Blockchain and Building Information Management (BIM) for Sustainable Building Development within the Context of Smart Cities

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Abstract: 'Smart cities' are a new type of city where stakeholders are jointly responsible for urban management. City Information Management (CIM) is an output tool for smart city planning and management, which assists in achieving the sustainable development of urban infrastructure, and promotes smart cities to achieve the goals of stable global economic development, sustainable environmental development, and improvement of people's quality of life. Existing research has so far established that blockchain and BIM have great potential to enhance construction project performance. However, there is little research on how blockchain and BIM can support sustainable building design and construction. Therefore, the aim of this paper is to explore the potential impact of the integration of blockchain and BIM in a smart city environment on making buildings more sustainable within the context of CIM/Smart Cities. The paper explores the relationships between blockchain, BIM and sustainable building across the life cycle stage of a construction project. This paper queries the Web of Science (WoS) database with keywords to obtain relevant publication, and then uses the VOSviewer to visually analyze the relationships between blockchain, BIM, and sustainable building within the context of smart cities and CIM, which is conducted in bibliometric analysis followed by micro scheme analysis. The results demonstrate the value of this method in gauging the importance of these three topics, highlighting their interrelationships and identifying trends, giving researchers an objective research direction. Those aspects reported in the paper constitute an original contribution.

Keywords: smart cities; blockchain; building information management (BIM); city information management (CIM); sustainable building; life cycle; VOSviewer

1. Introduction

The term 'smart cities' first appeared in the 1990s [1]. Since then, there have been several definitions of smart cities. In different development periods, various stakeholders will give different definitions. Among the more widely definition relates to the six dimensions—namely, smart people, smart economy, smart governance, smart mobility, smart life, and smart environment—to measure the development of smart cities [2]. Cities can make further adjustments and improvements according to their own actual development conditions, and form their own characteristic development ways. The British Standards Institution (BSI) [3] defines the smart city as 'the effective integration of physical, digital and human systems in the built environment to deliver sustainable, prosperous and inclusive future for its citizens'.

The development of smart cities takes 'citizen-focused and improving the quality of life of residents' [4] as the fundamental goal, and achieves the triad of economic, social and environmental development in the long-term development. Emerging technologies, as a tool for urban development, acquire data and knowledge all the time around the world, produce qualitative changes in substantial amounts of data, and promote innovation and

change [5]. Desouza et al. [6] identify three paths to the development of smart cities: green-field, neighborhood and platform. However, policymakers make it clear that technology is not the core of policy making and urban development, but care for citizens is. The smart city strategy brings innovative changes to the region that helps the region improve its image and status, promote industrial development, attract high-quality talents, and contributes to the formation of a smart city model that is urgently needed for resilient settlements in a climate emergency [7]. Smart sustainable cities are currently the main development mode adopted by cities around the world, because this mode can best respond to environmental changes, ensure that the government is clean and honest, innovate the global network economy, and improve the quality of life [8].

Urban development has undergone multi-stage evolution, facing the challenges of retention and elimination, rebirth and decline, and the evolution and regeneration of multiple industries such as agriculture and industry [9]. These changes have formed today's urban strategy. Every urban renewal is a process of urban iterative optimization. Western cities have undergone five transformations, from urban reconstruction in the 1950s, urban revitalization in the 1960s, urban renewal in the 1970s, urban development in the 1980s, to urban regeneration in the 1990s. The reform of the city improves the policies according to the actual development challenges and opportunities of the city, so as to carry out the systematic implementation and management of the city and improve the quality of life of the city at the same time [5].

Taking the transformation of Barcelona's Poblenou smart cities as a case, its development focuses on social inclusion [10]. From a long-term perspective, the development of the general direction is forward-looking and sustainable. Being a knowledge-intensive city can bring the following advantages to the city:

- The influx of knowledge-based talents brings strong innovation momentum to the society and the ability to face the challenges of urban development [11];
- Promote the construction of infrastructure and life security, such as business environment, cultural and recreational facilities, medical education, housing and transportation [12];
- Promote investment in real estate, such as talent centers, business districts, and school districts; and in public sectors such as transportation, universities, cultural facilities, and tourism [13];
- Promote the establishment of mutual help relationship between university education and companies, so that the university can get practical work experience and the company can get knowledge and skills [14];
- Promote citizens to participate in urban development discussions through dialogue [15];
- As a soft asset, knowledge can effectively create value for cities and provide more appropriate solutions for urban management [16].

The case of Barcelona's Poblenou smart cities shows that the construction of a smart knowledge city requires the support of all social stakeholders, analyzes the current situation, and develops strategic plans. The formulation of the plan requires the establishment of a knowledge management framework based on different city characteristics, capabilities, and limitations. Cities can learn knowledge and expertise from each other; develop innovative solutions and sustainable strategies; and develop green, open, inclusive and sustainable cities [17].

Sustainability is an important pillar for the development of smart cities [18]. Smart devices and smart services have become parts of the smart cities [19], and the application of City Information Management (CIM) can provide ideas for effectively dealing with problems in urban construction [20]. CIM is not only an innovative and comprehensive new infrastructure construction, but also a carrier for realizing the implementation of big data new infrastructure, which plays a leading role in the realization of accelerating the digital and intelligent transformation of urban industries, helping the formation of new economic and technological forms, and in the realization of urban industrialization and industrial urbanization [21]. Building Information Management (BIM) is a key direction of

information management in the future construction industry [22]. Its combined platform with GIS, data analysis tools, visualization tools, and parametric design tools constitutes CIM [23], which provides strong support for the comprehensive management of cities. As a part of smart city, smart buildings must also integrate sustainable development throughout the entire life cycle. In order to make the society more sustainable, various concepts of 'green', 'environmental protection', and 'sustainable development' have emerged, but there is a gap between the concept and the actual operation [24]. The realization of the sustainable development requires technical support, however, the construction industry has always lagged behind other sectors in the use of digital information technology [25,26].

An increasing body of work was published on BIM. Moreover, BIM has different functions for different stakeholders. However, due to the limited understanding of technology among practitioners and the current obstacles, the key functions of BIM cannot be brought into play, and the full potential of BIM has not yet been realized [27,28]. Interoperability is also challenged by decentralized collaboration in the construction industry. This opacity and lack of communication cannot give positive feedback to all stakeholders [19,29]. This will lead to disjointed teams with divergent priorities, which is not conducive to the overall progress of the project [25].

Blockchain is an encrypted distributed accounting technology and also is a decentralized database, which has the potential to address interoperability problems of barriers/challenges facing smart city [26,30]. Blockchain can store data securely and easily for query on the chain, providing support for the long construction cycle and reducing unnecessary work. Limited yet increasing studies explored the integration of blockchain and BIM in construction projects [31–33]. These studies, however, focus on applications in the financial aspects of construction (payment security, comprehensive project delivery) and security. Penzes [27] further emphasizes the importance of blockchain in the construction industry and describes its potential applications in Payment and Project Management, Procurement and Supply Chain Management, and BIM and Smart Asset Management. There are few related explorations on how blockchain and BIM affect the development of the entire cycle of sustainable building for smart cities and there is insufficient research on investigating the relationship between BIM, blockchain, and sustainable building. In addition, the potential benefits of integrating blockchain and BIM have not been fully realized in the construction industry. Hence, this paper explores the integration of blockchain and BIM to support sustainable building practices in smart cities.

2. Methodology

The adopted methodology queries the Web of Science (WoS) database with keywords to obtain relevant publication, and then uses the VOSviewer to visually analyze the relationships between blockchain, BIM and sustainable building within the context of smart cities, which is conducted in bibliometric analysis followed by micro scheme analysis. The bibliometric analysis is used via VOSviewer for conducting a macro analysis of the research field, which generates big pictures of the research focus and trend in the field. VOSviewer has the functions of visualizing keywords, co-authors, and citations. It can visually present research hotspots and trends year by year; and present their relevance or frequency through color changes and distance. The micro scheme analysis summarizes the development of sustainable building life cycle in smart cities and the application of blockchain and BIM, which presents three phases of the building life cycle—namely, design, construction, and operation—for verifying and refining the content obtained in bibliometric analysis.

WoS is selected as the database source, which is an internationally recognized database that reflects the level of scientific research. It covers a wide range of journals recognized as authoritative. WoS core collection is selected to search keywords for comprehensive publication retrieval based on 'topics'. In the field of smart cities, when searching for keywords related to sustainable building and blockchain at the same time, there are few papers that match all keywords. Keywords include 'Building Information Modeling', 'Sustainable Building', 'Sustainable Building Design', 'Sustainable Building Construction',

'Sustainable Building Operation' and 'Blockchain'. Therefore, the conjunction 'or' will be used flexibly to find the connection between design, construction, operation, blockchain, sustainable building and BIM. Blockchain is a state-of-the-art approach to BIM and for sustainable building development, hence this research surveys articles published between 2011 and 2020.

VOSviewer was used for bibliometric analysis. Few studies use keyword visualization methods amongst the studies reported in existing publications, most of which use logical diagrams [34–36], scene diagrams [37–40], roadmaps [41–43], and strategy diagrams [44–46]. The VOSviewer has been used to review the latest technology of BIM supported building performance [47], and at the same time, vosviewer is used as a Scientometric Analysis in scientific landscape of sustainable urban and rural areas research [48] and mapping two decades of autonomous vehicle research [49]. However, there is otherwise little research using keyword co-occurrence analysis in BIM. Such techniques have been used in patent analysis [50], databases [51], social networking sites [52], and the recording and prediction of subject changes in biological and medical computers [53]. The keywords research results demonstrate the effectiveness and reliability of keyword search, selection and processing [51,54]. Therefore, this paper attempts to use VOSviewer to visualize keywords to uncover relationships between blockchain, BIM, sustainable building development, and smart cities.

In the VOSviewer, the frequency gap between blockchain and other keywords is too large to appear in one view at the same time. Hence, other relevant keywords are visualized in addition to blockchain. There are 1305 research papers retrieved from the WoS keyword search, which are imported into VOSviewer, and 43,531 keywords are calculated by the software. It was found that 632 of these keywords are used in at least 13 papers. Then, unreated keywords are manually filtered out and 87 keywords selected, as shown in Figure 1. These keywords are automatically divided into three colors (red, green, and blue) by the VOSviewer, as three categories, and show the research hotspots in recent years.
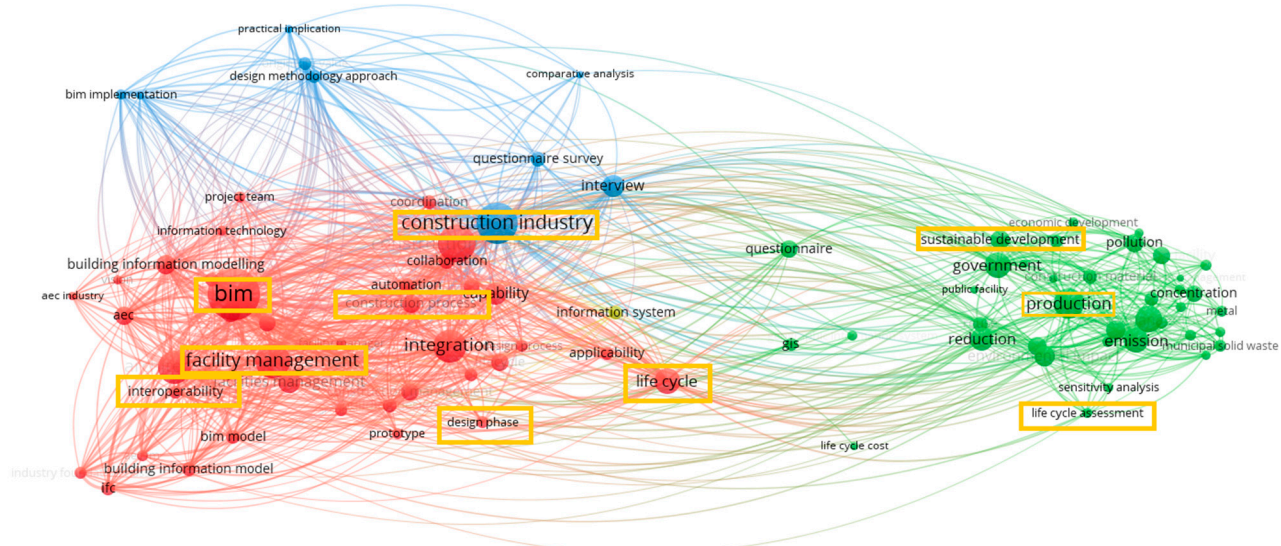

Figure 1. Visualization of research hotspots of major cluster sets and keywords in the construction industry via VOSviewer.

3. Results

3.1. Bibliometric Analysis

VOSviewer includes three forms of analysis: network visualization, overlay visualization and density visualization. The size of each circle represents the weight of the keyword. The distance between two circles represents the affinity between the two circles. If the affinity is stronger, the distance is shorter, and the weaker the affinity is, the distance is

farther. The color of the circle represents the cluster to which it belongs, and different clusters are represented by different colors.

Figure 1 is a network visualization. BIM is the core in the red area, and the degree of closeness of keywords of 'Facility Management (FM)', 'Construction Process', and 'Design Phase' decreases. Most of the publication are FM related, and the construction and design part are weak. 'Life Cycle' connects the red and green sides. According to the data visualization analysis, the keywords in the green area taken 'Production' as the core, where the 'Sustainable Development' and 'Life Cycle Assessment' are associated with it. However, the keywords 'Construction Industry' and 'BIM' are far away from the keyword 'Sustainable Development', which means that it is less relevant. At the same time, the correlation with the whole life cycle is insignificant. This situation or a lack of construction industry development, reflected in the sustainable building development.

Figure 2 shows the visualization of research trend with time as the criterion, highlighting the keywords that connect with BIM as the core is the hotspot of research in the past five years. Thus, based on the bibliometric analysis, which are summarized in Figures 1 and 2, the following current picture of the field can be revealed:

- The integration of BIM and network systems can support the improvement of the construction and operation phases of the Architecture, Engineering and Construction (AEC) [55–58], which makes information retrieval and management easier, but is currently in the preliminary and intermediate stage.
- The use of BIM in the entire life cycle of a building has both potential and obstacles [30,58–61].
- The interoperability of data information throughout the building life cycle is still a challenge [62,63].
- In the research into construction industry and BIM, the FM stage received more attention than the building design, construction and maintenance phases. Life cycle issues should be addressed early on, but it has only been mentioned many times in recent years.
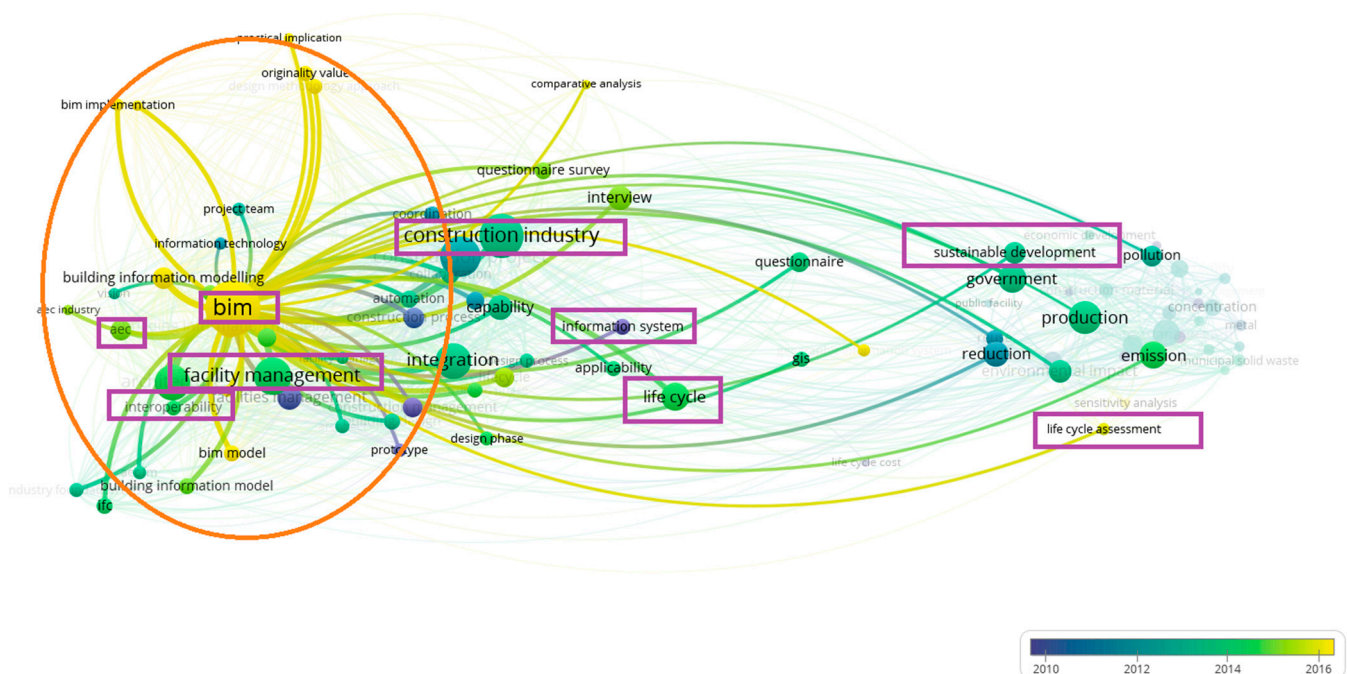

Figure 2. Visualization of research hotspots in the construction industry.

As an emerging technology, blockchain has been applied in many fields such as smart cities, agriculture, medical care, finance, transportation, the Internet of Things and other fields. As a platform, blockchain provides stakeholders in smart cities a mechanism to

participate in urban construction. In recent years, blockchain has become popular, and explored widely [25,26]. The construction industry has also joined the wave of this digital technology. However, there are few studies on blockchain in the construction industry at present. Hence, it is necessary to search the keywords of blockchain and construction industry separately.

As such, 11 research papers with 463 keywords were selected from ScienceDirect. 59 of these keywords were used in at least two papers. Keywords unrelated to blockchain and construction have been manually filtered out, leaving 27 keywords, as shown in Figure 3. From the number of papers and Figure 3, it can be seen that there is less research on the integration of blockchain and construction industry, and the affinity between them is not clearly established. There have been few studies linking BIM, blockchain, and construction industry in the past three years. The integration of construction industry and blockchain is still in its infancy, and the speed of digital transformation is very slow, but a number of researchers have highlighted the potential of this integration [30,33].
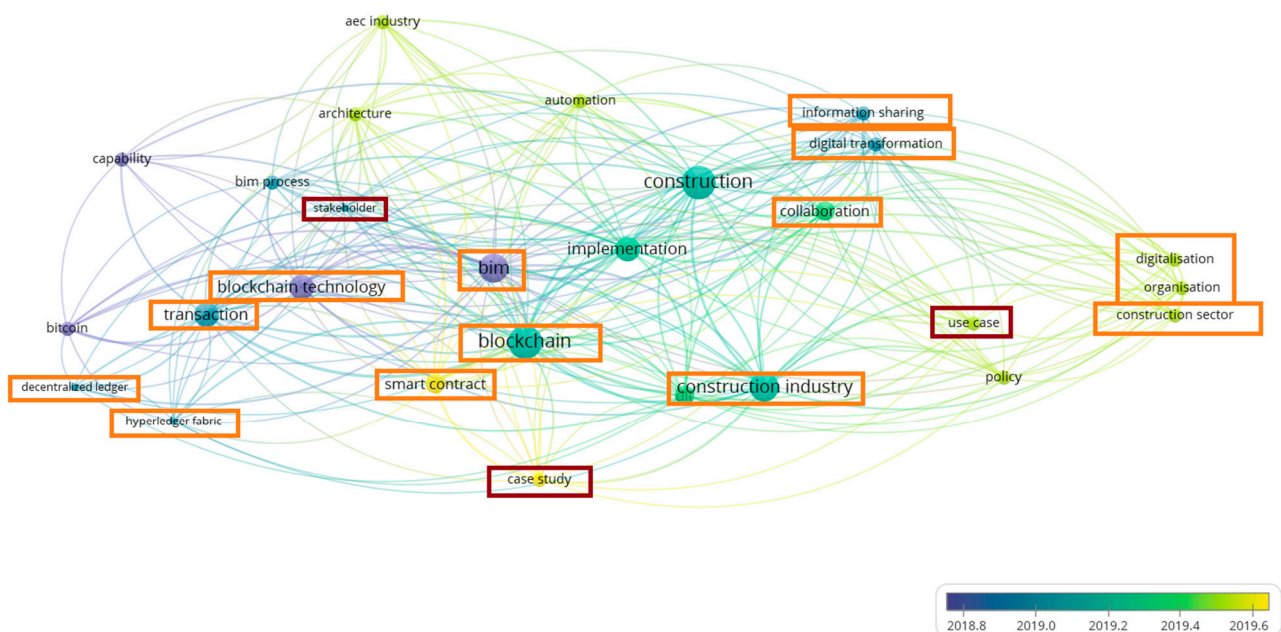

Figure 3. Visualization of research hotspots in the application of blockchain in the construction industry.

It can be seen from Figure 3 that the digital transformation of the construction industry has emerged in recent years. This will become the development trend of the construction industry in the future, and the use of blockchain in the construction industry is worth exploring.

3.2. Micro Scheme Analysis

After the macro analysis of VOSviewer keyword visualization, 61 articles associated with blockchain, BIM, and sustainable building development were specifically selected and included in the micro scheme analysis. The articles were mapped to particular building life cycle phases, including design, construction and operation. Organized according to three stages and comprehensive stages, and pointed out the research methods used in each publication and the research situation of blockchain, BIM and sustainable building.

As shown in Tables 1–4, judging from the number of publications, in the past three years, studies associated with blockchain, BIM and sustainable building are focused on the operation phase of the building life cycle than in the design and construction phase. In addition, the application of blockchain in the design and construction stage is insufficient, while the application in the operation aspect is gradually increasing in recent years, mainly

studying the potential and challenges of blockchain in the construction industry [26,30,64]. The data storage of blockchain adopts a decentralized distribution way, which can reduce the risk of centralized storage. Even if one node of blockchain is lost, the overall data will not be affected [65]. The characteristics of blockchain can meet the needs of real-time communication of data information between different stakeholders on the basis [19].

The integration of blockchain and BIM in the construction industry can provide a more positive impetus for the future development of smart buildings [25,29]. As an important technology in construction projects, BIM is widely used in all stages of the construction life cycle. BIM has been deemed as an effective tool for the integration of natural systems and technical systems in building design [66]. BIM includes databases in multiple fields [22], providing a basis for editing and managing data throughout the life cycle of smart building [20]. It will help significantly reduce construction duplication and waste, reduce errors caused by traditional methods, and accelerate project delivery time [42]. Currently, various BIM performance models have been developed to assist in building design, construction, operation, and maintenance [45]. The applicability and focus of these vary, so that the needs of different BIM users are met [67].

Table 1. The application of blockchain, Building Information Management (BIM), and sustainable building in the design stage of building life cycle.

Source	Year	Research Method	Sustainable Building	Blockchain	BIM
Kuster et al.	2020	Literature and the NeOn methodology	*		
Rajaee et al.	2019	Questionnaire	*		*
Xue et al.	2019	Experimental tests			*
Ghosh	2018	Review			*
Olawumi et al.	2018	A Delphi survey	*		*
Fathi et al.	2016	Case studies	*		
Kylili et al.	2015	Literature review	*		
Farias Stipo	2015	Literature reviews, case study and interviews	*		
Shoubi et al.	2014	Case study	*		*
Jrade et al.	2013	Modelling	*		*

* indicates that the literature contains the content.

Table 2. The application of blockchain, BIM, and sustainable building in the construction stage of building life cycle.

Source	Year	New Build	Renovation	Research Method	Sustainable Building	Blockchain	BIM
Manganelli et al.	2020		*	Model and a case study	*		
Passer et al.	2020	*		Review	*		*
Shrubsole et al.	2019	*		Literature review	*		
Olawumi et al.	2018	*		A Delphi survey	*		*
Chen et al.	2018		*	Literature review			*
Ghaffarianhoseini et al.	2017	*		Literature review	*		
Bretherton	2017		*	Case studies	*		
Capeluto et al.	2016		*	Comparative analysis	*		
Khaddaj et al.	2016		*	Literature review			*
Jones et al.	2015	*		Literature review	*		*

* indicates that the literature contains the content.

As shown in Table 1, research in the design phase is mostly reflected in the construction of environmentally friendly buildings [62,68–70] and integrated design processes [71]. It is proposed that designers should strengthen the ability to use BIM [62], promote the combination of BIM and theory, and find decisions that support sustainable building development through design [56], and pursue a balance between the environment, econ-

omy, and society [24,62]. The design phase is based on compliance with building codes and engineering codes, and several requirements should be considered when establishing BIM models: building energy requirements, ecological building parameters, quality control requirements, user comfort, user requirements, local climate conditions, and life culture [37,72]. The combination of intelligent sensor system and BIM can help develop a smart, humane and sustainable built environment, promote the realization of sustainable strategic initiatives in the built environment, and realize green buildings, safe and healthy lives surroundings [73]. The main research methods used in this phase are literature review, questionnaire survey, experiment, case analysis, and interview.

Table 3. The application of blockchain, BIM, and sustainable building in the operation stage of building life cycle.

Source	Year	FM	Maintenance	Research Method	Sustainable Building	Blockchain	BIM
Eicker et al.	2020	*		Case study	*		
Marmo et al.	2020	*	*	Case studies			*
Chen et al.	2020	*		Modeling			*
Olawumi et al.	2020	*		Literature review and questionnaire	*		*
Li et al.	2020	*		Modeling			*
Quinn et al.	2020	*		Case studies			*
Perera et al.	2020	*		Literature review and a use case analysis		*	
Sheng et al.	2020	*		A case study		*	
Elghaish et al.	2020	*		Experiment		*	*
Chong et al.	2020	*		A questionnaire and a case study		*	*
Marzouk et al.	2020	*		Case study	*		*
Kumar et al.	2020	*		Case studies and test	*		
Matarneh et al.	2019	*	*	Literature review			*
Cachat et al.	2019	*		Literature review			*
Ammari et al.	2019	*		Usability testing and questionnaire			*
Chen et al.	2019	*	*	Case study			*
Gao et al.	2019	*		Literature review			*
Gong et al.	2019	*		Case study			*
Bonci et al.	2019	*		Case study			*
Lokshina et al.	2019	*		Evaluation	*	*	*
Yilmaza et al.	2019	*		Expert reviews and case study			*
Bortoluzzi et al.	2019	*		Case studies			*
Chen et al.	2018	*		Literature review			*
Lin et al.	2018	*		Case study			*
Wong et al.	2018	*		Literature review and focus group			*
Pardis et al.	2018	*		Case studies and semi-structure interview			*
Araszkiewicz	2017	*		Case study			*
Chien et al.	2017	*		Experiment			*
Zadeh et al.	2017	*	*	Case studies			*
Nicał et al.	2016	*		Literature review			*
Aziz et al.	2016	*		Literature review			*
Oti et al.	2016	*		Example description and test case			*
Singh et al.	2011	*		Literature reviews, focus group and case study			*
Arayici et al.	2011	*		Case study			*

* indicates that the literature contains the content.

Table 4. The application of blockchain, BIM, and sustainable building in the whole stage of building life cycle.

Source	Year	Building Life Stage					Research Method	Sustainable Building	Blockchain	BIM
		Design	Construction		Operation					
			New Build	Renovation	FM	Maintenance				
Liu et al.	2020	*			*		Literature review	*		*
Liu et al.	2019	*	*		*		Questionnaire & semi-structured interviews	*	*	*
Tang et al.	2019	*	*	*	*	*	Literature review	*		*
Ustinovichius et al.	2018	*		*			Case study			*
Kim et al.	2018			*	*		Evaluation			*
Turk et al.	2017		*			*	Scenarios		*	*
Wong et al.	2015	*	*	*	*	*	Literature review	*		*

* indicates that the literature contains the content.

As shown in Table 2, an in-depth study of the obstacles and challenges faced by stakeholders in the integration of BIM and sustainability practices during the construction phase [56,60]. Based on BIM to restore heritage buildings [74], post-earthquake buildings [75,76], and refurbished buildings [77]. Promote the implementation of the BIM platform to optimize the construction process, improve the quality of project transformation, and effectively track the project with visual data [63]. This stage reflects urban renewal, which is an opportunity for sustainable development and intelligent growth of towns. The establishment of urban reconstruction plan indicators can carry out quality inspections on existing buildings, reduce the vulnerability of buildings, and contribute to the evaluation and decision-making of the seismic capacity of buildings [76,77]. The protection of the building does not mean sticking to the old appearance, but it can be rebuilt into a resilient, sustainable, and green building with innovative materials and technology [74]. The main research methods used in this phase include case studies, literature review, interviews, and comparative analysis.

Table 3 building operation phase discusses how urban renewal is more sustainable [34,61,78], by identifying and alleviating barriers to smart and sustainable practices in the built environment [61], and prioritizing them, which provides a basis for decision makers to make feasible decisions. Operating information is managed through the integration of BIM and FM systems. This traditional maintenance management is combined with digital technology to improve management performance and maintenance efficiency in the future operation and maintenance phase [34,35]. Chen et al. designed the framework into five modules, including project documents, personnel and contacts, FM planning and execution, technical performance evaluation, and safety and emergency management [44]. In addition, the potential and application of BIM in FM and maintenance are also studied [36,45,55]. From the perspective of equipment managers, evaluate and summarize the current BIM-O&M research and application progress, analyze research trends, and find research gaps and promising research directions in the future [45]. Using BIM to obtain real-time information [39,79] and conduct final inspection [40] during the completion of the project to strengthen communication and information management capabilities [80]. Araszkiewicz proposes the possible directions for further research on the digitalization of property management, and the influence of digitalization on the implementation process of the concept of intelligent sustainable building engineering [80]. Reference [26] proves the potential of blockchain in the construction industry and uses it for quality information management [81] and integrated project delivery (IPD) [32] in construction. Solve the problem of security of payment (SOP) through the integration of blockchain, BIM, and smart sensors [31]. The main research methods used in this stage include case analysis, literature review, focus group, interview, and questionnaire.

Table 4 is about the literature involving multiple phases of life cycle. It can be seen that there are few systematic comprehensive studies on the whole life cycle of a building according to the design–construction–operation phase in the literature. From a sustainability perspective, integrating sustainability into all stages of building is something that all stakeholders in the construction industry must consider and implement [62]. Integrating

physical buildings with digital modeling provides a collaborative platform in a visual manner to help designers, architects, engineers, developers, and even end users build green and sustainable buildings throughout the project life cycle [66]. In order to achieve more effective low-carbon management, BIM tools need to incorporate the concept of 'reduce, reuse, and recycle'. There are many kinds of BIM models, but it is still necessary to improve the practicability, ease of use, and compatibility of BIM tools, so as to maximize their effectiveness and be used by more stakeholders without obstacles [28]. Blockchain provides reliable technology for building information management in the overall life cycle stage [33], which can reduce counterfeiting risks and costs without third-party management. This ensures the security, reliability and privacy of the data and establishes trust between the device and the user [82].

4. Discussion

4.1. Smart Cities and City Information Management (CIM)

The combination of information and infrastructure lays the foundation for smart city management, which greatly improves construction efficiency and reducing construction risks [20]. CIM in cities is similar to the role of BIM in architecture, which is the integration of all spatial data models. CIM helps optimize the management process [83], improve public services, and improve the quality of life of citizens [84]. In its unique database, all stakeholders jointly participate in decision-making in terms of project design, planning, operation, and maintenance, and comprehensively integrate information on the built environment, the legal environment, and the natural environment [85] to obtain an optimal solution. However, in the process of model information management, information integration is a complicated process, and there are many problems and challenges. As a distributed ledger, blockchain can safely store data and information in the chain; and the messages, it transmits have integrity, consistency, and reliability. Only authorized users have the right to make changes, and the rest are not allowed to make changes, ensuring the security of information.

In addition to information resources, infrastructure is also an important part of smart cities. As an important field in smart cities, the construction industry contains complex management, and construction projects involve the joint cooperation of multiple companies. From a sustainable perspective, buildings consume massive energy around the world. Under the major premise of ensuring the health of users, the life cycle of building should be maximized to achieve energy saving, water saving, material saving, and environmental protection [86]. For energy management, it can reduce energy waste by developing smart grids and regulating power generation on demand. For carbon management and water management, companies should give full play to their sense of corporate social responsibility, visually disclose carbon emissions and water transactions. For waste management, a unified waste management system based on blockchain will be developed to reuse or recycle construction waste to achieve the sustainability of construction projects. The openness, fairness, and transparency of blockchain can satisfy the decentralized management of construction quality information [81]. All stakeholders are encouraged to cooperate together, and collective interests are put before personal interests [30] to ensure the orderly implementation of decentralized management of the construction industry. Blockchain can efficiently process transactions, secure data, reduce labor costs, and improve transparency and security [87].

4.2. Blockchain and BIM

Although the use of blockchain in the construction industry has not yet been widely used, the integration of BIM and blockchain has shown a potential in the construction industry for sustainable development. BIM is a shared knowledge resource that can store important information collected in blockchain to ensure information security and obtain the required information from blockchain at any time. However, BIM information will be constantly updated by stakeholders. This will produce multiple new BIM files with a lot of

duplicate information in the files. The Semantic Differential Transaction (SDT) can capture these changes and protect these changes in blockchain to reduce this duplication [29].

Moreover, BIM and blockchain are complementary platforms, and blockchain can make up for the shortcomings of BIM applications. For example, when different stakeholders cannot seamlessly collaborate and communicate easily when using the model, and cannot exchange effective information, blockchain will be a trusted means of collaboration. There are a large number of temporary companies participating in the construction asset management system, which is fragmented and complicated and troublesome in management. Blockchain can store all necessary data related to assets, providing a better asset life cycle [31].

Furthermore, BIM and blockchain data are transmitted electronically, but the complex collaboration framework of BIM cannot achieve complete security protection [25]. However, blockchain can safely store privacy-sensitive sensor data. Hence, the integration of blockchain and BIM can solve the obstacles of BIM development [33].

4.3. Blockchain and Sustainable Building

The characteristics of blockchain can avoid the centralized control of traditional management. The security of blockchain provides a trustworthy platform for stakeholders in the construction industry. There are practical applications or theoretical research on the three stages of the sustainable building life cycle: design–construction–operation.

In the design phase, it is very important to protect the design results from being violated. The management of digital copyright involves the scope of intellectual property rights. In order to prevent plagiarism and theft, blockchain establishes a complete chain of trust from the copyright holder to the service provider [88]. The watermark-based multimedia framework prevents tampering with the original content of the media [87]. During the design process, the design drawings and construction drawings will be continuously updated, and the unified opinions of the construction parties are also required. The blockchain system based on smart contracts [87] can update the latest drawing information to all parties without causing omissions. Distributed consensus protocol is adopted to ensure the consistency of data on the chain of participants [89], and real-time negotiation, modification, and information sharing can be carried out.

In the construction phase, in the face of the global pandemic or the future environment, electronic bidding is a desirable way. This method can protect the privacy of user identity, conduct transactions and submit bids anonymously, free from distance and weather, save time, and reduce fraud in black box operations [64]. It is important to prevent fraudulent digital signatures when signing construction contracts and approval procedures. It is conducive to mutual authentication and the establishment of trust [90].

In the operation phase, the building consumes huge energy during the use and maintenance stage, accounting for 90% of the building life cycle [91]. Operation is a long-term process, and maintenance is one of the most costly and longest stages in the process [34]. Therefore, it is very important to establish a circular and sustainable design–construction–operation system. Through the transparency of blockchain, the status of maintenance requests and the maintenance process can be known, so that the maintainer will know the time, place and maintenance components. By sharing information through blockchain, the maintenance department can monitor the update of information in real time and maintain in time. It can improve management performance and maintenance efficiency, reduce the cost of FM [41], and reduce economic losses and safety hazards caused by construction hazards.

In addition, the operational phase also includes various management systems. For building supply chain management, blockchain helps audit and track supply chain information. Under the premise of ensuring quality, it reduces operating costs, logistics costs and the risk of tampering with products [88]. There are also building management systems (BMS), which manage system components such as access control, building control and mobile applications [19].

Funds should not be sloppy during the entire operation phase. For the procurement system, the traceability of blockchain makes the supervision more transparent and easier, it can also formulate a detailed timetable to avoid default [88]. On delivery payment (transfer of large amounts of funds)/security of payment (SOP), security can be guaranteed and payment risks eliminated. The use of virtual currency eliminates the need for bank notes or cash, reducing labor costs. It can also reduce late payment and default settlement [31]. In integrated project delivery (IPD), blockchain assists in the establishment of decentralized, automated, and secure financial platforms [32], where data providers are paid and users receive data [92].

4.4. Sustainable Building, Blockchain, and BIM

The integration of digital technologies, such as BIM and blockchain, has contributed to the digital transformation of sustainable buildings [19]. It can be seen from the table in the results that there are few studies that discuss the three together.

In the design phase, information, construction knowledge, environmental, social and economic impacts need to be taken into overall consideration [93]. It is necessary to unify decision-makers, supervisors, investors, designers, construction parties, owners, and other stakeholders to participate in the design of BIM [8]. BIM integrates with sustainable building design process model [71] to collect a lot of unstable data information. Meanwhile, blockchain can balance privacy and accessibility to ensure the safe transmission of data to organizations or devices [94]. Liu et al. [95] established the relationship and role of BIM and blockchain in sustainable building design information management from the perspective of architects, which emphasizes how users (stakeholders of sustainable building design projects/BIM customers) manage.

With the assistance of BIM, the project was designed to comply with architectural and engineering specifications during the preliminary design [73]. In the process of simulation, the model is continuously optimized, and problems are solved in time. This can foreseeably avoid many problems encountered by traditional architectural design and construction [96]. Such as the order of construction, size, safety, placement, selection of materials, shapes, and environmental issues caused by spaces. Early planning for these issues will make the initial design more standardized, and each stakeholder can understand the design process, clarify the work content of all parties, and make the work more organized. At the same time, blockchain can provide interoperable protocols for all partners to ensure effective authorization interactions among decision makers, designers, and construction parties; and handle data interoperability issues well [97].

During the construction phase, renovation is more energy-efficient, environmentally friendly and cheaper than new ones [68]. However, BIM is not mature enough to maintain and update existing BIM in renovation projects, and data collection is a challenge [63]. Therefore, it is very important to provide a rich semantic database and integrate different information sources [36]. Using architectural design knowledge can improve the effectiveness of BIM reconstruction [98]. For worn-out buildings that do not meet legal requirements, using BIM for repairs has huge energy-saving potential [72].

In the operation phase, effective operation activities can improve the built environment and enable it to have more integrated functions [99]. Blockchain can realize transactions from sales and operations to finance and management, of which the smart contract can balance the profits of each partner and the interests of the company and users in an open and transparent manner [100]. The circular economy runs through the construction industry, retaining used building materials as a material library [101]. City managers and architects are familiar with the reuse of these building materials. These experiences can increase the market for reused materials, reduce the use of raw materials, focus on environmental benefits, and promote the sustainable construction of smart cities. BIM and blockchain can help analyze the most valuable materials for recycling [102].

The integration of FM, BIM, and blockchain can greatly improve the execution of construction projects and provide assistance for maintenance management and construction

performance evaluation activities [35]. The implementation of BIM needs to adopt the bottom-up approach and ensure that all parties participate in planning and the participants have sufficient understanding and technical capacity [103]. Blockchain can assist BIM to efficiently use data to objectively evaluate projects, simulate building performance and full-cycle usage to improve the overall construction project quality, and achieve the goal of environmental protection and efficient resource conservation [47,104].

5. Conclusions

The aim of this paper is to explore the potential impact of the integration of blockchain and BIM in a smart city environment on making buildings more sustainable within the context of CIM/Smart Cities. This paper queries the Web of Science (WoS) database with keywords to obtain relevant publication, and then uses the VOSviewer to visually analyze the relationships between blockchain, BIM, and sustainable building within the context of smart cities and CIM, which is conducted in bibliometric analysis followed by micro scheme analysis. The main contributions and novelties of this paper are as follows: (1) This is the first attempt to explore the relationship between blockchain, BIM, and sustainable building under smart cities and CIM by using bibliometric analysis and scheme analysis. (2) A tool to visualize scholarly publications, VOSviewer, is used to conduct a macro analysis. The method of visualizing keywords can bring out insights into blockchain, BIM and sustainable building. This includes the relationship among the three, the development trend, the research hotspots, and the application, providing a reliable research method for the future research. (3) Compared with the existing similar publications, this paper discusses more comprehensively, including the relationship and application of blockchain and BIM, blockchain and sustainable construction, blockchain and BIM, and sustainable construction. (4) Compared with the existing similar publications, this paper incorporates the design–construction–operation of the building life cycle into the research. A complete life cycle study can help designers, constructors, decision makers, and supervisors who use information technology in the construction industry to make informed project decisions. Regarding CIM, although there are few research publications on CIM retrieved so far, the application of CIM in smart cities will be the trend in the future. The CIM basic platform is a new type of infrastructure for smart cities and an important tool to promote more information and intelligent city management. CIM integrates all urban spatial models, including BIM, as well as visualization, data analysis and parameterization functions. It can directly obtain information from the virtual model to improve urban development and provide services for citizens, which is of great significance to the more sustainable development of cities. The publications retrieved are represented by keywords, which makes the data reported in this paper limited to the content contained in the WoS database. Future research will explore the expansion of BIM to a wider range of CIM, and study the practical application of CIM in supporting more sustainable urban development.

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