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Review

Blockchain and Smart Cities for Inclusive and Sustainable Communities: A Bibliometric and Systematic Literature Review

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Abstract: Smart cities are urban areas that leverage technological solutions to enhance traditional network management and efficiency to benefit residents and businesses. Based on the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol, this study presents a systematic literature review aimed at analyzing the existing literature on smart cities research. The literature review specifically focuses on the impact of blockchain technology on the urban environment and its potential to contribute to the development of inclusive and sustainable communities, including financial systems and infrastructures with similar characteristics to serve these societies. The findings reveal a lack of studies on the practical applications of distributed ledger technologies (DLTs), particularly blockchain, that specifically focus on the urban context capable of developing the (financial) ecosystem of smart cities. To address this gap, a future research agenda is proposed, highlighting several research questions that could guide academics and practitioners interested in exploring the development of smart city systems, with particular attention on the financial framework.

Keywords: smart cities; sustainable development; urban agenda; blockchain; distributed ledger technologies (DLTs)

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1. Introduction

Cities can fundamentally be interpreted along two closely interlinked dimensions: as a collection of real estate assets, represented by buildings and infrastructures located within a geographically delimited urban space, and as a set of related governance structures and services, such as transportation, security, connections, and waste management, that enable residents to use the same spaces either for living or working. Based on this perspective, cities have a significant impact on the following: (i) quality of life, which largely depends on amenities and opportunities; almost 75% of Europeans live in cities [1], and in turn, the urban environment affects sociological behaviors in a cause–effect relationship; (ii) sustainability and climate change, considering that metropolitan areas contribute circa 75% of the total greenhouse gas emissions worldwide [2]; and (iii) overall economy, because urban areas represent between 3 and 6% of the total geographic land use but roughly 90% of the overall land/real estate values in financial terms (where, in turn, real estate represents almost 55–57% of the overall wealth of households' portfolios) [3].

In that context, "smart" cities may be defined as metropolitan areas where technological solutions, both private and public, help improve "the management and efficiency of traditional networks for the benefits of their residents and business" [4] (i.e., the type and quality of the abovementioned urban governance and services, such as transportation and security, are enhanced by applying digital advancements and new technologies to their production and management processes and overall urban governance). Implementing such digital advancements and new technologies aims to reduce metropolitan environments' climate and environmental impacts and improve urban vitality by boosting positive externalities at societal and governance levels.

Following that perspective, this study aims to review the existing literature and assess the body of knowledge on smart cities research, focusing on how blockchain technology impacts the urban environment and may contribute to constructing inclusive and sustainable communities, including financial systems with the same characteristics to serve these societies. Blockchain as a distributed ledger technology (DLT) has immense potential for urban settings because it is perfectly suited to conveying secure and trusted information spread across sites and market participants from various perspectives that might be used for micro- and macro-level constructs: at the micro-level, e.g., for incorporating legal, environmental, social, and governance (ESG), technical, and financial data on urban real estate assets and development projects; at the macro-level, for integrating reliable and certified information in traditional metropolitan services and the overall planning and renewal of cities.

This is because of the perceived lack of a systematic comprehension of the existing literature in the field and the fact that, despite the research efforts by scholars, crucial knowledge about smart cities remains scattered and fragmented on several fronts, leading to limited contributions in terms of potential policy indications. Moreover, the perception, confirmed by the analysis, is that there is a scarcity of studies referring specifically to applications of blockchain technology to urban activities and phenomena that allow, as a whole, an integrated vision of their impacts on the overall urban system. In particular, studies related to financial applications specifically devoted to smart cities from an integrated perspective, such as in the field of payment systems, smart contracts, digital currencies, and financial real estate and investments, seem to be largely missing. Addressing this gap would benefit both economic operators and governance authorities in charge of the regulatory choices on the subject and managing the urban contexts.

In light of that, the main objective of this study is to conduct the following: (i) identify the reference literature investigating smart cities and, more specifically, blockchain technology applied to the urban environment; (ii) outline the knowledge in the field—with a focus on economic and business applications and, in particular, financial issues—in terms of research topics and results, as well as map the emerging trends and intellectual structures in smart cities research over an extensive period (from 1950 to 2023); and (iii) highlight the directions for potential future research with a research agenda concerning financial system development in smart cities.

The original contribution of this study is twofold and lies, on the one hand, in the mapping and systematization of the existing literature and also in terms of the covered research topics and results related to smart cities and blockchain and, on the other hand, in proposing further research issues for developing a systematic investigation agenda based on the previous analysis. This is especially true for research directions, such as the financial perspective, which have not yet been sufficiently explored by existing studies in terms of urban applications of blockchain with the capability to obtain a global view of their impact on smart cities.

2. Methodology and Design

According to Paul and Criado's [5] suggestions for literature reviews, the research methodology of this study combines qualitative and quantitative methods. Notably, we used bibliometric indicators to provide a more comprehensive understanding of the knowledge in the field and to map emerging trends, collaboration patterns, and intellectual structures in smart city research over time [6]. The research was conducted using statistical and graphical interfaces, such as the VOSviewer software (1.6.20) [7] and the Bibliometrix package of R [8–13]. We also conducted a systematic literature review (SLR), which is a well-established scientific research method in management and social sciences, to enhance our analysis and specifically focus on the financial systems of smart cities. The literature review included a transparent and replicable review protocol that can be used to analyze research insights and trends, identify gaps, and propose ways to advance the field [14–20].

To organize relevant research on smart cities and blockchain technology, this study adopted, alternatively to the common PRISMA (Preferred Reporting Items for Systematic

Reviews and Meta-Analyses) guidelines [21,22], the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol proposed by Kumar et al. [17], Paul et al. [18], and He et al. [23], which consists of assembling, arranging, and assessing data. The methodology of the SPAR-4-SLR protocol is described below and charted in Figure 1.

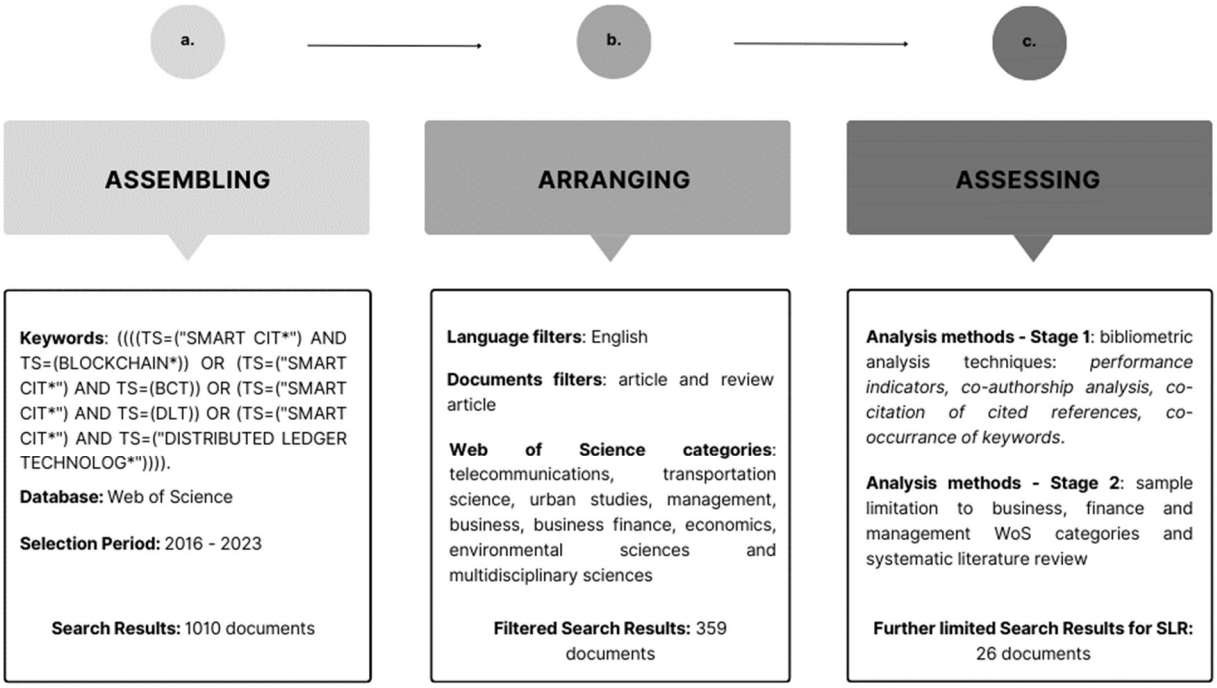

Figure 1. Research design using the SPAR-4-SLR protocol.

- Assembling: The authors conducted a preliminary review of the most significant literature on smart cities and blockchain technology to commence the process. They also brainstormed to determine the most accurate combination of keywords representing the knowledge body in this field [6]. One of the most comprehensive bibliometric databases of high-quality peer-reviewed journals, the Web of Science (WoS), was selected as the research engine. This database captures missed references and involves most scientific articles in the field [15,20,24,25]. To conduct the article search, we used the following combinations of keywords ("TS" corresponds to the title, keywords, and abstract in the WoS Core Collection) and Boolean operators ("AND/OR"): ((((TS=("SMART CIT*") AND TS=(BLOCKCHAIN*)) OR (TS=("SMART CIT*") AND TS=(BCT)) OR (TS=("SMART CIT*") AND TS=(DLT)) OR (TS=("SMART CIT*") AND TS=("DISTRIBUTED LEDGER TECHNOLOG*")))).

All of the articles in the database were considered for selection, covering the period from 1950 (the first year available in the field) to 2023. The research returned 1010 documents from 2016 to 2023.

- Arranging: In this stage, we applied WoS cleaning filters to limit the sample selection to articles written in English and to include, following Paul et al. [18], only articles and review articles. This filtering process was conducted to ensure the final sample's quality from a committed scientific perspective, since proceeding articles and book chapters may not require peer review. Then, we refined the research by selecting only articles published in the WoS categories of telecommunications, transportation science, urban studies, management, business, business finance, economics, environmental sciences, and multidisciplinary sciences to exclude more technical contributions related to blockchain technology applications in other scientific fields, such as engineering or computer sciences. In this way, we identified research related to the role of blockchain

technology in the construction of innovative, inclusive, and sustainable smart cities. After this stage, the final sample consisted of 359 articles.

- Assessing: To assess the final sample of 359 articles resulting from the arranging stage, this study adopted a bibliometric analysis approach that consisted of the following: (i) performance analysis in which we described the sample characteristics and the most influential authors, journals, and documents in the field; (ii) co-authorship analysis; (iii) co-citation analysis of cited references; and (iv) co-occurrence analysis of the most popular keywords [13].

Furthermore, to enhance the contribution of this study, the final sample (359) was further limited to business, finance, management, and economics WoS categories to systematically review and focus on articles related to the role and application of blockchain technology in the smart cities financial system. After applying this filter and after double-checking, the final sample included in the SLR consisted of 26 documents. Based on the analysis of the final selection of articles, we aim to contribute to the advancement of the field by providing a future research agenda that can guide researchers looking to identify and address research gaps in the field.

3. Results

3.1. Results of the Bibliometric Analysis

3.1.1. Information about the Sample and Performance Analysis

Examining the dataset resulting from the arranging stage (Table 1), we highlight that, although there are 87 journals involved in the field, the IEEE Access multidisciplinary journal is the top journal with 1996 total citations, which also hosts the most globally cited documents [26] (Table 2). Fuller et al.'s article reviews the definition of digital twin technology, focusing on the various definitions in manufacturing, healthcare, and smart cities research, providing insights for further study. However, looking at the local citations reported in Table 3, in which the number of citations received in the sample is considered, Fuller et al. have only one local citation. Therefore, the article may not have a direct connection to the research stream related to smart cities despite its high importance in the literature.

Looking at the most locally cited article, Xie et al.'s [27] study is the first, with 38 local citations and 298 global citations (the highest LC/TC ratio, 11.27). Moreover, this article was published in IEEE Communications Surveys and Tutorials (the fourth most influential source), which is the journal with the highest impact factor (35.9). Xie et al.'s article provides a comprehensive survey relating to the applications of blockchain technology in smart cities, providing future research challenges and directions. High levels of citations often characterize survey and literature reviews.

Table 1. Sample details.

Description	Results
Sources (journals)	94
Authors	1278
Documents	359
References	19,966
Average years from publication	2.53
Average citations per document	34.14
Average citations per year per doc	8.021
Documents per author	0.281
Authors per document	3.56
Co-authors per document	4.27
Collaboration index	3.73

Source: Data elaboration from Bibliometrix.

Table 2. Top 10 influential sources based on total citations.

Source	h_index	g_index	m_index	TCs	No. of Articles Published	PY_start	Impact Factor **
IEEE Access	22	39	3.14	1996	39	2018	3.9
IEEE Internet of Things Journal	21	38	3.50	1490	41	2019	10.6
Sustainable Cities and Society	13	13	1.86	1291	13	2018	11.7
IEEE Communications Surveys and Tutorials	6	6	1.00	1212	6	2019	35.6
Sustainability	14	23	2.00	632	37	2018	3.9
Cities	5	5	0.83	610	5	2019	6.7
IEEE Network	7	8	1.40	335	8	2020	10.294
Computer Communications	5	7	1.00	301	7	2020	6
Financial Innovation	1	1	0.11	279	1	2016	8.4
Transactions on Emerging Telecommunications Technologies	7	10	1.75	260	10	2021	3.6

Source: Data elaboration from Bibliometrix. ** Data from the journal website. PY start indicates the publication year. h_index is generally used to measure authors' productivity and influence and calculate the number of publications and citations received. m_index is another variant of the h-index that displays the h-index per year since the first publication. g_index is a variant of the h-index that, in its calculation, gives credit for the most highly cited papers in a dataset.

Table 3. Top 10 globally cited documents.

Author(s) (Year) [Ref. Number]	Title	Journal	Local Citations	Total Citations	TCs per Year	LC/TC Ratio (%)	Normalized TCs
Fuller et al. (2020) [26]	Digital Twin: Enabling Technologies, Challenges and Open Research	IEEE Access	1	630	126.000	0.16	103.753
Allam and Dhunny (2019) [28]	On big data, artificial intelligence, and smart cities	Cities	11	409	68.167	2.69	36.441
Dagher et al. (2018) [29]	Ancile: Privacy-preserving framework for access control and interoperability of electronic health records using blockchain technology	Sustainable Cities and Society	7	373	53.286	1.88	26.559
Xie et al. (2019) [27]	A Survey of Blockchain Technology Applied to Smart Cities: Research Issues and Challenges	IEEE Communications Surveys & Tutorials	40	355	59.167	11.27	31.630
Nguyen et al. (2021) [30]	Federated Learning for Internet of Things: A Comprehensive Survey	IEEE Communications Surveys & Tutorials	1	346	86.500	0.29	100.907
Stoyanova et al. (2020) [31]	A Survey on the Internet of Things (IoT) Forensics: Challenges, Approaches, and Open Issues	IEEE Communications Surveys & Tutorials	6	331	66.200	1.81	54.511
Sun et al. (2016) [32]	Blockchain-based sharing services: What blockchain technology can contribute to smart cities	Financial Innovation	30	279	31.000	10.75	10.000
Shen et al. (2019) [33]	Privacy-Preserving Support Vector Machine Training Over Blockchain-Based Encrypted IoT Data in Smart Cities	IEEE Internet of Things Journal	13	240	40.000	5.42	21.384
Banerjee et al. (2018) [34]	A blockchain future for internet of things security: a position paper	Digital Communications and Networks	11	240	34.286	4.58	17.089
Guan et al. (2018) [35]	Privacy-Preserving and Efficient Aggregation Based on Blockchain for Power Grid Communications in Smart Communities	IEEE Communications Magazine	2	232	33.143	0.86	16.519

Source: Authors' elaboration from Bibliometrix.

Furthermore, in Table 2, we also identified the top 10 influential journals in the research stream, ranking them by the total number of citations (TCs) received. Table 3 reports the top 10 globally cited documents in the database ranked based on the TCs received.

Finally, looking at the bibliometric performance of the sample, we noted that academic contributions are characterized by a growing increase in recent years, starting from 2016. Since 2019, the number of publications has surged by about 300% over the previous period, probably relating to the increase in interest in digitalization and the use of blockchain during and after the COVID-19 pandemic (Figure 2).

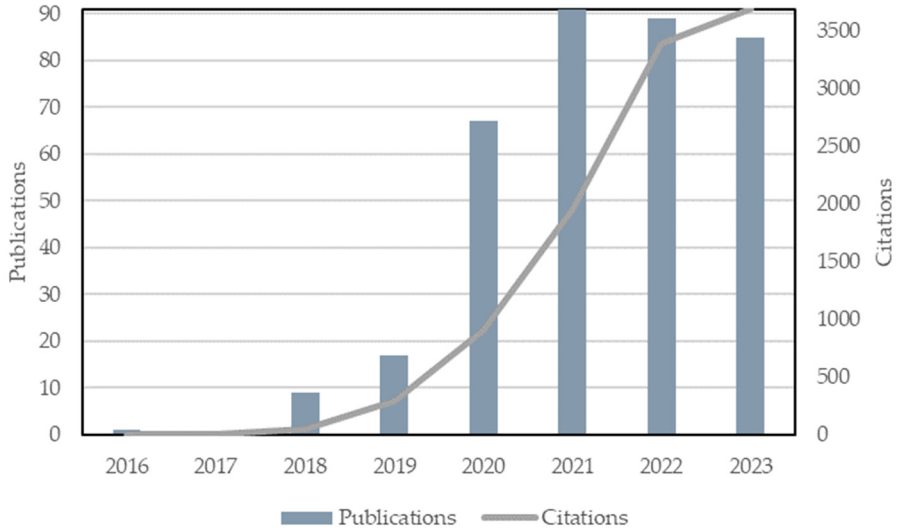

Figure 2. Citations and publications over time. Source: WoS citation report.

3.1.2. Co-Authorship Analysis

Co-authorship analysis, also named social network analysis, has become a common practice in literature reviews. This analysis method helps identify relationships between authors, which, in turn, helps scholars in their future research projects [36,37]. Co-authorship analysis is a technique used to create a network of authors based on the total link strength. This technique helps identify the social network of authors working on different aspects of the literature. The link strength is determined by the number of local citations (LCs) per author, making it easier to identify the network of authors and co-authors, including key persons in the field. Paltrinieri et al. [24] emphasize the significance of co-authorship analysis, particularly in the context of less-developed literature, such as the topic of this study. The co-authorship analysis charted in Figure 3 identifies four main groups of authors.

Looking at Figure 3 and Table 4, the blue group, consisting of Choo K.-K.R. and Kumar N., forms the network's core and, therefore, has direct relations to all other groups, making the realization of cross-group cooperation easier. Choo K.-K.R. was co-author of one of the most cited articles [34], underpinning their core position in the network. Guizani M. connects the green group to the red group with the highest total number of citations, which reflects the interdisciplinary effort and high collaborative impact of these authors. Led by Tanwar S. and Gupta R., the yellow group includes leading authors with high local citations, such as Tanwar S., who tops the list among the most locally cited in this dataset. Table 4 lists key authors who dominate the discipline, with Yu F. Richard and Nguyen Dinh C. contributing much to the literature. These two authors have a high number of citations per year on wide-ranging topics, from blockchain applications in smart cities to federated learning for the Internet of Things (IoT). The top list of authors includes Guizani M. and Du Xiaojang, who continue to demonstrate heavy collaboration and contribution. Table 5 presents the local impact metrics, with Tanwar Sudeep first, but Nguyen Dinh C. and Du Xiaojang are rapidly growing impact authors. This analysis was undertaken to underpin how the network is mapped to collaborative dynamics and spot contributors with great

value for blockchain and IoT research. Further, the span of topics and the high citation counts among the top authors reflect the depth and width of research in this field. Strong collaborative links can indicate a robust, dynamic research community, moving innovations and knowledge forward.

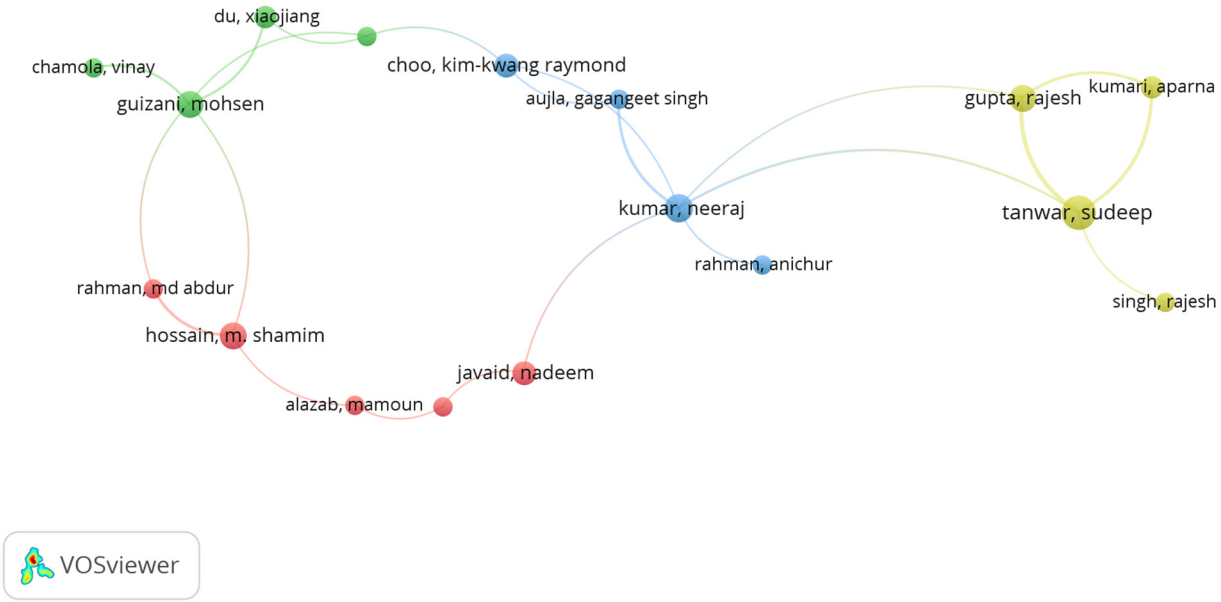

Figure 3. Chart of the co-authorship analysis by authors using VOSviewer software.

Table 4. Top 10 authors' articles.

Author(s) (Year)	Title	Journal	TCs	TCpY	Cluster
Yu F. Richard [27]	A survey of blockchain technology applied to smart cities: research issues and challenges	IEEE Communications Surveys & Tutorials	355	59.167	-
Nguyen Dihn C. [30]	Federated learning for Internet of Things: a comprehensive survey	IEEE Communications Surveys & Tutorials	346	86.500	-
Guizani Mohsen [33]	Privacy-preserving support vector machine training over blockchain-based encrypted IoT data in smart cities	IEEE Internet of Things Journal	240	40.000	2
Choo Kim-Kwang Raymond [34]	A blockchain future for internet of things security: a position paper	Digital Communications and Networks	240	34.286	3
Du Xiaojang [33]	Privacy-preserving support vector machine training over blockchain-based encrypted IoT data in smart cities	IEEE Internet of Things Journal	240	40.000	2
Du Xiaojang [35]	Privacy-preserving and efficient aggregation based on blockchain for power grid communications in smart communities	IEEE Internet of Things Journal	232	33.143	2
Guizani Mohsen [38]	Blockchain and IoT-based cognitive edge framework for sharing economy services in a smart city	IEEE Access	169	28.167	2
Hossain M. Shamim [38]	Blockchain and IoT-based cognitive edge framework for sharing economy services in a smart city	IEEE Access	169	28.167	1
Rahman Md. Abdur [38]	Blockchain and IoT-based cognitive edge framework for sharing economy services in a smart city	IEEE Access	169	28.167	1

Source: Authors' elaboration from Bibliometrix. TCpY is the number of total citations per year.

Table 5. Top 10 authors' local impact.

Author	h_index	g_index	m_index	TCs	NP	PY_start
Tanwar Sudeep	8	10	1.600	647	10	2020
Barlow Chris	1	1	0.200	630	1	2020
Day Charles	1	1	0.200	630	1	2020
Fan Zhong	1	1	0.200	630	1	2020
Fuller Aidan	1	1	0.200	630	1	2020
Guizani Mohsen	6	6	1.000	622	6	2019
Nguyen Dihn C.	4	4	0.800	535	4	2020
Du Xiaojang	4	4	0.571	505	4	2018
Pathirana Pubudu N.	3	3	0.600	505	3	2020
Yu F. Richard	4	4	0.667	483	4	2019

Source: Authors' elaboration from Bibliometrix. NP is the number of pages.

3.1.3. Co-Citation Analysis

In this section, we discuss the co-citation analysis of articles based on their cited references, as detailed in Table 6 and depicted in Figure 4. The co-citation analysis overcomes the mere counting of citations and is instrumental in identifying the most relevant aspect of the field. This bibliometric method allows for identifying the articles that cite each other on the same concept or topic. This method provides valuable insights into the commonalities and research streams or clusters in the literature, thereby aiding in the identification of emerging trends and areas of interest [11,24,39]. The most cited references in the sample are ordered by considering the number of citations received.

Table 6. Co-citation network and local cited references (top 10 list).

Author(s) (Year) [ref. Number]	Citations	Total Link Strength	Cluster
Xie et al. (2019) [27]	40	122	Green
Nakamoto (2008) [40]	33	82	Green/Red
Biswas et al. (2016) [41]	30	150	Blue
Sun et al. (2016) [32]	30	114	Green
Khan and Salah (2018) [42]	28	46	Green
Sharma and Park (2018) [43]	28	105	Red
Christidis and Devetsikiotis (2016) [44]	27	83	Red
Novo et al. (2018) [45]	26	68	Red
Zheng et al. (2017) [46]	23	77	Red
Bushan et al. (2020) [47]	22	46	Red

Source: Authors' elaboration from Bibliometrix.

The VOSviewer software identifies three different clusters, headed again by Xie et al. [27] in the green cluster and Nakamoto [40], with the article that made blockchain technology famous for introducing the Bitcoin payment system. Nakamoto's article is always cited most when discussing blockchain, cryptocurrency, or digital payments. The third most cited article with 30 citations is Biswas et al. [41], in the blue cluster, followed by Sun et al. [32] and Khan and Salah [42], which led to the green cluster. Sharma and Park [43] lead the red cluster, including all the other most cited articles in Table 6.

These articles all discuss the proposal of a framework architecture for blockchain applications in future smart cities. The authors discuss the advent of IoT applications and

the importance of blockchain in solving security problems, proposing a new framework for their combined adoption.

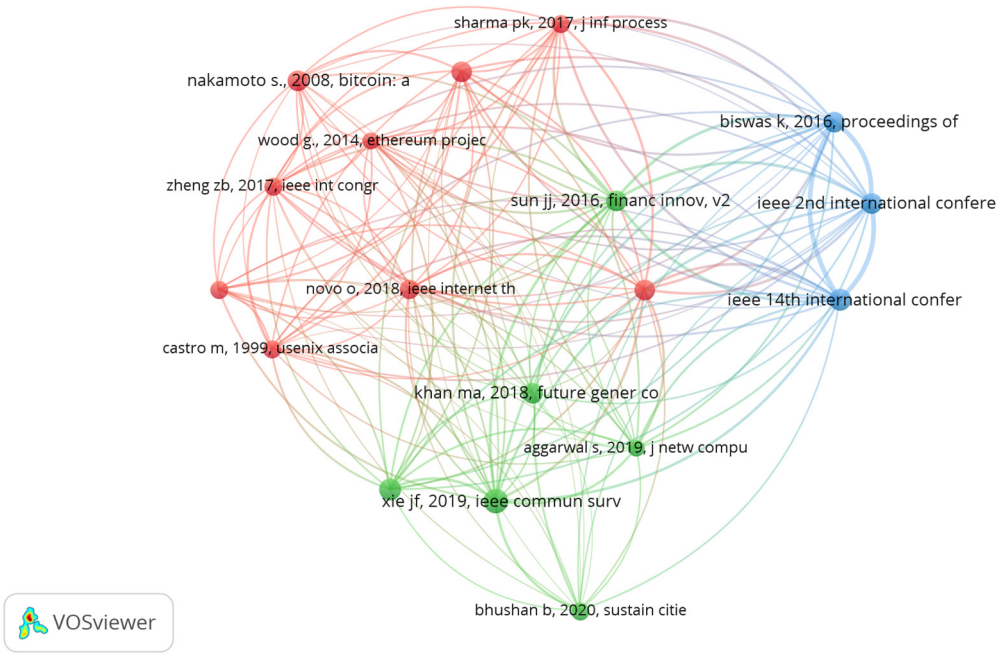

Figure 4. Chart of co-citation analysis of cited references using VOSviewer software.

3.1.4. Co-Occurrence Analysis

In this section, we present a co-occurrence analysis of the keywords available in the sample, which is also called a cartographic analysis. Cartographic analysis aims to map the keywords that identify different research streams by grouping them into clusters that represent content areas. The relatedness of these areas is evaluated by considering the total link strength and the number of occurrences of the keywords in the sample [13,36,48,49]. Table 7 and Figure 5 present the results obtained using the VOSviewer software. The keywords representing the topic of this literature review are indicated in green and are also the most used by the authors, such as blockchain and smart city/cities. The blue cluster, instead, contains keywords that recall another research stream related to the previous one, including IoT, big data, cybersecurity, or distributed ledger. The term IoT is also presented in the complete form of the Internet of Things in the red cluster, which also contains keywords related to another research stream that treated other blockchain applications such as cloud computing, 5G, wireless networks, or the Internet of Vehicles. These keywords also identify the most relevant articles discussed in the previous bibliometric analysis.

Table 7. Keyword occurrence and cluster details (top 10 list).

Keywords	Occurrences	Total Link Strength	Cluster
Blockchain	267	1574	Blue
Smart cities	124	844	Blue
Security	103	823	Blue
Internet	108	798	Red
Internet of Things	80	611	Green
IoT	66	490	Yellow
Smart city	86	487	Red
Challenges	56	451	Light blue
Privacy	49	393	Blue
Management	46	392	Purple

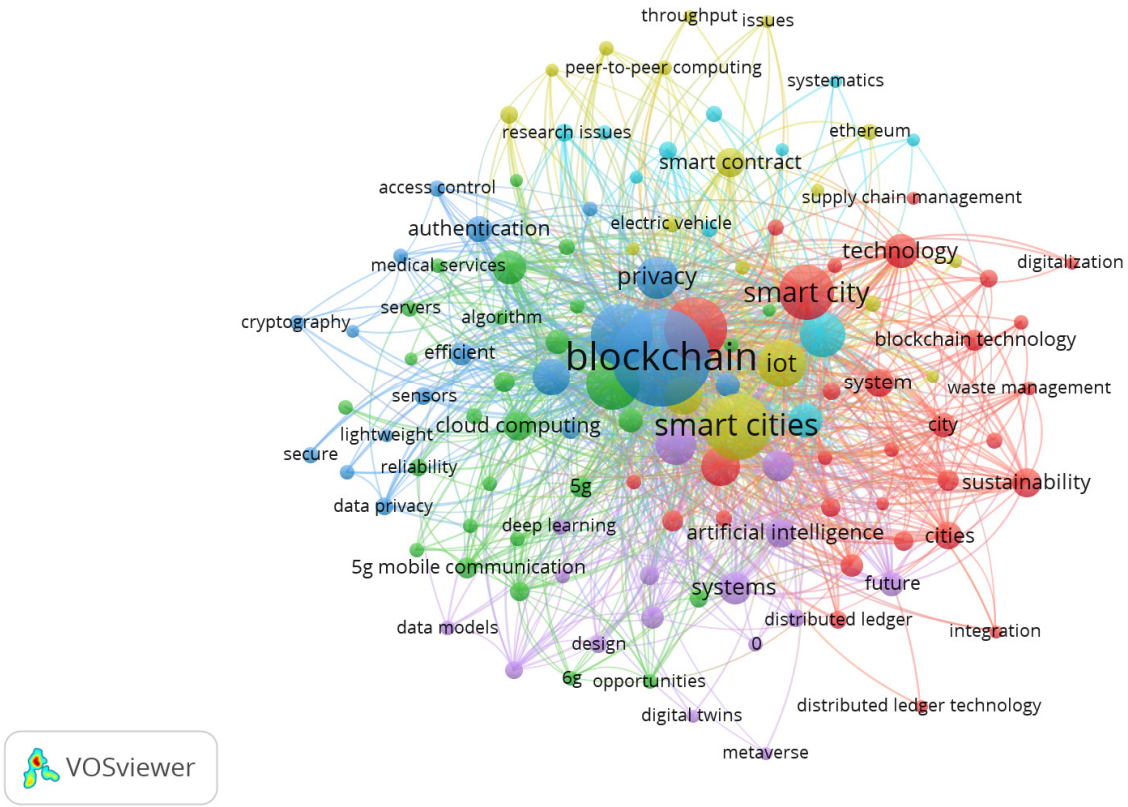

Figure 5. Cartographic analysis through VOSviewer software. Source: Authors' elaboration from VOSviewer.

3.2. Systematic Analysis: WoS Business, Finance, Economics, and Management

This section examines the current status of blockchain applications in developing financial ecosystems for smart cities, summarized in Table 8 below. We have limited the WoS database search to the business, finance, economics, and management categories to achieve this, yielding 26 documents published between 2016 and 2023. According to Paul et al. [18], the process of conducting an SLR is the best option to achieve our objective since it helps to develop a comprehensive understanding of the existing literature (state of the art) and provides new avenues for future research (stimulating agenda). The term "state of the art" refers to the mapping and up-to-date literature summary. In contrast, "stimulating agenda" refers to the potential directions for future research to enrich the literature and enhance our understanding of smart cities.

The emergence of specific technologies such as blockchain, 5G internet, virtual and augmented reality, and quantum computing can contribute to the development of smart cities.

The SLR process classifies the documents into nine main themes: (i) blockchain governance and infrastructure; (ii) definitions and key components; (iii) blockchain implementation and performance indicators; (iv) smart city development financing; (v) robotic services; (vi) blockchain applications in smart city development; (vii) transport and logistic systems; (vii) big data; and (ix) blockchain and sustainability of electric vehicle performance. Articles that cover more technical topics, such as Wi-Fi sensors, 5G, or data transmission, are classified as off-topic; since they do not cover financial topics associated with blockchain, they are unsuitable for the research aim. The results of the analyses are summarized in Table 8, which highlight each article's aims and main findings.

Table 8. Summary of the systematic analysis.

Topic	Article Aims	Main Findings	Reference [Number]
Blockchain, governance, and infrastructure	Systematic review and meta-analysis on the application of blockchain technology and smart contracts in decentralized governance systems.	• Blockchain-based smart governance systems involve public engagement by deploying data-computing capabilities, distributed ledger technologies, visual analytics, and smart connected devices. • Utilizing data visualization tools, spatial data mining, machine learning techniques, blockchain-based smart contracts, and decentralized applications can enhance trust in computationally networked urbanism. • Smart cities leverage the Internet of Things (IoT) to deploy decision support tools, computer vision techniques, and visual data mining. This enables scalable networked interoperability across urban environments and efficient data resource management. • Urban sensing technologies integrate geospatial big data analytics, IoT sensors, and smart city software systems, enhancing the overall functionality of urban environments.	Balcerzak et al. (2022) [50]
	Create a new searchable 3D city model to help managers improve their decision making.	The digitization of data and integration of new technologies into various management processes have made it possible to interconnect city systems. While numerous 3D city models are available, none identified in this research can be queried for multiple sectors.	Lafioune and St-Jacques (2019) [51]
	Examine the current implementation of strategic smart city agendas and the methods used to measure and present their performance. It proposes a new approach involving blockchain technology to create a more inclusive and collaborative platform known as the People's Smart City Dashboard (PSCD).	The People's Smart City Dashboard (PSCD) uses blockchain technology to empower and collaboratively reimagine smart city agendas and performance measurement, achieving citizen-centric governance.	Marsal-Llacuna (2020) [52]
	Propose the Digital Twin City model, a systematic review of advanced technologies applied in DTC, research directions, and a new framework.	Digital Twin Cities (DTCs) offer great potential in transforming urban governance paradigms towards smart cities by combining digital twins, IoT, blockchain, and AI technologies.	Deng et al. (2021) [53]
Definitions and key components	Review of definitions and components of current smart cities.	• There is no consensus about a standard definition of smart city, components, and applications due to the diverse nature of the field. • Provide a brief presentation of smart city key components such as smart buildings, smart transportation, smart healthcare, and smart energy. The emergence of specific technologies such as blockchain, 5G internet, virtual and augmented reality, and quantum computing can contribute to the development of smart cities.	Bohloul (2020) [54]
Blockchain implementation and performance indicators	Review and study the use of performance indicators to evaluate blockchain implementation projects in smart cities using the Delphi method.	According to the Delphi method, the experts proposed eight additional performance indicators: user base growth over time, environmental sustainability, risk density, policy revision based on the implementation of new data, ease of access, data integrity, resiliency, and number of transactions executed.	Ivanisevic et al. (2023) [55]
Smart city development financing	Identify modern investment processes in developing smart technologies for the world's smart cities amidst large-scale digitization.	Investment in the development of smart cities involves using advanced technologies and innovations to improve the lives of residents, optimize resources, and increase the efficiency of the urban economy. This investment can take various forms, including direct investment, venture capital, corporate investment, corporate partnerships, state and local funds, crowdfunding, bonds and municipal bonds, fintech, blockchain, and more.	Kalenyuk et al. (2023) [56]

Table 8. *Cont.*

Topic	Article Aims	Main Findings	Reference [Number]
Robotic services	Describe different methods of organizing robotic services for smart cities using secure, encrypted decentralized technologies and market mechanisms.	• In the article, Ethereum and ROS were proposed as interaction mechanisms in a smart city. These market mechanisms ensure the effectiveness and practicality of the agents. • The study demonstrates that the services of a smart city are more efficiently and effectively managed when implemented based on the robot economy.	Kapitonov et al. (2019) [57]
Blockchain applications in smart city development	Show how blockchain networks will disrupt the urban context, similar to what is happening in the fintech and insurtech industries, among other emerging applications.	Blockchain networks will disrupt urban networks, similar to other network fevers such as Cybernetics, Ekistics, and IoT, and serve as the enabling network for cities.	Marsal-Llacuna (2018) [58]
	Investigate the applicability of blockchain in the governance process in autopoietic smart cities.	• Blockchain has the potential to enable self-regulation and self-sufficiency in the governance systems of smart cities. • Integrating blockchain technology with IoT devices such as cars, houses, and public places is hindered by people's lack of familiarity with blockchain. • The main challenges hindering the implementation of blockchain technology in government services are the management of smart contract variables related to the origin, transportation, and consumption of resources, as well as health and financial services. Another significant factor is the need for higher-speed broadband connections to enable seamless blockchain integration. • The lack of awareness and education from the public sector contrasts with the private sector's greater investment in blockchain technology and information.	Migliorini et al. (2021) [59]
	Security of IoT devices, resilience to cyber-attacks, flexibility, and rapidity of system development.	A DLT-based attestation system provides decentralized security for IoT devices, ensuring connectivity and correct functioning in smart cities.	Moro and Duke (2020) [60]
	Propose a framework to identify the features of smart cities from the angle of the sharing economy.	Blockchain-based sharing services can contribute to smart cities by enhancing the sharing economy's human, technology, and organizational factors.	Sun et al. (2016) [32]
Transport and logistic systems	Review smart city transport and logistic systems.	• The research outlines the dominant trends and specifics of the smart mobility services development in real-time for businesses and individuals, as well as intelligent transportation systems and highly autonomous vehicles in smart cities worldwide. • The rise of IoT is driving a shift towards a multimodal environment. • The study highlights the need to develop urban logistics as a tool to expand opportunities for managing flow processes sustainably in an urban area.	Savin et al. (2021) [61]
Big data	Systematic review of big data in smart cities.	• The bibliometric analysis indicates a significant increase in research publications in recent years, with China leading research efforts on smart cities in developing countries. • The network analytics and article classification identified six domains within the literature on smart cities. • A conceptual framework has been proposed to implement Industry 4.0 technologies in smart cities successfully.	Tiwari et al. (2019) [62]

Table 8. *Cont.*

Topic	Article Aims	Main Findings	Reference [Number]
Blockchain and sustainability of electric vehicle performance	Test the readiness of electric vehicles (EVs) in the UAE, the role of EVs as a mediator to sustainability, and the role of blockchain as a moderator.	• The study revealed a positive correlation between EV readiness in the UAE and quality of service, power quality, and infrastructure. • The adoption of blockchain technology in the UAE is still in its early stages, as its role in enhancing the relationship between power quality, infrastructure, and sustainability is not yet significant. • The adoption of blockchain technology has the potential to save energy.	Sundakarani et al. (2023) [63]
Off-topic *	[64–74]		

* Note: Upon analyzing these papers, we have noticed that they do not strictly cover financial issues.

A brief discussion of the documents highlights that the first category includes a systematic literature review on decentralized governance systems, which first highlights the impact of blockchain technology in smart city governance. Blockchain-based smart governance systems utilize data computing, DLTs, visual analytics, and smart devices to engage the public. These technologies have multiple applications and can increase trust in computationally networked urbanism. Blockchain technology enables seamless data-sharing and reduces transaction costs, while smart contracts democratize governance structures. The decentralized nature of blockchain optimizes smart city self-governance [50]. For this purpose, Marsal-Llacuna [52] proposed using community-led technologies such as blockchain to solve the problem of smart cities, which fail to be citizen-centric due to the top-down approach. The author proposes using a People's Smart City Dashboard (PSCD). This community-led initiative aims to provide an alternative to the current top-down approach to smart city development. The project uses blockchain technology, which is designed to be community led, allowing citizens to significantly implement smart city agendas and collaborate with society. Furthermore, Bohloul [54] provides a comprehensive review of challenges, trends, and opportunities in the topic of smart cities, and also provides an overview of the main definition of a smart city, which does not present a consensus about the exact definition. The author affirms that certain technologies, such as blockchain, 5G internet, virtual/augmented reality, and quantum computing, can contribute to the advancement of smart cities. These technologies have created numerous opportunities for research and entrepreneurial endeavors. Although the current state of smart cities is promising, it remains a rapidly evolving field, with new trends expected to shape its future. A similar assessment of the field of smart cities is presented by Marsal-Llacuna [58], Migliorini et al. [59], and Sun et al. [32], who highlight the role of blockchain technology in disrupting urban networks and being essential for governance, infrastructure [61,63], and financial services development in smart cities through the use of smart contracts and IoT. Another interesting point of view is provided in an article by Tiwari et al. [62], which presents a conceptual framework of the smart city for the adoption of Industry 4.0. Their article also highlights challenges and trends in technologies, such as big data, cloud computing, edge computing, and IoT. These advanced technologies are crucial for successfully implementing and monitoring a smart city.

4. Further Discussion of the Results

The bibliometric and systematic analysis results provide several insights into the research landscape of blockchain applications in smart cities. From the bibliometric analysis, *IEEE Access* emerges as the most influential journal with the highest number of total citations and the most globally cited documents, such as Fuller et al. [26]. Though globally influential, Fuller's research receives limited local citations, which may further imply that the research relevant to this specific smart city research niche was either indirectly utilized or underutilized in localized contexts. With high local citation counts, Xie et al. [27]

represent direct relevance and influence on the smart cities research community, thus forming a cornerstone of subsequent research and application development in this field.

The co-authorship and co-citation networks underscore the collaborative nature of this research domain. Notable authors, such as Choo K.-K.R. and Guizani M., serve as central hubs in the network, fostering interdisciplinarity and cross-group research efforts within this area. This structure provides a solid platform for blockchain and smart city research, which is inherently dynamic and fast-paced.

Systematic analysis shows that blockchain is instrumental in the decentralized governance system for transparency, security, and increasing public engagement in urban management. In overall terms, the studies largely focus on the concept of smart cities and the potential impact of blockchain considering the following: (1) the merging of information systems and urban infrastructure such as, e.g., transportation/mobility, connections, electricity and waste management, and safety and healthcare [32,59–63]; (2) the progressive extension to the areas of planning, development, civil/administrative services, and sustainability issues [52–56]; and (3) citizens' participation and cooperation in urban governance in terms of both actions and processes, moving from a largely technological focus to a social, economic, and political approach [50–53,57,58].

This is evidenced by studies, such as Balcerzak et al. [50], which adduce how blockchain democratizes governance structures with smart contracts and decentralized applications to have a more inclusive model of urban governance. Although there has yet to be a single agreed definition of what constitutes a smart city, which reflects the field's diversity and multidisciplinarity, common components identified include smart buildings, transportation, healthcare, and energy systems. Most of the emerging technologies are related to 5G, IoT, and artificial intelligence; thus, being already recognized as critical enablers of smart city advancement would point out a trend towards their integration for holistic urban development. The Delphi method reveals a number of other performance indicators relevant to evaluating blockchain projects in smart cities. These include environmental sustainability, data integrity, and increasing the user base, among others, which consequently provide a holistic framework for assessing blockchain impact and effectiveness within urban contexts.

These findings are within the larger research trends that put blockchain at the core of efficiency and security in smart city infrastructures worldwide. Other authors of research papers, such as Marsal-Llacuna [52] and Deng et al. [53], underline blockchain's disruptive role in urban governance, relating its integration to digital twins and IoT technologies. This perspective contributes to the novel identification of specific performance indicators regarding blockchain implementation in smart cities, which needs to be explored more in future literature. This provides more granularity in understanding how blockchain can be effectively used and measured within urban environments.

The research conducted in this study uncovers several implications for future studies. The absence of a unified concept of smart cities presents a research opportunity: developing an agreed core set of components and applications could enhance the comparability and coherence of this area of research. Moreover, the integration of emerging technologies such as quantum computing and augmented reality into the contexts of smart cities is certain to reveal additional lines of research inquiry. The systematic application of bibliometric and co-authorship analyses strengthens the methodology for understanding the research landscape. Future research could consider similar approaches to map the evolution of other emerging technologies and their applications across different domains, inspiring further exploration and discovery.

The results of this study also highlight the dynamic and interdisciplinary nature of blockchain and smart city research. There is significant potential to improve urban governance and infrastructure through the integration of blockchain. For instance, it has already been proven that blockchain can be applicable to enhancing the transparency, security, and efficiency of urban management systems with decentralized governance and seamless data sharing. The previously mentioned Marsal-Llacuna [52] has introduced the

idea of the People's Smart City Dashboard based on blockchain to enhance community-led governance and collaboration in overcoming top-down traditional smart city development deficiencies. Further, Balcerzak et al. [50] underline how blockchain democratizes the governance structure ruled by smart contracts and makes models of urban governance more inclusive. Again, the research performed by Deng et al. [53] proved that blockchain will be powerful in creating disruptions if it is combined with digital twin technologies and IoT to make urban planning and real-time decision making more effective. Though the prospect looks bright, a set of standard definitions and performance metrics remains indispensable to be developed to complete the deployment of blockchain benefits for smart cities. Future research should, therefore, address such standardizations and work out synergies between blockchain and other emerging technologies like quantum computing or augmented reality.

In addition, more research is required to standardize definitions, develop comprehensive performance metrics, and explore synergies between blockchain and other emerging technologies. This ongoing exploration and discovery should excite and engage researchers in the field.

Most of the articles studied in the bibliometric analysis are mainly qualitative, signaling the need for stronger quantitative research. Hence, future research should focus on producing quantitative analyses to provide more depth and scope to the knowledge base on the subject. Moreover, a comprehensive framework for the economic implementation of blockchain in smart cities appears to be missing. The current studies follow a scattered and fragmented approach of smaller, transversal application areas, which are largely driven by technical analysis methods that lack the capability to measure the performance gains of DLTs compared with conventional information systems. In this sense, metropolitan government authorities would be required to define and coordinate the overall action plan for a smart city considering the various target sectors of interest and related potential blockchain applications (especially those referred to in the proposed research agenda—Table 9), in order to ensure an aggregate economic perspective capable of capturing potential operational synergies.

Furthermore, narrowing the sample to focus specifically on the WoS categories of economics, business, and management, the SLR reveals that most articles are centered on DLTs, particularly on blockchain technology applications (through smart contracts) in smart city organizations and governance. However, most articles did not adequately focus on blockchain but included this technology in describing all those essential for developing smart cities (such as IoT, cloud computing, edge computing, robotics, 5G). Some of the articles proposed a review of the definition of what constitutes a smart city and its elements as the basis for the proposal of frameworks for smart city development.

In summary, however, none of the reviewed literature investigated applications of DLTs and blockchain in developing the financial systems of smart cities, revealing a significant lack of research highlighted by this systematic literature review. From this perspective, there is great potential for further studies to develop economic and financial applications specifically intended for smart cities that might commonly be used for shared micro- and macro-constructs. Moreover, it is crucial to consider aspects related to economics and finance in the early stage when raising funds for smart city infrastructure constructions, as well as in the later stage when an efficient, inclusive, and sustainable financial system is necessary for the urban operation of smart cities.

Table 9. Future research agenda.

Research Area	Further Research Issues
Payment services in smart city transactions	• How can blockchain systems be scaled to handle increasing transactions in smart cities without compromising performance? • What strategies can be developed to enhance interoperability between different blockchain platforms and traditional payment systems in the context of smart cities? • What regulations and standards are necessary for blockchain adoption in smart city payment services, and how can they be effectively implemented? • What is the most suitable governance model for managing decentralized payment systems in smart cities, and how can it balance decentralization with the need for regulatory vigilance? • What factors influence the adoption of blockchain-based payment systems in smart cities, and how can user experience be improved to encourage widespread acceptance? • How can blockchain networks be made more energy-efficient to ensure sustainability, especially in smart cities where environmental concerns are crucial?
CBDC and application for the cities of the future	• How can CBDCs be integrated seamlessly into the existing and future infrastructure of smart cities, including transportation systems, utility networks, and public services? • What are the challenges in ensuring CBDC interoperability with digital currencies from other regions, and how can they facilitate cross-border transactions within smart cities? • What strategies can ensure CBDCs promote financial inclusion and accessibility across diverse socioeconomic groups in smart cities? • How can the efficiency and transparency of public services, such as tax payments, licensing, and social welfare distributions, be enhanced in smart cities using CBDCs and smart contracts? • How can CBDC platforms be designed to be resilient to cyber threats and attacks, ensuring the security and continuity of digital currency transactions in smart cities?
Blockchain for the smart city real estate market	• How can blockchain technology be utilized to create secure and immutable records of title and ownership (i.e., asset market) and leases (i.e., space market) for real estate properties, thereby reducing fraud and enhancing transparency in smart cities? • How might the implementation of blockchain technology enable the creation and preservation of immutable records of real estate assets in terms of single property characteristics in terms of historical ESG and technical data, cash flows, yields, appraisal values, transaction prices, etc.? • How can blockchain be used to tokenize real estate assets, allowing for fractional ownership and enabling a broader range of investors to participate in smart city real estate markets? • How can blockchain protect sensitive information in real estate transactions while ensuring transparency for relevant parties? • How might the implementation of blockchain technology enable the creation and preservation of immutable records of property development processes, such as planning, construction, and regulatory approvals, within the context of smart cities? • How can blockchain technology improve transparency in the real estate supply chain? It can track the origin and authenticity of construction materials while ensuring compliance with sustainability standards. • How can blockchain technology play a role in determining a property's value in real time while considering factors such as market demand, neighborhood development, and economic indicators in smart cities? • How can smart contracts be employed to automate and enforce rental agreements, ensuring efficient property management and tenant–landlord relationships in smart cities?
Smart contracts and urban services	• Can smart contracts enable automated parking reservation and payment systems, ensuring transparency and efficiency? • Is it possible for smart contracts to streamline the waste collection and disposal processes, leading to cost savings in labor, enhancing overall efficiency, and supporting sustainability? • Optimizing waste collection routes and minimizing waste overflow can be achieved by integrating smart contracts with smart waste bins and sensors. How can this integration be achieved? • Is there a way to utilize smart contracts for managing prescriptions and delivering medication in an automated manner that can help reduce errors and improve patient adherence? • How can smart contracts optimize energy distribution and reduce reliance on traditional grids for decentralized renewable energy source management? • In what ways can smart contracts be utilized to enhance energy efficiency in buildings and households, thereby leading to decreased energy expenses and encouraging sustainability?

Table 9. *Cont.*

Research Area	Further Research Issues
Blockchain and data storage, security, and privacy	• As smart cities generate ever more data, it becomes increasingly important to implement storage solutions that can handle the volume and complexity of these data. To achieve this, research is required to develop decentralized data storage systems that use blockchain technology. These systems must ensure data integrity, security, and immutability while efficiently handling large datasets. • Smart cities produce vast amounts of data that can be used for various purposes. However, conducting research and developing reliable and secure data marketplaces is essential to allow data sharing and monetization while ensuring data privacy, ownership rights, and fair compensation for data providers. • The increasing vulnerability of smart city infrastructure to cyberattacks and data breaches calls for research on blockchain technology-based cybersecurity solutions that improve data security, network resilience, and incident response capabilities in smart cities.
Smart city governance and integration with other systems	• Blockchain technology can be utilized to develop secure and transparent e-voting systems that protect voters' privacy and prevent electoral fraud. Therefore, researching to create robust e-voting protocols that incorporate blockchain technology to ensure fair and verifiable elections in smart cities is essential. • Blockchain technology can automate governance procedures by utilizing smart contracts and self-executing agreements that enforce rules and regulations without intermediaries. There is a need for further research to investigate the potential applications of smart contracts for enhancing service delivery, managing resources more efficiently, and effective contract management in smart city governance. • Blockchain technology can potentially improve supply chain transparency and traceability by creating a tamper-proof record of product movement and origin. Further research is required to investigate how blockchain can enhance food safety, prevent the circulation of counterfeit goods, and ensure ethical sourcing in supply chains for smart cities. • For blockchain to be fully utilized in smart city governance, it must integrate seamlessly with existing systems and technologies. This requires research to develop standards and protocols that enable the integration of blockchain solutions with legacy systems, e-government platforms, and other smart city infrastructure.

5. Conclusions and Further Research

Smart cities leverage digital technologies to promote sustainable environments, optimize public service delivery, and boost citizens' well-being. Developing an efficient, sustainable, and inclusive financial system is crucial to support the development and resilience of smart cities. This kind of financial system significantly improves citizen participation in city life and increases the efficient use of resources, services, and spaces. The financial system represents the beating heart of every economic system; without it, it would be impossible to ensure the functioning of smart cities. Blockchain and DLTs are new technologies that can merge with the need to increase the inclusiveness and participation of people in the financial system and contribute to the construction and development of smart cities. This pioneering study provides a bibliometric and systematic literature review to highlight the impact, potential, and challenges of using blockchain and DLTs in the development and functioning of smart cities. Unlike previous research, this study focuses on the financial and economic applications and implications of using these pioneering technologies in the environment of smart cities, highlighting a lack of research on the topic. The bibliometric analysis reveals that the majority of the reviewed articles focused on various technologies and applications in the urban environment of smart cities, including blockchain, and conjugated their characteristics compared with the possible uses and applications. Thus, the bibliometric analysis demonstrates scholars' scarce interest in blockchain technology's practical implications on smart city financial system development and functioning.

Finally, this literature review sheds light on the challenges and opportunities of blockchain in the realm of smart city financial systems, bridging the gap in this research

stream. The results of this study can guide researchers and policymakers in exploring the impact of blockchain technology on citizen participation in urban financial activities and the efficient utilization of financial resources while considering the public externalities of most urban services. This may lead to more collaborative research in this area, exploiting findings from the bibliometric analysis. Table 9 below aims to stimulate further research by suggesting some open research questions identified after the literature review analysis. The future research agenda presented in Table 9 also includes several research questions that could be food for thought for academics and practitioners interested in covering aspects related to the financial system development of smart cities. The development of this research agenda comes from the need to stimulate potential directions for future research to enrich the literature and enhance our understanding of smart cities. It includes relevant topics, above all related to the economic and financial aspects of blockchain in smart cities, which were not mentioned in previous literature but which we consider fundamental in the context of designing future smart cities.

As previously mentioned, the literature review did not detect specific studies on the potential of blockchain applications in developing a payment system serving the urban environment. However, it is essential to explore this topic since it encompasses different disciplines and other applications in urban services (transportation, waste management, and energy services) and is related to smart city governance in general. In addition, the organization of the payment system does not overlook the use of future Central Bank Digital Currency (CBDC) initiatives, which, owing to the characteristics of CBDCs, perfectly match the needs of citizens and the functioning of smart cities. Furthermore, using blockchain for the real estate market constitutes a trending topic that is driving the old concept of urban organization toward future smart city constructions. Blockchain can provide a secure and transparent land registry system that reduces fraud, streamlines property transactions, and enhances land management in smart cities. However, research is necessary to develop blockchain-based solutions for land registration, title verification, and property taxation in smart city governance.

Additionally, since this study specifically focuses on the application of DLTs, particularly blockchain, we acknowledge some issues related to (i) the rapidly evolving nature of the technology and the urban environment; (ii) the sample selection process, which was limited to peer-reviewed papers and did not consider proceedings and working papers and (iii) the novelty of the subject, which is still in development.

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