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Blockchain applications in smart sustainable city context—A systematic mapping study

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Abstract

The advancement in blockchain applications in the smart sustainable city infrastructure is evaluated in this paper through a comprehensive mapping review. The evaluation is carried out by posing four research questions that address current developments in blockchain technology in the context of smart cities and point out areas where additional study is needed. This study also includes a scoping of blockchain applications in a smart city context to highlight the obstacles to incorporating blockchain technology into smart city infrastructure. Finally, some suggestions for overcoming the problems of incorporating blockchain technology with smart city infrastructure are offered. This research will help researchers and policymakers gain a better understanding of blockchain applications in smart cities.

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Keywords: Smart city; Sustainable environment; Blockchain; Mapping study

1. Introduction

Increased urbanization is a contributing factor to the world's rapid population rise in the modern period. Cities have faced tremendous pressure from difficulties related to this situation during the previous several decades. Many environmental, economic, and social challenges arise due to urbanization, and these issues have far-reaching consequences for human civilization. According to a United Nations estimate, 55 percent of the world's population lives in cities in 2018, and it is expected that by 2050, more than 70 percent of the world's population will live in cities [1]. Citizens raised their living standards in a variety of areas for the benefit of urbanization, including transportation, education, health, the economy, working conditions, and lifestyle [2]. With the rapid expansion of

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urbanization, a number of challenges have arisen, including traffic congestion, pollution, non-renewable resource depletion, waste management, and the challenge of maintaining social equality [3–5]. The researcher presented the concept of a "smart city", which is an intelligent effort for the sustainable development of cities, as well as an intelligent way to address the aforementioned concerns and obstacles [6–8]. Several urban sustainability and smart city methods have been recommended in recent decades [9,10]. They provide ways for assisting metropolitan authorities in making decisions, taking actions, and assessing city growth in the direction of a more sustainable future [11].

Researchers have lately begun to promote the notion of "blockchain cities" as the next step in transforming the urban environment to address urbanization-related challenges. Many people believe that blockchain will play a large role in the global economy's long-term growth, raising people's living standards and, in the end, bringing fundamental changes to the society they live in [12,13]. Blockchain is a database management system based on a distributed ledger that assures transaction history transparency and immutability. Furthermore, much attention has been paid to evaluating the use of blockchain in a variety of applications, such as solutions that provide identity confidentiality and transaction security using a decentralized structure and various agreement techniques (e.g. proof-of-work) among many geo-located IoT devices [14]. Using ICT, AI, and IoT intelligent services, blockchain provides a wide variety of potential to tackle the aforementioned urbanization concerns and deliver a better lifestyle [15–17].

This study aims to investigate the research trends in recent years to identify the knowledge gaps in the field. A systematic mapping technique is deemed suitable for performing an in-depth assessment of this field. This approach of analyzing the information regarding the recent developments of a vast topic in a comprehensive manner enables a thorough assessment with clearly defined outputs and examples. The contributions of this study are two-fold.

- By carefully formulating research questions, the study provides a comprehensive illustration of the evolution of blockchain technology research in a smart city context
- It identifies the key factors influencing the blockchain applications in smart cities and provides a future direction on how blockchain technology can further contribute to attaining smart city goals.

The following is how the rest of the paper is organized: The study's methodology is presented in Section 2. The answers to research questions are discussed in Section 3. Section 4 concludes with a discussion of the important takeaways.

2. Methodology

For this study, a systematic mapping approach is chosen to develop a comprehensive overview of the topic by performing categorization of the topic and quantifying the contributions of each category [18]. It is possible to summarize the contributions in the field made in recent years by scoping relevant publications and previous case studies. Using the systematic mapping process, the relevant data can be laid out to form relevant conclusions [19]. The outcome of this systematic mapping process will be a comprehensive overview of the field in a structured manner. Fig. 1 shows each review process step, highlighting the decision parameters. The steps are discussed briefly in the following subsections

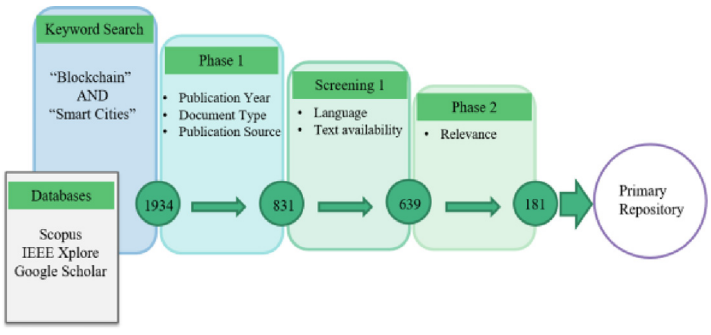


Fig. 1. Illustration of each step of the methodology.

Table 1. Research questions addressed in this study.

	Research Questions
RQ1	How far has Blockchain research progressed in the smart city context?
RQ2	What are the Key research streams identified in Blockchain applications in the smart city context?
RQ3	What role has BlockChain had in developing smart city infrastructure in the past, and how may it play a role in the future?
RQ4	What steps may be taken to help Blockchain-based technology adapt to the future growth of smart cities?

2.1. Research questions

The goal of this article was to get a comprehensive knowledge of Blockchain applications in Smart Cities and compile a representative collection of existing research on the subject. This was done in numerous steps to verify the process's dependability, as previously mentioned. Once the scope of the issue had been established, the first step was to determine the precise research questions that would guide the work throughout this study. To completely examine this subject matter, each research question was chosen to address a distinct facet of the issue. Table 1 shows the research questions of this study.

2.2. Creating repository

In this step, a well-defined research article repository must be developed to obtain answers to the research questions mentioned in the previous section. The success of this study is dependent on the creation of a comprehensive and well-defined repository. By conducting preliminary research, some keywords and relevant search criteria are established from related review articles, which will later be used in the repository's creation. The literature database structure is then constructed with unique features to reflect the aspects and complexities of blockchain applications in smart cities. The tailored features provide the most metadata and information pertinent to research questions, qualifying appropriate articles for inclusion in the repository. Using Microsoft Excel, a collection of relevant articles was gathered into a spreadsheet. The keyword used to build the repository is shown in Table 2.

Table 2. Search Terms.

	Keywords
Search Terms	"Blockchain" AND " Smart Cities" "Blockchain Technology" AND "Smart City" AND "Sustainability"

2.3. Initial search

The publications were gathered from a mix of three relevant peer-reviewed sources, including IEEE Xplore, Scopus, and Google Scholar. Other resources, such as the Web of Science, were investigated, but they were eventually deemed excess to needs. The extra databases were removed from the search list owing to a high cross-over in publications between Scopus and google scholar, a lack of relevancy in database descriptions and scope, and the absence of full access at the time. Each of the three databases had its search capabilities, ranging from simple single-entry engines to more complex procedures that allowed for more advanced search criteria requirements. A variety of publications were discovered using the search terms indicated in Table 2 that would form the foundation of the research paper repository.

2.4. Screening phase

Following the completion of the search and the compilation of relevant papers, an initial screening process was necessary to exclude certain non-qualifying articles. Inclusion and exclusion criteria are presented in Table 3. Only relevant, peer-reviewed publications published in English and available in full form advanced to the next level during this phase. The qualifying papers, as well as their metadata, were collated in the repository under preset themes. Each paper's title and abstract were examined in this step to assess its relevancy.

Table 3. Search criteria for the study.

	Inclusion Criteria	Exclusion Criteria
Databases	Scopus, IEEE Xplore, Google Scholar	Others
Publication Period	2017–2021	Before 2017 and After 2021
Document Type	Journal, Conference	Book chapters, Letters, Erratum, Editorials, Notes
Source Type	Journal, Conference proceedings	Book Series
Language	English	Other languages

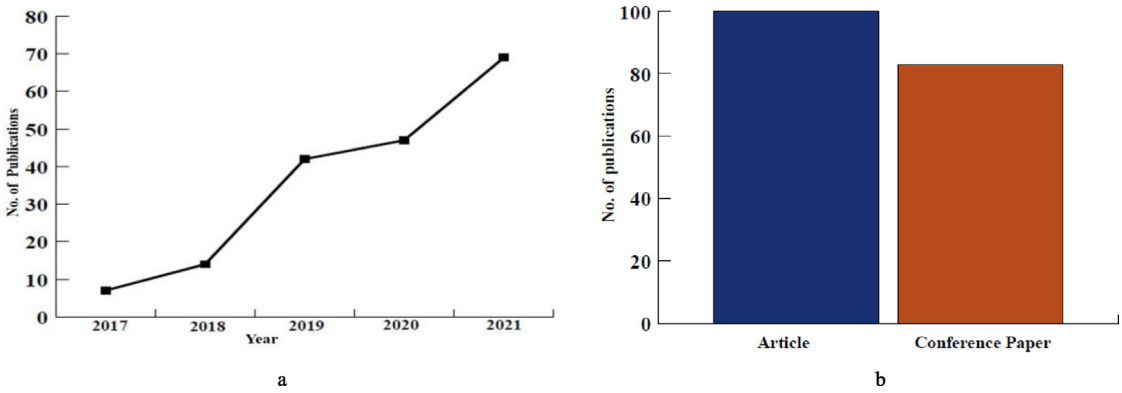


Fig. 2. (a) Publication fora (b) Type of Publications.

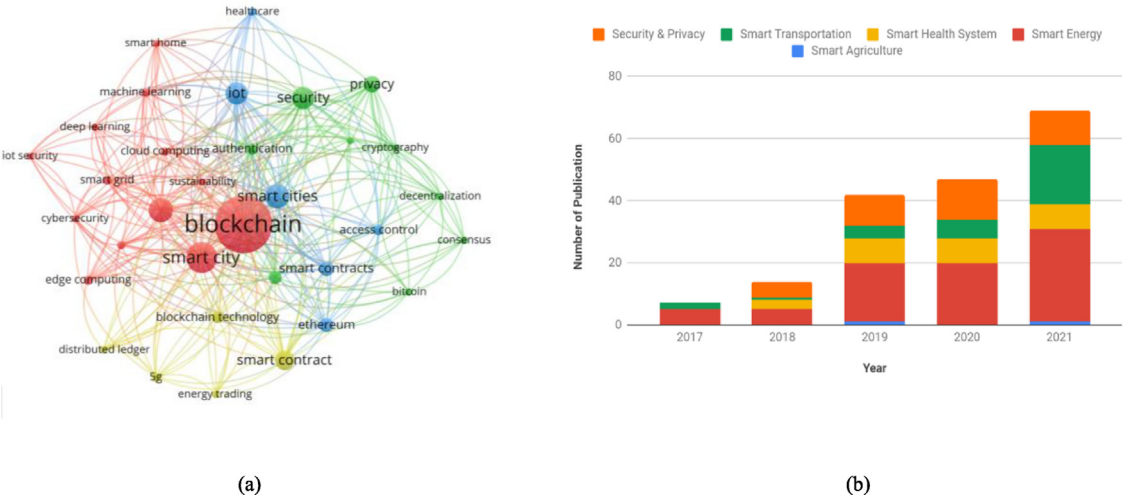
3. Results

3.1. Research Question 1- How far the blockchain research has progressed in the smart city context at the moment?

By examining the previously recognized body of literature and extracting the publication date of each article, it was able to track the growth of the topic of each of the 181 papers that constitutes the primary repository. Fig. 2(a) shows how research in blockchain applications in smart cities has progressed through time, from a few publications in 2017 to 181 articles at the time of the study in 2022. Subsequently, it is been observed from Fig. 2(b) that about 60% of the papers are journal articles in the published literature, and 40% are conference articles. In the primary repository, most of the literature is still at its early stages of research, where authors only proposed the solution; however, no pilot has been done to prove the effectiveness of the proposed solution.

3.2. Research Question 2- "What are the key research streams identified in blockchain applications in a smart city context?"

A keyword co-occurrence analysis is performed to identify key research streams from the keywords of published research. The study of keywords co-occurrence networks aids scholars in determining the most important research topics mentioned in a certain field of study. Keyword co-occurrence is a powerful bibliometric analysis approach for visualizing and showing similarity in the publications between often co-occurring terms or subjects. Researchers may get a better picture of an article's content and vital information about methodologies, aims, and opinions using this bibliometric methodology. The keyword co-occurrence analysis of the articles in the primary repository is shown in Fig. 3(a). The keywords are interconnected via links in Fig. 3(a), forming various clusters that represent distinct research streams. Each node in Fig. 3(a) represents a keyword, with the size of the node corresponding to the number of times the keyword appears in articles from the primary repository. Blockchain applications in smart energy, smart transportation, smart health care, security and privacy, and smart agriculture have been recognized as five primary research streams from the clusters. The growth of publications in each of these recognized research streams is seen in Fig. 3(b). The figure shows a constant increase in publications over time, which indicates the growing interest in blockchain-based technologies in smart city applications.



(a) (b)

Fig. 3. (a) Keyword co-occurrence analysis (b) Growth of papers in identified research streams.

3.3. Research Question 3- "What role has blockchain had in developing smart city infrastructure in the past, and how may it play a role in the future?"

Blockchain-based technology has played a significant part in developing smart city infrastructure throughout the years. Five significant streams have been identified from the preceding section that has been regularly reported as expanding topics in this subject matter. The following subsections briefly describe the role of blockchain in the development of smart city infrastructure highlighting these five research streams,

3.3.1. Smart energy

One of the most important aspects of a smart sustainable city is its energy generation and energy infrastructure. The primary goal of smart energy is to maximize the efficient use of clean, low-cost energy. Through the facilitation of peer-to-peer energy generation and consumption, blockchain has the potential to make the energy business more robust [20]. The usage of blockchain in the city ecosystem can help maximize energy efficiency and enhance energy resource management [21,22]. The use of blockchain for the regulation of energy transformation and distribution can provide greater transparency to energy transactions. Blockchain may be used in the energy network to create a robust communication backbone, simplifying and securing peer-to-peer energy trade transactions. Data created by energy management systems may be stored using blockchain technology [23–25].

3.3.2. Smart transportation

Smart transportation aims to increase access to modernized transportation systems that are both efficient for users and sustainable for the smart city and the environment as a whole. This is an important aspect of any Smart City. The proper administration of a transportation network is one of the key challenges that each city faces [26–28]. For continuous real-time tracking of vehicles and passengers, blockchain technology may be utilized in conjunction with IoT devices and systems. Various blockchain applications can help transportation decision-makers optimize routing methods and timetables, prepare for passengers' diverse demands and achieve more efficiency in terms of environmental and sustainability goals [29,30]. Users may safely pay for transportation services throughout an efficient transportation network that uses blockchain technology.

3.3.3. Smart healthcare

Healthcare is a significant industry where blockchain might find a variety of applications to help with the construction of an infrastructure that provides openness of health data, analytical approaches, repeatability of outcomes, and improved confidence in the translational medical value chain in the smart city [31–33]. As a result, they may significantly lower the cost of developing new medications, diagnostic tools, and medical protocols [34,35].

3.3.4. Security & privacy

The Internet of Things (IoT) is a network of interconnected devices and things that gather and transmit data and are assigned an Internet Protocol (IP) address, and it has the power to impact every aspect of human existence. Despite its numerous benefits for human civilization, the IoT poses major data security concerns due to its unique and specific properties [36,37]. Even when many IoT devices are put in hostile human situations or left unattended, monitoring and safeguarding the massive number of IoT systems related to more significant hazards becomes unfeasible. Adversaries can physically obtain control of and seize IoT devices, for example, to attack IoT networks [38].

3.3.5. Smart agriculture

Green development has been a major priority in smart, sustainable city development to help the deteriorating natural environment. One of the most noteworthy green developments is the increase in the use of renewable energy in agriculture. An innovation system and policy are required to create a favorable external environment for sustainable energy technology innovation to facilitate green agriculture. Blockchain-based smart agricultural coupling mechanisms and the clean energy innovation ecosystem's future possibilities are reported in Lamtzidis et al. [39],Andoni et al. [40]. The suggested model calculates and evaluates the clean energy innovation ecosystem's geographical–temporal differences, regional disparities, and spatial aggregation. The findings might be utilized to establish a clean energy innovation ecosystem based on blockchain in smart agriculture.

3.4. Research Question 4- "What steps may be taken to help blockchain-based technology adapt to the future growth of smart cities?"

Blockchain faces substantial challenges, such as probable malfunctions in the early stages of development, due to a complete lack of knowledge of a wide variety of applications. The majority of blockchain systems rely on developing unique algorithms, which may be a time-consuming and error-prone procedure. Before the technology matures, security breaches are still a possibility, which might result in delays and breaches of clients' trust. In terms of cyber-attacks, Bitcoin, the first blockchain application, has shown to be rather resistant, but other systems, such as Ethereum, have been the target of large attacks in the past. Peripheral programs, such as digital wallets or smart contracts, are notorious for introducing cyber-security problems. The ability to withstand such attacks is critical, especially for applications in critical smart city infrastructure such as energy systems [41,42]. In both the regulatory and legal framework, significant barriers to blockchain technology adoption exist. Regulatory agencies encourage city planners to accommodate blockchain technology actively in smart city services [43] . Furthermore, several authorities have implemented policies to promote local or neighborhood initiatives for the use of blockchain-based technologies to increase consumer living standards, boost energy-efficient sustainable technologies, and tackle the education gap. As a result, blockchain technology corresponds well with present regulatory aims in various smart city applications, but regulatory frameworks would need to be updated to allow for broader implementation of blockchain-based technology. For example, as seen by various P2P energy trading systems, current regulatory frameworks do not authorize consumer-to-consumer power trading. To define interactions between producers and consumers, new contract types will be required, especially when the counterparties use the public grid.

4. Conclusion

In this paper, a comprehensive review of blockchain applications in smart sustainable city infrastructure is presented. The work aims to give a comprehensive overview of the current state of the art and significant factors shaping the research landscape of this subject. The study follows a defined structure of the review and incorporates the information from 181 research papers selected through several screening process steps and research questions. The research questions were developed to determine where the majority of the research is being conducted, what stages the investigation is now at, what research streams are being pursued, and what function blockchain technology plays in smart city development. Blockchain has clearly played a substantial influence in the creation of smart and sustainable cities, according to a quantitative study of the available literature. The studies, however, are still in their early phases. To fully benefit from blockchain technologies, new regulations and pilot projects will be needed to better understand the value and usefulness of blockchain technology in the creation of smart and sustainable cities.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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