insights highlighted. The outcomes proved the efficiency and applicability of the presented recommender system.

The study by Rahim et al. [70] was centered on providing an effective and innovative recommender system based on collaborative filtering. In this regard, the authors came up with an original approach, more specifically, a technique called TrustASVD++, which integrates matrix factorization and users' trust data and assesses the efficiency of the system using various datasets (Epinions, FilmTrust, and Ciao), proving its significance and utility compared to existing approaches. The evaluation metrics involved five important indicators, namely, precision, recall, F-measure, mean absolute error (MAE), and root-mean-square error (RMSE). The authors provided all the formulas, required information needed for understanding the computations, along with values recorded for each indicator, distributed separately for each dataset involved in the analysis: CIAO dataset (MAE = 0.574, RMSE = 0.782, precision = 0.647, recall = 0.990, and F1-score = 0.782), Epinions dataset (MAE = 0.650, RMSE = 0.888, precision = 0.720, recall = 0.959, and F1-score = 0.823), and FilmTrust dataset (MAE = 0.574, RMSE = 0.746, precision = 0.701, recall = 0.965, and F1-score = 0.812). All the values suggest the increased performance of the innovative technique presented. More insights and details about this area are presented in the article.

Papers That Incorporate Content-Based Recommender Systems

This subsection covers the articles that incorporate recommender systems, being the most abundant category among the four delimited at the beginning of the review section. It contains a significant number of almost half of the entire dataset included in the current bibliometric analysis: 12 out of 31 papers. Please direct your attention to Table 7 for more information.

The study performed by Habibzadeh et al. [52] focused on an interesting topic associated with smart cities. The authors' main desire was to prove the efficiency of using recommender systems, along with machine learning and data analysis, to enhance big data's collection and processing. Since soft sensing is directly influenced by three main aspects (the three Vs), as the scientists stated in this manuscript, namely, veracity, volume, and velocity, the presented approach seemed to register pleasing results. The paper is truly relevant for the scientific community and represents a valuable resource for future strategies that address the development of soft sensing, which are highly important for smart transport, parking, energy conservation, etc.

The article written by Anthony [53] focused on providing an effective recommender system that involved case-based reasoning (CBR). The main purpose of the work was to support city planners in tackling the current challenges encountered, as well as developing

improved strategies that contribute to urban sustainability. In order to demonstrate the efficiency of the system and assess the initiatives and recommendations offered by it, a survey involving 115 participants was performed. The outcomes showed an increased level of satisfaction, with the article underlining crucial perspectives for decision-makers.

Deebak et al. [57] suggested an innovative approach, which has a foundation based on a community-based trust-aware recommender system (CB-TARS). The main purpose of the study was to demonstrate the efficiency of the framework in challenges associated with massive amounts of data in cloud service networks. Trusted neighbors are involved, and the results showed an increased level of confidence with real-world data, placing the system as superior in contrast to other available variants. The approach was evaluated in terms of mean absolute error (MAE), rate coverage, root-mean-square error (RMSE), and F-measure on the Epinions, FilmTrust, and Ciao datasets, with favorable results.

The study performed by Xu et al. [60] started from the premise that the recommendation accuracy and performance can be improved. In order to present a novel option, the authors created a new approach consisting of a deep users' multimodal preference-based recommendation (UMPR), which has the potential to extract text-matching from past reviews that may be more relevant for suggestions. For testing purposes, UMPR was assessed on applications linked to restaurants or even different products, and the results evidenced its high efficiency compared to existing methods. During the evaluation, two datasets were involved (Yelp—related to recommendations for restaurants, and Amazon-5-cores—including 24 categories of different products). The assessment was performed using matrix factorization (MF), neural matrix factorization (NeuMF), dual-attention mutual leaning (DAML), visual Bayesian personalized ranking (VBPR), multi-view visual Bayesian personalized ranking (MVBPR), visually explainable collaborative filtering (VECF), and the multi-modal aspect-aware latent factor model (MMALFM). In terms of the values obtained, the authors provided a table with values for each indicator, associated with the specific datasets: Yelp (MF = 1.866, NeuMF = 1.735, DAML = 1.502, VBPR = 1.729, MVBPR = 1.652, VECF = 1.694, and MMALFM = 1.547) and Amazon-5-cores (MF = 1.524, NeuMF = 1.437, DAML = 1.335, VBPR = 1.368, MVBPR = 1.362, VECF = 1.316, and MMALFM = 1.357). More insights about all these values, as well as averages for all datasets associated with each indicator, can be found in the related section from the article.

Another issue encountered in the context of smart cities was highlighted in the manuscript of Kinawy et al. [62]. Since citizens are also considered key participants within the process of decision-making, they have to be informed about the project's updates. The challenge here is that most of the time, there is too much information, and people can become overwhelmed. In this scope, the authors offered a new approach, more specifically, an innovative system, which takes advantage of semantic analysis and recommender algorithms to improve the system's usefulness and precision. In this manner, the information delivery can be customized, and the individual's interests will be matched with the information provided. The evaluation of the approach focused on the usability aspects and relied on a qualitative approach involving a focus group with four participants.

The manuscript by Negre et al. [63] was anchored on the desire to find an optimum way to upgrade other cities to achieve the title of "smart" by carefully analyzing and comprehending the characteristics of "smart" cities that are already in place. For this purpose, a good approach for a city that is not considered "smart" is to apply the same steps and actions that were already implemented in an analogous "smart" city. The similarity between two cities results from indicators such as the level of pollution, energy consumption, traffic congestion, etc. By using a "toy example" (Smallville, Metropolis, and Gotham) with synthetic data, the authors analyzed all the indicators, provided tables with values, along with possible actions that can be performed to make a city "smart", and computed the utility matrix. The authors validated this hypothesis through current research and underlined the need to enhance the cities' level of intelligence.

Arnaoutaki et al. [65] studied another relevant topic for smart cities, more specifically, an advanced recommender system that will offer personalized travel plans to citizens ac-

cording to their needs. In order to accomplish this aspiration, a new recommender system was proposed for the decision-making of mobility-as-a-service (MaaS) plans, involving both the constraint satisfaction problem (CSP) and cosine similarity. The assessment was performed using real data from the city of Budapest, and the high efficiency of the system was proven by evaluating the perception of the users toward the proposed recommendations using a questionnaire.

The vehicle ride-sharing topic was addressed in the article written by Anagnostopoulos [67]. The author came up with a new recommender system based on an artificial intelligence (AI)-enabled weighted pattern-matching model, which offer individuals personalized car-sharing options according to their preferences and needs, having major contributions in decreasing the level of congestion in urban areas, minimization of the time spent in traffic, increasing the quality of life for citizens, and sustaining the green ecosystem. The framework was examined using authentic data gathered from New Philadelphia (Greece) associated with ride-sharing, including GPS coordinates. The study demonstrated its high efficiency by analyzing the prediction accuracy. The author presented many visual representations, numerical values, formulas, strengths, and weaknesses of the study, which is very useful for future research initiatives.

Neves et al. [69] contributed to the scientific literature with a valuable manuscript focused on how recommender systems can be used in the healthcare domain. After carefully analyzing the existing academic papers written around this subject, they introduced a new framework, which is based on multiple machine learning algorithms, capable of predicting diseases, discovering potential risks, and supervising medical treatments. In order to prove the efficiency of the architecture, the authors examined and evaluated it using two case studies, highlighting both the importance and the necessity of recommender systems in the medical domain. The two case studies mentioned were associated with chronic kidney disease and wound healing control, while the evaluation metrics involved were precision, recall, F-measure, mean absolute error (MAE), and root-mean-square error (RMSE).

The ride-sharing challenge was also addressed in the article by Narman et al. [72]. The authors presented an improved vehicle-sharing model, consisting of two layers, one for pairing riders according to their characteristics, and the other one for offering timely personalized choices, matching drivers with passengers. Feedback from users at the end of the travel was also taken into consideration and classified via the machine learning component. The system was tested using real data from New York City, and the evaluation was performed by considering popular indicators, such as F1 score, precision, recall, and the confusion matrix. The outcome suggested both the effectiveness of the model, with an increased level of accuracy of 90%, and its impact and importance for a green and friendly environment.

Li et al. [74] proposed an innovative, semi-asynchronous, hierarchical federated recommendation system, referred to as HFSA, with an improved architecture. The authors discussed the HFSA's efficiency, the aspects that might influence it, and its increased accuracy, registered in terms of suggestions.

Papers That Incorporate Other Approaches

Based on the notes provided in Table 7, 6 out of 31 papers included in the dataset for the present bibliometric analysis encompassed other approaches.

Anthony Jnr [53] focused on building a case-based reasoning recommender system for smart city initiatives. The developed system was evaluated through a questionnaire with eight components, namely, recommendation content, recommendation presentation, system quality, information quality, service quality, CBR search, security and trust, and system support. After analyzing the data from 115 respondents, the author concluded that the proposed system succeeded in providing recommendations that can improve smart city practice for municipalities.

The study conducted by Liu et al. [55] focused on successive point-of-interest (POI) recommendations associated with traveling enterprises. In order to fulfill the main objective,

the authors came up with a modern approach, more specifically, the design of an innovative graph convolution network with improved interactions and time-sensitive, referred to as ITGCN, along with a self-attention aggregator. The results, evaluated in terms of recall and normalized discounted cumulative gain, demonstrated the manuscript's relevance and the efficiency of ITGCN in terms of predictions.

Assem et al. [66] addressed an emerging topic of high importance nowadays: the crowd mobility patterns. The authors offered a great technique to deal with this issue by employing Gaussian kernel density estimation, non-negative matrix factorization, and an algorithm based on hierarchical clustering. The data relevant for this study originated from location-based social networks (LBSNs): a dataset from Twitter, covering the period between 2013 and 2014, from the geographical zone associated with Manhattan. The authors examined the data corpus through their novel framework, and based on the results obtained, this manuscript is valuable for developing the future strategies and improvements in managing the challenges associated with crowd mobility in cities.

Smets et al. [68] focused on how serendipity can be involved in the recommender systems in such a manner that challenges such as urban homogenization will be avoided. The authors organized a survey consisting of 1641 individuals, with the main purpose of investigating the key aspects of suggested products, which lead to unexpected experiences and impact users' satisfaction. The questionnaire evaluated aspects concerning relevance, novelty, diversity, serendipity, and satisfaction. The findings brought forward crucial information and underlined the intense correlation between the significant innovative recommendations and the associated serendipity occurrences.

Another important topic was discussed in the article by Gill et al. [71]. The discourse was more oriented toward public health, more specifically, the monitoring of epidemics in the context of smart cities. The scientists demonstrated the effectiveness of their system, which encompasses a deep neural network (DNN), on a dataset associated with the Zika epidemic (Brazil—year 2016). The results proved the significance of the research, obtaining a high accuracy level (87%), and this represents a valuable study within both the scientific community and healthcare institutions.

The article of Li et al. [76] outlined a new technique for improving recommendation systems associated with online travelling platforms (OTPs). The originality of the work is seen in the introduction of an innovative method with flexible multitask learning (FMTL), along with a multi-representation extractor that can be adapted based on the temperature (T-MRE), which had a positive impact on the data analysis. In order to demonstrate the relevance of FMTL and its increased significance compared to other existing approaches, the authors performed both live and offline testing.

The study conducted by Alawadhi et al. [78] focused on another relevant topic: context-based recommender systems. The authors presented a novel dynamic search radius algorithm and tested its significance associated with issues such as crowding, proving that deep neural networks are truly relevant for these kinds of challenges. Furthermore, the article led to foundations for other possible future research directives oriented toward this topic.

Overko et al. [79] focused on the subject of smart mobility, utilizing distributed ledger technology (DLT) architecture for route recommender systems. The originality of the work and the efficiency of the framework, in terms of security, arose from the combination of acyclic graph design together with proof-of-work and proof-of-position. The authors upheld the significance of their approach with numerical values and consider this manuscript valuable for the scientific community.

Review Papers

Review papers represent the last category, based on the division proposed at the beginning of this section. This category consisted of 5 papers out of the total dataset of 31 articles. For more information, please consult Table 7.

The first study on the list is that of Ng et al. [50]. Noting its place of second according to the number of citations, one can easily see its high significance within the scientific

community. This statement may be supported by the fact that in the manuscript, the authors addressed a high-demand topic nowadays, namely, Internet of Things, and provided an in-depth co-citation examination of 68 relevant articles, shedding light on a multitude of significant aspects related to IoT (challenges, management of data, lifecycle management, security issues, recommender systems, applications, etc.). The outcomes highlighted are crucial and very important, being considered a strong basis for future research initiatives.

Nassar et al. [56] provided an overview of the existing scientific literature published around a noteworthy subject, more precisely, the smart street furniture and its integration within the Internet of Things infrastructure. Through the in-depth presentation of the topic by involving multiple works, crucial insights were brought to the foreground (challenges, issues, forms of exploitation, etc.). The possible improvements, opportunities, and future directives were also highlighted in this article.

Rafique et al. [73] presented a survey of the existing scientific literature around the topic of intent-aware recommender systems (IARS), focusing on how they can be implemented in the context of smart cities, highlighting possible challenges and potential paths for future studies.

The article written by Katarya [75] concentrated on an interesting topic that captures the reader's attention from the first paragraph. By providing an overview of the existing scientific literature around the area of taxi recommender systems in smart cities, published within a predefined timespan, more specifically, over a period of 22 years between 2001 and 2022, the author outlined interesting details about route planning, passengers' experiences, security, pricing, congestion, and many more. This manuscript serves as a great weapon for scientists and institutions oriented to this subject matter, underling the current trends, challenges, issues, and future directions, laying the foundation for possible effective strategies.

The article by Sharma et al. [77] offered a comprehensive examination of recommender systems based on Internet of Things approaches, focusing on the current issues and challenges, as well as on possible future strategies and areas that require improvements. The significance of the study was further increased through the inclusion of a bibliometric analysis of this emerging field.

3.4.3. Word Analysis

This section outlines an investigation of the initially collected dataset, from the perspective of words, with the intention of revealing hidden trends, themes, topics, or even challenges encountered. More specifically, in the following, information on keywords plus, authors' keywords, bigrams, and trigrams in both abstracts and titles, along with some visual representations, such as co-occurrence networks or even thematic maps, are presented.

Table 8 provides the top 10 most frequent words found in keywords plus, along with the number of occurrences. By analyzing this, one can easily notice that most of the papers address the topic of smart cities, being focused on the architecture of the IoT systems, prediction models, as well as exploring the challenges, such as security aspects.

Table 8. Top 10 most frequent words in keywords plus.

Words	Occurrences
Architecture	3
Challenges	3
Framework	3
Internet	3
System	3
Cities	2
IoT	2
Model	2
Prediction	2
Security	2

The words depicted can be divided into two categories based on the number of appearances: "architecture", "challenges", "framework", "internet", and "system" (each with three occurrences), and "cities", "IoT", "model", "prediction", and "security" (each with two occurrences).

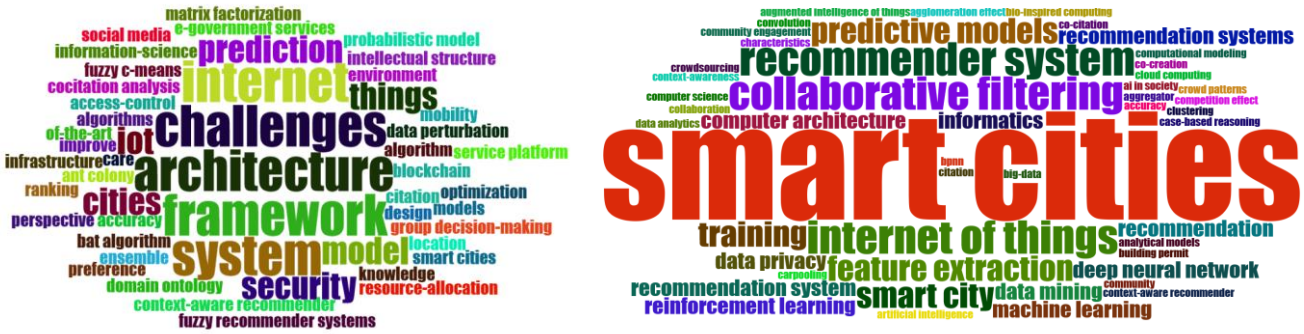
Table 9 includes the top 10 most frequent words, this time searched in authors' keywords, listed in order as: "recommender systems" and "smart cities"—each with 13 occurrences, "collaborative filtering", "internet of things", and "recommender system"—each with 4 occurrences, "feature extraction", "predictive models", "smart city", and "training"—each with 3 occurrences, and "computer architecture"—with 2 occurrences.

Table 9. Top 10 most frequent words in authors' keywords.

Words	Occurrences
Recommender systems	13
Smart cities	13
Collaborative filtering	4
Internet of Things	4
Recommender system	4
Feature extraction	3
Predictive models	3
Smart city	3
Training	3
Computer architecture	2

By examining the content of the table, the hypothesis from which we initially started above is further evidenced. Namely, most of the manuscripts included in the dataset focused on recommender systems in the context of smart cities, addressing subjects such as Internet of Things and computer architecture, exploring various techniques, including feature extraction, training, predictive models, and collaborative filtering.

Two word clouds for the top 50 keywords plus and authors' keywords were generated and are shown in Figure 17, which highlights a positive correlation between the size of the word in the image and its number of occurrences. To be more precise, an increased size of a specific word suggests an increased number of occurrences within keywords plus or authors' keywords.



(**A**) (**B**)

Figure 17. Top 50 words based on keywords plus (**A**) and authors' keywords (**B**).

As can be observed, in the case of keywords plus, the most used words, each with three occurrences, were "architecture", "challenges", "framework", "internet", and "system", while in terms of authors' keywords, one can notice "recommender system" and "smart cities", each with thirteen occurrences.

The most frequent bigrams in both abstracts and titles are listed in Table 10. In the case of abstracts, the first position was held by "smart city" with 33 occurrences, while

for titles, "recommender system" was identified, with 7 occurrences. In second place was "recommender systems" (abstracts—27 occurrences; titles—7 occurrences), while in third place was "smart cities" (abstracts—24 occurrences; titles—7 occurrences). For the entire list, please consider Table 10.

Table 10. Top 10 most frequent bigrams in abstracts and titles.

Bigrams in Abstracts	Occurrences	Bigrams in Titles	Occurrences
Smart city	33	Recommender system	7
Recommender systems	27	Recommender systems	7
Smart cities	24	Smart cities	7
Collaborative filtering	14	Smart city	7
Recommender system	9	Collaborative filtering	4
Proposed framework	7	Filtering recommender	2
Data analytics	6	Recommendation system	2
Proposed recommendation	6	Ride sharing	2
Similar users	6	Advanced metering	1
Experimental results	5	Aware recommender	1

These findings once again confirmed the main theme addressed in all the articles from the dataset, namely, the recommender systems in smart cities.

Advancing the analysis toward the next topic, Table 11 presents the top 10 most frequent trigrams in abstracts and titles.

Table 11. Top 10 most frequent trigrams in abstracts and titles.

Trigrams in Abstracts	Occurrences	Trigrams in Titles	Occurrences
Machine learning algorithms	4	Collaborative filtering recommender	2
Temporal functional regions	4	Advanced metering infrastructure	1
Proposed recommendation approach	3	Aware recommender systems	1
Proposed unified approach	3	Based context-aware smart	1
Smart city dimensions	3	Based social networks	1
Smart city services	3	Building permit system	1
Bio-inspired grey wolf	2	Case-based reasoning recommender	1
Collaborative filtering based	2	Characteristics machine learning	1
Communications technology ICT	2	City user evaluations	1
Context-aware recommender framework	2	Cloud service networks	1

As for abstracts, the hierarchy positions in first place showed "machine learning algorithms" and "temporal functional regions", each with four occurrences, and "proposed recommendation approach" with three occurrences.

In the case of titles, in the first three places were "collaborative filtering recommender", with two occurrences, "advanced metering infrastructure", and "aware recommender systems", each with one occurrence.

For the entire list, please consider the information in Table 11.

The four delimited clusters found in the co-occurrence network for the terms in authors' keywords are highlighted in Figure 18:

- Cluster 1 (red): smart city and data mining.
- Cluster 2 (blue): predictive models and training.
- Cluster 3 (green): collaborative filtering, recommender system, and recommendation system.
- Cluster 4 (purple): recommender systems, smart cities, Internet of Things, feature extraction, computer architecture, data privacy, informatics, and recommendation.

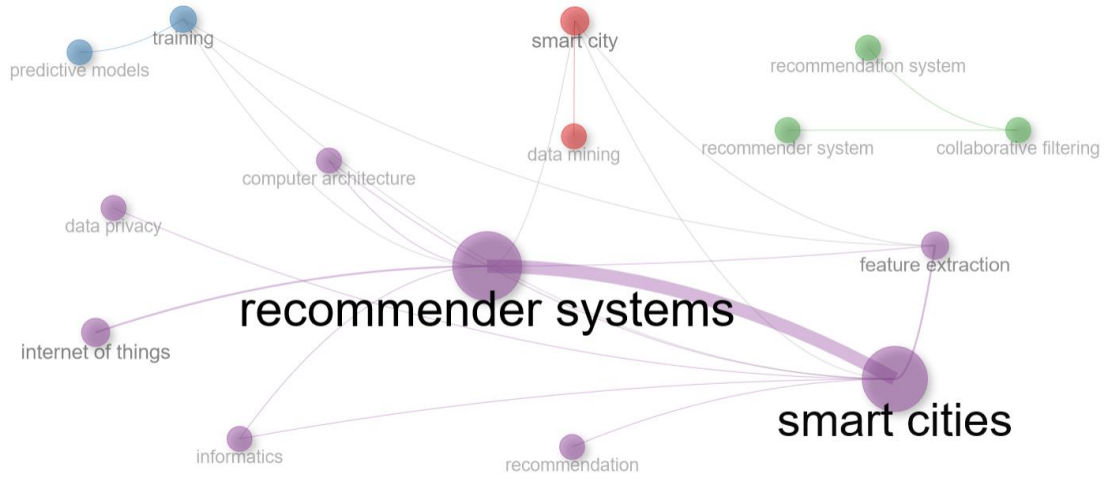


Figure 18. Co-occurrence network for the terms in authors' keywords.

Figure 19 presents the thematic map based on authors' keywords, which consists of four distinct themes: niche, motor, basic, and emerging or declining. This figure offers a broad perspective about the key tendencies in the studied area of recommender systems in smart cities. From a theoretical point of view, niche themes consist of zones that are more complex and require detailed knowledge to be understood or used, motor themes are the ones that lead to innovation and growth of a particular domain (in our case, the advancement of economic, technological, or even social areas), basic themes are comprised of essential components, emerging themes suggests the innovative areas that experience increased interest, and declining themes are considered topics that have started to become not as relevant.

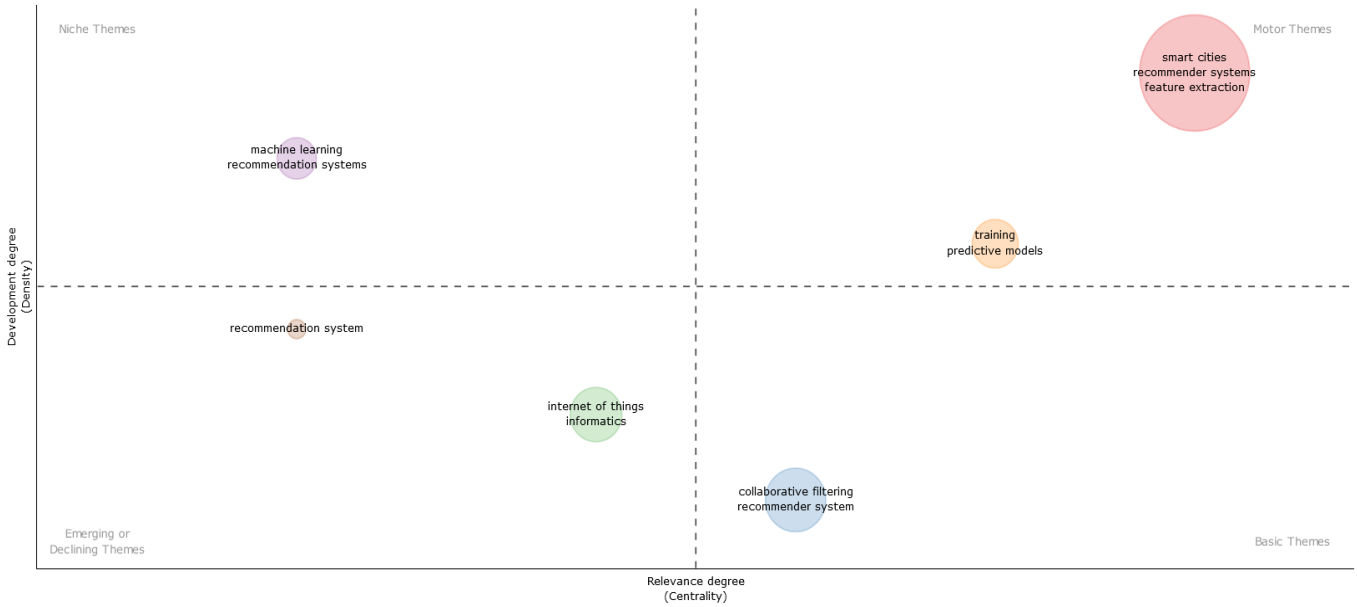


Figure 19. Thematic map based on authors' keywords.

The niche themes included machine learning and recommendation systems, the motor themes comprised of smart cities, recommender systems, feature extraction, training, and predictive models, the basic themes involved collaborative filtering and the recommender system, while the emerging or declining themes included Internet of Things, informatics, and the recommendation system.

3.5. Mixed Analysis

In the following, a mixed analysis was performed for the purpose of providing more in-depth information on this subject matter, highlighting the connection between different categories, such as countries, authors, journals, affiliations, and keywords.

The first three-field plot is visually represented in Figure 20, focused on the associations between the following groups: countries (left), authors (middle), and journals (right).

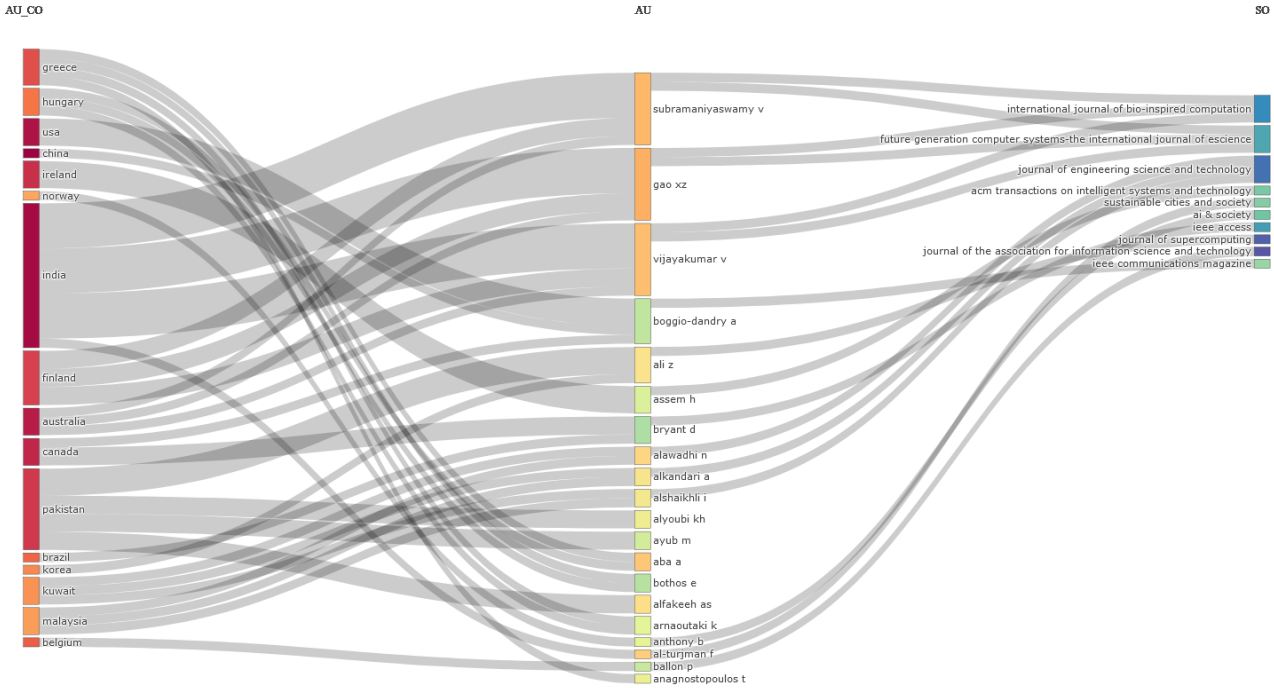


Figure 20. Three-field plot: countries (**left**), authors (**middle**), and journals (**right**).

By investigating the content of Figure 20, some conclusions can be drawn:

- India holds the top-most position in terms of authors' country of origin.
- The most prolific scientists that addressed the area of recommender systems in smart cities in their studies are Gao XZ, Subramaniyaswamy V, and Vijayakumar V.
- The most preferred journals for publishing papers in this domain are *International Journal of Bio-Inspired Computation*, *Future Generation Computer Systems—The International Journal of Escience*, and *Journal of Engineering Science and Technology*.
- There is a high degree of collaboration between academics belonging to different countries.
- Instead of publishing their manuscripts exclusively to just one journal, scientists prefer several sources.

The second three-field plot in Figure 21 is focused on other associations, more specifically, between affiliations (left), authors (middle), and keywords (right). Some of the insights deduced from Figure 21 include:

- The affiliation with the highest contribution is Vellore Institute of Technology (VIT).
- The most productive academics are Gao XZ, Subramaniyaswamy V, and Vijayakumar V.
- The most popular keywords are "smart cities", "collaborative filtering", and "recommender system", which was expected based on the knowledge gathered up until this point, highlighting once more that the main topic addressed in the collected papers is recommender systems in smart cities.
- Some top-20 authors have affiliations with several of the institutions, while others are not connected to any of the universities.

- The increased degree of collaborations and the affiliation of authors with multiple universities are the main factors that contribute significantly to enhancing the scientific value of the manuscripts written in the area of recommender systems in smart cities.

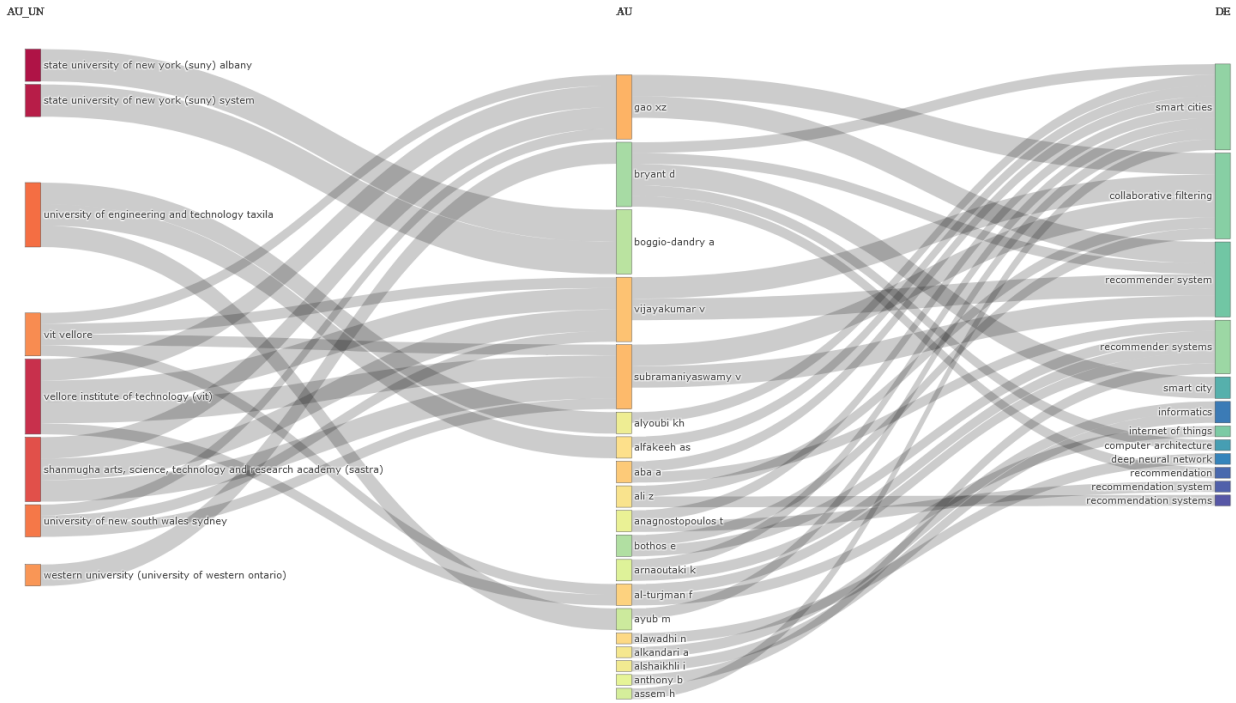


Figure 21. Three-field plot: affiliations (**left**), authors (**middle**), and keywords (**right**).

4. Discussion

As previously delineated and substantiated, the primary aim of this bibliometric investigation was to conduct a thorough examination of the extracted dataset, comprising 31 English-language articles published within the predefined timeframe of 2014–2023, focusing on the theme of recommender systems in smart cities.

Utilizing a plethora of tables, graphs, and visual representations generated through the R tool Biblioshiny, the study explored various facets, including sources, authors, collaborations, affiliations, countries, citations, scientific production, keywords, and connections between different categories. The overarching objective was to illuminate crucial information pertinent to this burgeoning domain and deliver a valuable manuscript to the academic community.

With this objective in mind, the ensuing paragraphs will summarize the main findings gleaned from the analysis.

The initial inquiry posed in the introduction pertained to the esteemed journals and prolific authors specializing in the domain of recommender systems in smart cities. The findings yielded intriguing insights.

In terms of sources, the foremost position, according to the number of published papers, was occupied by *IEEE Transactions on Industrial Informatics*, with three articles. The journal belongs to the IEEE publishing house, internationally recognized in the academic community, as further evidenced by its rank among the top journals in other bibliometric studies conducted on different topics and published in the scientific literature [25,26,28–30,80–84].

In discussions concerning authors, as previously highlighted in the dedicated section, the domain of recommender systems in smart cities experienced a gradual onset in terms of publications. This could potentially be attributed to the constraints of the database utilized for paper extraction. Notably, the most prolific contributors in this field, namely, Gao XZ, Subramaniyaswamy V, and Vijayakumar V, each contributed two manuscripts to the scientific discourse between 2018 and 2020.

The subsequent inquiry identified in the first section pertained to the characterization of production trends over time within this dynamic domain. As anticipated, considering the significance of the subject matter, a discernible upward trend was evident, indicating an average annual scientific production growth of 25.85%. Throughout the analyzed timeframe of 2014–2023, certain years witnessed no publications in this domain (e.g., 2015 and 2016), while others experienced heightened publication rates, with a peak of six articles in 2021.

An assessment of country-wise scientific production underscored the leading contributors based on citation counts. The top three positions were occupied by China (202 citations), India (91 citations), and the USA (62 citations). The notable engagement of these countries in the scientific community, irrespective of the academic subject, positions them as prominent leaders in bibliometric investigations across various timespans and diverse topics compared to the focus of the present article [25,26,29,30,82,83].

The subsequent topic under discussion pertained to collaborations in the creation of manuscripts addressing the domain of recommender systems in smart cities. Building upon insights unveiled in the previous section, the degree of collaboration exhibited a significant boost, initially evidenced by the substantial ratio of authors to articles, nearly five-fold higher. Notably, several authors were found to be involved in multiple papers, along with the inclusion of three single-authored papers in the dataset.

As anticipated, the most prominent corresponding author countries emerged at the forefront of collaboration. China led with seven published papers on recommender systems in smart cities, followed by India with five articles and the USA with three scientific works.

Furthermore, analysis revealed the involvement of only 15 countries worldwide in publishing articles within this domain, namely, China, India, the USA, Australia, Canada, Greece, Ireland, Belgium, Brazil, France, Ghana, Korea, Malaysia, Norway, and Pakistan.

China ranked first among countries fostering the highest number of collaborations, engaging in collaborative partnerships for manuscript creation with Australia, Canada, Finland, India, Iran, Iraq, and the USA.

The most prestigious affiliations, according to the number of published articles, that were uncovered during the analysis were San Jose State University and State University of New York (Suny), Albany, each with three published works.

Continuing the discourse, the subsequent inquiry initiated at the outset directed attention toward the insights gleaned from the word analysis and the thematic map based on authors' keywords.

Through meticulous analysis of the textual content, it became apparent that the majority of papers within the dataset focused on the subject of smart cities, particularly exploring aspects related to the architecture of IoT systems and addressing challenges such as security considerations. Additionally, a notable emphasis was placed on computer architecture and various techniques, including feature extraction, training, predictive models, and collaborative filtering.

Moreover, the thematic map constructed from authors' keywords unveiled distinct thematic categories, comprising niche themes, such as machine learning and recommendation systems, motor themes, such as smart cities, recommender systems, feature extraction, training, and predictive models, as well as basic themes, including collaborative filtering and recommender systems. Additionally, emerging or declining themes, such as Internet of Things, informatics, and recommendation systems, were also identified.

Lastly, the significance of citations within this domain was underscored, as they serve as crucial indicators for comprehending the prominence and visibility of a specific domain within the scientific community.

The evolution of average citations per year manifested as an oscillating pattern, ranging between 0.67 and 5.40, indicative of a moderate to high level of visibility. The academic significance surrounding the domain of recommender systems in smart cities was inferred from the values recorded for average citations per document (16.03) and average citations per year per document (3.153), in conjunction with the substantial number of references (1760).

Regarding the articles included in the dataset, the 31 manuscripts were categorized into 5 distinct groups based on the methodologies employed in the investigation. The first category pertained to papers involving collaborative filtering (8 out of 31 articles), followed by the second category, which explored content-based recommender system approaches (11 out of 31 articles). The third category included other approaches (7 out of 31 articles), while the final category was comprised of review papers (5 out of 31 articles).

Furthermore, in terms of context-aware approaches, it was observed that 12 of the 31 papers considered various context situations, most of them dealing with elements related to geographical–temporal influence, time, or location.

In terms of case studies, 23 of the 31 papers provided insights from various case studies, featuring elements taken from well-known datasets, such as Epinions, Film Trust, Ciao, Foursquare, MovieLens I, and MovieLens II, while other studies focused on real-world data extracted for various cities, such as New York, Dublin, or Budapest.

As for the evaluation criteria, it was observed that the most popular metric was the accuracy metric. Other metrics, such as root-mean-square error (RMSE), mean absolute error (MAE), precision, recall, and F-measure, completed the list of the most used evaluation criteria. Additionally, some studies used a questionnaire approach for measuring the users' satisfaction regarding the elements proposed in the application.

Considering the papers included in the dataset, as well as the elements related to the types of systems used, the criteria for their effectiveness, and specific case studies, it was also observed that a series of the technical challenges and barriers to the recommender systems' implementation in the context of smart cities were highlighted.

As a result, Ng et al. [50], for example, noted in their research that "the extra-large network scale, high-level device heterogeneity, dynamic topology change, unreliable communication medium, i.e., wireless communication, scaling issue will be a significant barrier to the IoT development". Apart from this, the authors also mentioned challenges associated with "deployment density issues of IoT devices and issues of IoT localization systems", and even the security issue, which "raise other problems in different areas, such as cryptography, data management, identity and ownership management, trust management, and privacy protection".

Furthermore, in their study, Habibzadeh et al. [52] mentioned that designing the smart city component focusing on soft sensing faces challenges stemming from the three Vs, namely, veracity, volume, and velocity.

Concerning the thematic focus of these works, as anticipated, all articles revolved around the domain of recommender systems in smart cities. They explored various emerging areas, such as privacy, transportation, urban infrastructure, permit systems, electricity tariffs, social trust, vehicle ride-sharing, and healthcare, among others. These articles provide crucial insights, unveil interesting results, and substantiate their significance within the scientific community.

5. Limitations

As anticipated, the initial limitation considered pertains to the deliberate selection of a single database, namely, the Web of Science. This decision was informed by several compelling reasons, including its widespread acceptance within academic circles, comprehensive source coverage, user-friendly interface, and compatibility with tools, such as Biblioshiny. The choice was arrived at following a meticulous evaluation of multiple databases, weighing their respective strengths and weaknesses. Furthermore, the authors conducted a thorough review of the existing literature and examined the approaches taken by other researchers in conducting bibliometric analyses across various subjects.

However, it is acknowledged that the resultant dataset is relatively limited, comprising only 31 articles. Consequently, the authors recognize that employing multiple databases, such as Scopus or IEEE, in conjunction with Web of Science could have expanded the dataset, potentially influencing the obtained results.

Since the authors' main desire was to provide a bibliometric analysis as accurate as possible, presented in an objective manner, apart from the specified advantages associated with Biblioshiny that were previously mentioned in the second chapter, it should also be considered that this tool is designed to work with only one database and, unfortunately, the use of more databases was not possible in this case. For us, this was not thought of as a limitation, since we had already decided to use a single database approach, as in other similar studies [85,86], but this aspect should be taken into consideration by future researchers who want to extend this study further.

Another limitation identified in this study pertains to the search terms utilized in the database query. Initially, the authors filtered papers containing both "smart cities" and "recommender system" in the abstracts, titles, or authors' keywords. It is conceivable that this filtering process may have overlooked relevant works related to recommender systems in smart cities that employed different terminology.

Additionally, while the dataset remained unaltered after excluding non-English papers, future research endeavors should carefully consider and address this constraint.

A notable impact on the dataset stemmed from the exclusion of works not classified as articles. This criterion, based on document type, carries inherent risks, as valuable insights may be present in other types of publications, such as books, which could have contributed to the investigation and influenced the results.

The final limitation highlighted in the article concerns the chosen timeframe. The decision to exclude papers published in 2024, a year still ongoing at the time of the bibliometric analysis, was deemed prudent to ensure completeness of prior years. Including a year that had not concluded from a scientific perspective may have introduced bias and distorted the findings.

Through this section, we aimed to elucidate the limitations inherent in the bibliometric study, thereby fostering transparency and showcasing the quality and rigor of the research conducted.

6. Conclusions

We aimed to explore the topic of recommender systems in smart cities. Leveraging the widely used R tool, Biblioshiny, we meticulously analyzed a dataset comprising 31 English-language articles sourced from the Web of Science database, spanning the years 2014 to 2023. This facilitated a comprehensive bibliometric analysis.

Key findings from the study revealed that *IEEE Transactions on Industrial Informatics* emerged as the most prominent journal in this domain, publishing three articles. Notable productivity was observed from authors Gao XZ, Subramaniyaswamy V, and Vijayakumar V, each contributing two manuscripts between 2018 and 2020. The contributions from China, India, and the USA stood out, underscoring their significance as key contributors. The San Jose State University and State University of New York (Suny), Albany, were identified as the most prestigious affiliations based on the number of published articles, with each having three works.

The analysis also revealed a rising trend in scientific production, with an annual growth rate of 25.85%, alongside increased collaboration among authors. The evolution of average citations per year exhibited an oscillating pattern, indicating moderate to high visibility. Analysis of the textual content highlighted a predominant focus on smart cities, particularly exploring IoT architecture and addressing challenges such as security aspects.

Furthermore, we comprehensively examined the 31 papers, categorizing them into 4 distinct groups: collaborative filtering, recommender systems, other methods, and review papers. These manuscripts addressed various topics within the domain, ranging from privacy and transportation to healthcare, contributing significantly to the evolution of this critical field.

Additionally, in the current bibliometric analysis, we also performed an n-gram analysis across keywords, abstracts, titles, and keywords plus. This investigation brought to light notable details, hidden trends, and semantic associations between words, helping us

to obtain an enhanced comprehension of the topics addressed within the papers found in the dataset, along with the most popular subjects of interest, issues, and challenges encountered in the area of recommender systems in smart cities. Along with the words related to the search terms, such as "recommender system/recommender systems" and "smart city/smart cities", various terms highlighted either the recommendation approach—such as "collaborative filtering", "aware recommender", "similar users", "filtering recommender", "collaborative filtering based", "context-aware recommender framework", "collaborative filtering recommender", "aware recommender systems", "based context-aware smart", and "case-based reasoning recommender"—or the implementation approach—"machine learning algorithms", "temporal function regions", "bio-inspired grey wolf", "characteristics machine learning", "feature extraction", "predictive models", and "training". Furthermore, through the n-gram analysis, some information regarding the recommender systems' applications in the context of the smart cities were observed, such as "ride sharing", "smart city services", or "building permit systems".

As a result, it was determined that the recommender systems in smart cities are pivotal within the scientific community, especially amidst the pronounced migration to urban areas. The recommender systems represent not just a theoretical concept but a fundamental necessity for urban management and development. Leveraging recommender systems and high-performance algorithms can notably enhance urban living standards, safety, and happiness, while also addressing environmental concerns and resource management.

Furthermore, it can be stated that recommender systems in smart cities represent an exceedingly contemporary and pertinent topic, reflecting heightened interest in the realm of technology. Scientific papers addressing this subject matter are deemed essential and valuable, not only within the scientific community but also for institutions and individuals interested in this domain.

Further explorations can be conducted in this field by utilizing multiple databases, which could help in broadening the scope of the research and provide a more comprehensive dataset. Additionally, adopting an approach that relaxes the filters imposed in this paper could yield valuable insights.

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