ISSN 1392-3730/eISSN 1822-3605

JOURNAL of CIVIL ENGINEERING and MANAGEMENT

2024
Volume 30
Issue 7
Pages 646–669
https://doi.org/10.3846/jcem.2024.21638

Review

WHEN BIM MEETS BLOCKCHAIN: A MIXED-METHODS LITERATURE REVIEW

Yongshun XU[1], Ming CHI[2], Heap-Yih CHONG[3,4]✉, Cen-Ying LEE[5], Keyu CHEN[1]

[1] *School of Civil Engineering and Architecture, Hainan University, Haikou, China*
[2] *International Business School, Hainan University, Haikou, China*
[3] *School of Engineering Audit, Nanjing Audit University, Nanjing, China*
[4] *School of Design and the Built Environment, Curtin University, Perth, Australia*
[5] *Faculty of Society & Design, Bond University, Gold Coast, Australia*

Article History:
- received 3 October 2023
- accepted 2 May 2024

Abstract. Building information modeling (BIM) and blockchain applications have introduced significant benefits to the architecture, engineering, construction, and operation (AECO) industry in recent years. Although publications on BIM and blockchain integration have been increasing, no systematic examination of the present status and managerial implications of integrated BIM and blockchain has been conducted. To bridge this gap, this paper conducts a state-of-the-art review of the development of integrated BIM and blockchain in a built environment. A combination of qualitative and quantitative methods was adopted to synthesize and analyze the research evidence. The results revealed five key managerial implications of BIM integration with blockchain at the project level: design and collaboration, financial management, construction management, information management, and integration management (with other cutting-edge technologies). Challenges and opportunities are outlined and articulated from both technological and managerial perspectives, such as stakeholder management, impact assessment, real-time project management, information redundancy, and incompatibility.

Keywords: BIM, blockchain, mixed-methods, integration, design and collaboration, financial management, construction management, information management, integration management, managerial implications.

✉Corresponding author. E-mails: ***heapyih.chong@curtin.edu.au; johnchong1983@163.com***

1. Introduction

In recent years, traditional construction companies have encountered significant opportunities and challenges in digital transformation (Wu et al., 2021). The rapid growth of digital technologies such as blockchain and building information modeling (BIM) has provided strong support for the advanced management and intensive development of the construction industry (Liu et al., 2021). Construction organizations also tend to combine BIM with other emerging technologies, particularly blockchain (Jia et al., 2022; Xu et al., 2022). The reason for this is that, while BIM is a required technology in the construction industrialization transformation, it cannot effectively solve production relations problems such as trust, efficiency, and fragmented management under complex systems from a technological perspective (Oraee et al., 2019; Hijazi et al., 2021). When blockchain is combined with BIM, the problem is solved because determining fragmented management under trust, collaboration, efficiency, and complex systems is the natural advantage of blockchain, which can supplement BIM (Xu et al., 2022; Li & Kassem, 2021). Thus, integrating BIM and blockchain is likely to become a new paradigm for the digital transformation of the architecture, engineering, construction, and operation (AECO) industry.

BIM and blockchain are two relatively new methodologies. Although they are yet to fully develop, they are already indispensable. BIM is a game-changing technology that transforms conventional practices in the AECO sector (Li et al., 2023; Hadavi & Alizadehsalehi, 2024). Blockchain serves as an advanced and decentralized system that is considered a disruptive innovation technology under "Construction 4.0" (Perera et al., 2020). Because of the advantages of these two technologies, scholars have already conducted research on the integration of BIM and blockchain. For instance, Mathews et al. (2017) indicated that integrating BIM and blockchain can solve the trust problem among stakeholder collaborations. Ye et al. (2018) introduced the cup-of-water theory, in which blockchain is the cup wall for redefining storage methods and BIM serves as the bottom of the cup for managing digital data. According to Liu et al. (2019), integrating BIM and blockchain can significantly boost information systems and enable sustainable design. Xue and Lu (2020) developed a system framework using blockchain to reduce BIM information redundancy. Akbarieh et al. (2020) constructed a research framework for recycling building materials by integrating BIM and blockchain. Elghaish et al. (2020) recommended combining 5D BIM and blockchain to create an automated monetary system. Chong and Diamantopoulos (2020) indicated that blockchain, smart contracts, and BIM can be used to solve payment problems. Tao et al. (2022) presented a confidential framework for BIM design collaboration by introducing blockchain, stating that blockchain is a revolutionary innovation in safeguarding integrity of data, immutability, and provenance of BIM. Sonmez et al. (2022) presented a novel BIM-integrated blockchain secure payment management system that uses BIM data to connect the physical world to the blockchain to enhance the traditional payment procedure. Celik et al. (2023a) examined the integration of BIM and blockchain from practitioner and decision-maker perspective, and pointed out that the integration of the two could enhance collaboration, efficiency and traceability in construction.

Although previous studies on this topic have made valid and valuable contributions (Liu et al., 2021; Hijazi et al., 2021; Erri Pradeep et al., 2019; Nawari & Ravindran, 2019a, 2019b; Meng et al., 2020; Das et al., 2021), they had the following limitations. First, most of them were qualitative and conceptual, which may be influenced by subjective prejudices and may reduce repeatability and reliability. Second, previous review studies focused on specific applications or fields. For example, Nawari and Ravindran (2019b) focused on the post-disaster recovery phase, Liu et al. (2021) focused on the smart city environment, Hijazi et al. (2021) and Selvanesan and Satanarachchi (2023) emphasized construction supply chain data delivery, Das et al. (2021) focused on BIM security, and Yu et al. (2024) focused on a sociotechnical system perspective. Furthermore, although some literature reviews have mentioned integrating blockchain with BIM, it was not the focus of their research, such as Zhong et al. (2023), Saah and Choi (2023), Xu et al. (2022), Li and Kassem (2021), and Elghaish et al. (2021). A growing body of literature recognizes the importance of integrating advanced technologies in the AECO industry (Sarkar et al., 2023; Alizadehsalehi & Yitmen, 2023). Although blockchain and BIM are also becoming more prevalent among professionals and researchers (Xu et al., 2022), the scientific community considers these two technologies independently (Zhang et al., 2022). More importantly, most of the current scattered research explores technical developments of the integrated BIM and blockchain and lacks exploration of its implications from the management perspective. Therefore, a comprehensive review of the managerial aspects is required for a complete understanding of the integrated BIM and blockchain.

To fill this gap, this paper provides a state-of-the-art review of the integrated BIM and blockchain using a qualitative-quantitative hybrid approach, particularly for its managerial implications and opportunities for future research directions. The scope of managerial implications focuses on managerial strategies, including technological inferences for project performance of the integrated BIM and blockchain. The specific objective of this review was to address the following four research questions:

- **(a)** What is the current status of BIM and blockchain integration in the AECO industry?
- **(b)** What are the key managerial implications of integrated BIM and blockchain in the AECO industry?
- **(c)** What are the challenges of the integrated BIM and blockchain in the AECO industry?
- **(d)** What are the future research opportunities and directions of BIM and blockchain integration in the AECO industry?

The remainder of the paper is organized as follows: Section 2 introduces the research method; Section 3 presents the bibliometric analysis; Section 4 provides an in-depth content analysis; Section 5 highlights discussions and conclusions; and Section 6 presents the limitations and future work.

2. Research method

2.1. Literature search and identification

To ensure a comprehensive literature coverage of the integrated BIM and blockchain, we conducted search queries on Scopus and Web of Science because of their broad scope of scientific journals and fast indexing workflows. The search for articles began in August 2022 and was repeated in December 2023. In determining the search keywords, to make the search results more accurate and reasonable, the search keywords mainly refer to previous literature reviews on blockchain or BIM. For example, the literature review on blockchain in the construction industry by Xu et al. (2022) and Wu et al. (2022a), the literature review on BIM and GIS integration by Wang et al. (2019) and the literature review on BIM and AI integration by Pan and Zhang (2023). Each technical concept is described by several synonyms or similar phrases. To be more specific, the two complementary terms blockchain and BIM are research objectives in this review. Finally, according to the objectives of this research and based on Boolean search rules, the following keywords were used for retrieval: ("Blockchain" or "Block chain" or "Distributed ledger") and ("BIM" or "Building information model" or "Building information modeling" or "Building information modelling"). The retrieval process had no set year limit because integrated BIM and blockchain is a nascent and rapidly evolving research topic. After a preliminary search,

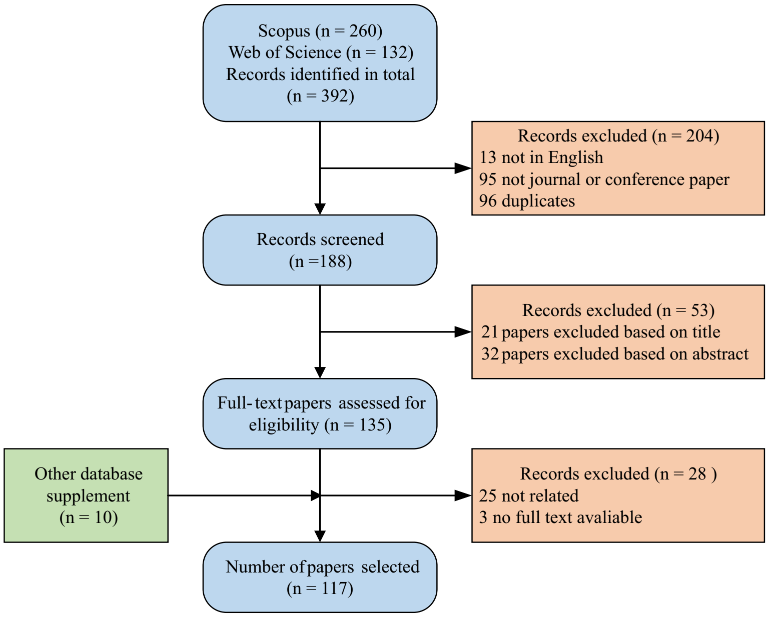

Figure 1. Search query process

392 papers were collected, of which 260 and 132 were retrieved from Scopus and Web of Science, respectively.

Figure 1 depicts the specific search queries. Multiple refinements were conducted to increase the quality of the initial retrieval. First, "English" was selected as the language, and the document type selected was only journal or conference papers. Duplicate publications were excluded. Second, the articles whose titles or abstracts included the words blockchain and BIM but the content did not discuss the integrated BIM and blockchain were excluded. After refinement, 135 articles remained. Third, the full texts of the remaining publications were acquired and evaluated, and 28 were eliminated (three full texts were unavailable, and 25 were out of the scope of this research). Additionally, 10 papers were supplemented by backward and forward snowballing, and 117 papers were finally selected (see Appendix).

2.2. Review steps

The state-of-the-art review consisted of a combination of descriptive statistical analysis, bibliometrics, and content analysis. First, a descriptive analysis was performed on the identified articles to extract the following items: year of publication, journal, research methodology, country, and author. Subsequently, bibliometric analysis was conducted using VOSviewer software, which included creating a cooperative network between authors, a network of countries, and an author keyword co-occurrence network. In addition, through content analysis, the implications of integrated BIM and blockchain were analyzed. Finally, opportunities for future research and their challenges are discussed from the dual perspectives of technology and management.

3. Descriptive and bibliometric analyses

3.1. Posting trends

Figure 2 shows the trend of publications on integrating BIM and blockchain. Although we did not set a time limit for retrieval, the first relevant paper appeared in 2017, illustrating that research on integrating BIM and blockchain is relatively new. In addition, in 2018, the number of related papers did not increase significantly, and only three related articles were published throughout the year. However, in 2019, the number of related research publications increased, reaching 29, almost ten times that of the previous year. Although there was a slight decline in 2020, it continued to exhibit a significant growth trend in 2021. The number of published papers reached 39, including 24 journal articles, indicating that integrated BIM and blockchain research began to shift from conferences to journal articles, and high-quality results were also increasing. The number of journal articles published in 2023 is 23, which once again proves this trend. The continuous increase in publications shows that the integration of the two technologies has captured the interests of practitioners and researchers.

3.2. Journal distribution

A statistical study of journals assists researchers to quickly receiving suitable information and identifying journal titles for future reference (Xu et al., 2022; Zhang et al., 2022). Of the 117 publications selected, 66 were journal articles and 51 were conference papers. The sources of the 66 journal articles are shown in Appendix. They were retrieved from 36 journals, 10 of which have published at least two papers each (see Table 1 for details), and the remainder published one.

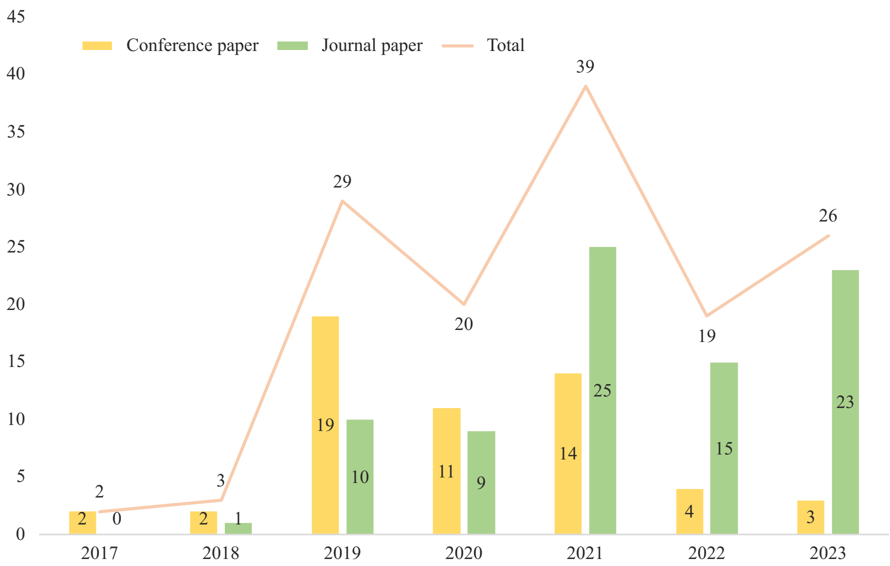

Figure 2. Annual trends of publications on integrated BIM and blockchain

Table 1. Journal list

Journal title	Total	2018	2019	2020	2021	2022	2023	Total citations
Automation in Construction	15			3	6	4	2	1339
Journal of Construction Engineering and Management	4				1	1	2	157
Buildings	4		1				3	140
Computers in Industry	4					1	3	121
Journal of Information Technology in Construction	3		1		1		1	167
Journal of Building Engineering	2		1				1	209
Sustainability	2				2			106
IEEE Access	2			1	1			34
Scientific Reports	2					1	1	8
Construction Innovation	2						2	1

It is worth noting that *Automation in Construction* published the most articles (15 in total), with a total of 1339 citations, demonstrating that it is the leading journal in this scientific field. In addition, *Journal of Construction Engineering and Management*, *Buildings*, and *Computers in Industry* have published four articles that demonstrate that integrating BIM and blockchain has also captured scholars' interest in the field of construction management. Despite both the *Journal of Cleaner Production* and *Frontiers of Engineering Management* issuing one article each, they received 141 and 122 citations, respectively. These two journals are also important in this field.

3.3. Research methods

Research methods can reflect the type and depth of the research to a certain extent. Figure 3 depicts the research methods of the 117 publications. The conceptual framework is the most popular method, followed by case studies (see Appendix). Insight and literature review articles occurred 37 times, indicating that the current research remains at an early stage of development. The proof of concept and case studies represent the state-of-the-art of the literature in the field and are increasing in number.

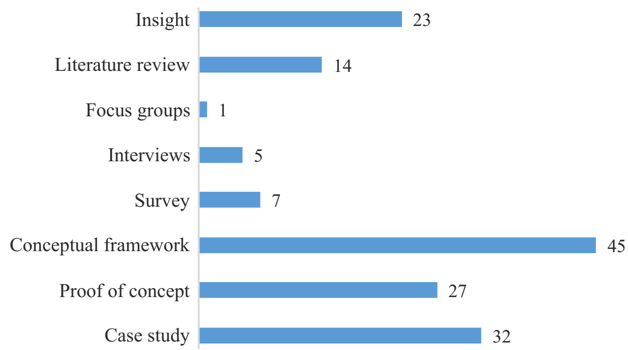

Figure 3. Research methods

However, it is important to mention that most case studies included here were simulated cases that accompanied the proof of concept. Only a few studies have demonstrated real-world application. In addition, only a few articles used methods such as survey, interview, and focus groups, which also shows that fewer experts currently understand how to integrate the two technologies. Finding qualified experts or respondents is difficult. However, as technology continues to mature, these methods should be actively used in future research to better understand what practitioners think of integrated BIM and blockchain.

3.4. Countries

A total of 31 countries contributed to this research topic in the 117 selected articles. Table 2 shows countries with four or more publications. China published the most papers, ranking first with 35 papers. The United Kingdom followed with 25 papers, ranking second, and the United States published 11 papers, ranking third. Articles published in these three countries accounted for 60.68% of the total publications. This also shows that integrating blockchain with BIM is not yet universal, and related research on this topic in other countries is lacking. It is worth noting that, while China ranks first in terms of publication number, it ranks after the United States, Ireland and Australia in average citations. China had the highest total citations at 1515, which also shows that China contributed the most to research related to integrated BIM and blockchain. Interestingly, although Ireland published only four articles, it ranked fifth in total citations (261 times) and ranked second in the average number of citations. This demonstrates that the four papers published in Ireland sparked widespread interest and were cited by academics.

Figure 4 depicts the academic cooperation links between the authors' countries in the collected papers. The circle size indicates the number of papers published by the country; the distance between the circles indicates the degree of connection between countries, and the closer the distance, the closer the connection; the connecting thickness line symbolizes the frequency of their cooperation. We can observe from the figure that the entire cooperation network is relatively sparse, which also shows that the integration of BIM and blockchain is still in its primary stage. Cooperation between the countries was not close. The United Kingdom was at the center of the entire cooperation network, with a total link strength of 18. It established cooperative relations with seven countries, followed by China, which created cooperative relationships with four countries, and had a total link strength of 13.

Table 2. Top 10 most productive countries

No.	Country	Publications	Citations	Average citation
1	China	35	1515	43.29
2	United Kingdom	25	1034	41.36
3	United States	11	1206	109.64
4	Australia	10	461	46.10
5	Italy	7	169	24.14
6	Indonesia	6	38	6.33
7	India	5	37	7.40
8	Ireland	4	261	65.25
9	New Zealand	4	166	41.50
10	Germany	4	163	40.75

3.5. Authors

Tracking works by notable authors or teams can aid in quickly understanding the field's frontiers (Xu et al., 2022). Among the 117 selected articles, there were 294 authors, of which 12 authors have published at least four papers. As demonstrated in Table 3, Nawari N. O., Elghaish F., Cheng J. C. P., Das M., Tao X., and Perera S. published the most articles, with five each; they were from the University of Florida, the University of Hong Kong, Queen's University Belfast, the Hong Kong University of Science and Technology and the Western Sydney University, respectively. It is worth noting that although Ravindran S., a scholar from University of Florida, did not publish the most articles, he had a very high number of citations, ranking second (537 citations).

Author co-occurrence analysis is a text mining technique used to discover relationships between authors in texts (Xu et al., 2021). It can help researchers better understand the relationships between authors, as well as the influence between authors. In addition, author co-occurrence analysis can also be used to discover the collaborative relationships between an author and other authors as well as the common research areas between an author and other authors (Xu et al., 2022). Figure 5 shows the coauthorship collaboration network. Each circle represents a different author. The circle size represents the number of papers published by the authors in this field. The color indicates the year. As the figure shows, previous scholars established some cooperative networks, for example, Cheng J. C. P., Perera S., Xue F., Elghaish F., and Wong P. K. Y. established a good cooperation network. However, from the perspective of the entire network, cooperation among scholars is not sufficiently close. The existing research on integrated BIM and blockchain has been conducted largely independently. Authors often collaborate with fixed partners and rarely with different research groups.

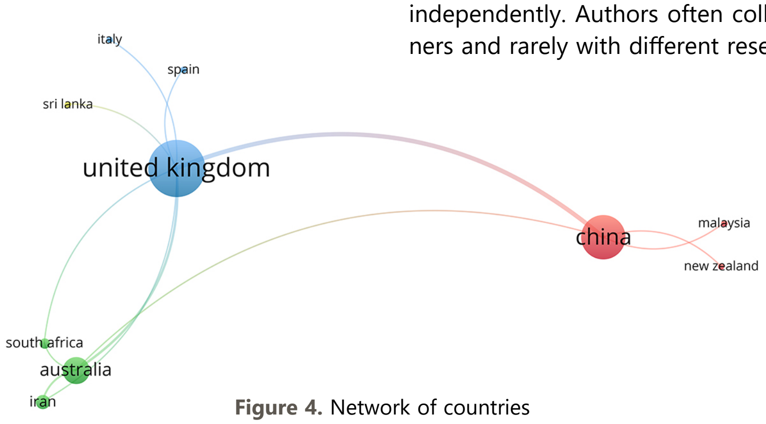

Figure 4. Network of countries

Table 3. Top 12 most productive authors

Author	Organization	Documents	Citations	Total link strength
Nawari N. O.	The University of Florida	5	555	4
Elghaish F.	Queen's University Belfast	5	292	14
Cheng J. C. P.	The Hong Kong University of Science and Technology	5	218	25
Das M.	The Hong Kong University of Science and Technology	5	218	25
Tao X.	The Hong Kong University of Science and Technology	5	218	25
Perera S.	Western Sydney University	5	95	18
Ravindran S.	University of Florida	4	537	4
Xue F.	University of Hong Kong	4	460	18
Dounas T.	Robert Gordon University	4	147	7
Lombardi D.	Xi'an Jiaotong-Liverpool University	4	147	7
Liu Y.	The Hong Kong University of Science and Technology	4	129	23
Hijazi A. A.	Western Sydney University	4	95	12

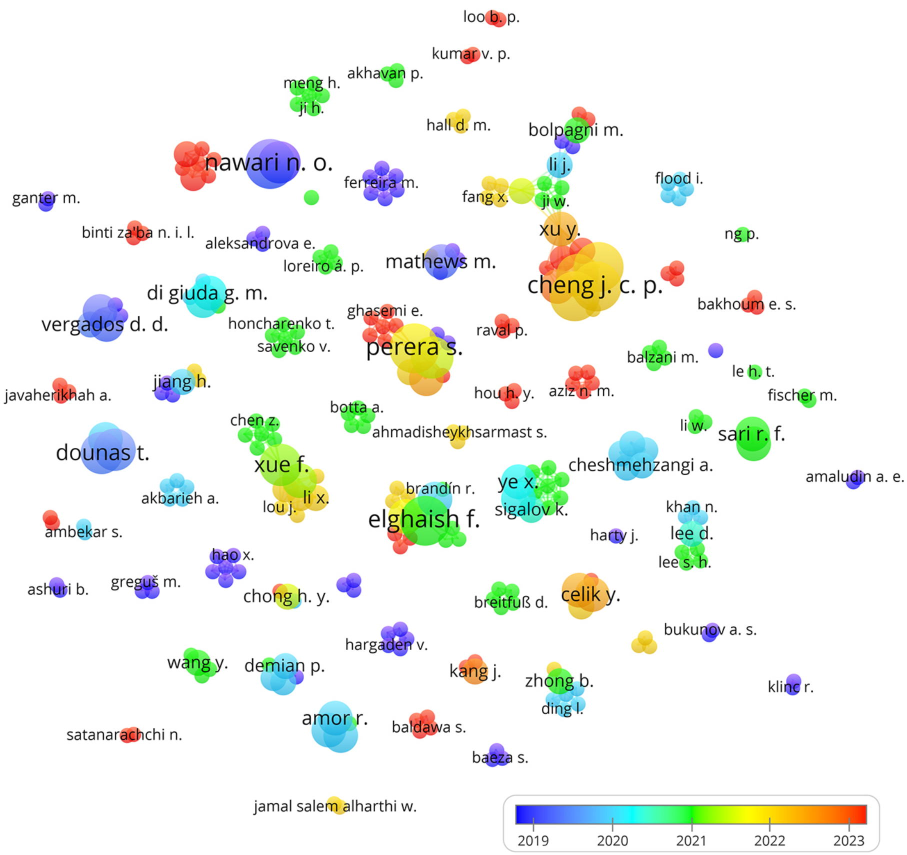

Figure 5. Co-authorship network

3.6. Author keywords

By assessing the strength of the links between representative keywords in selected articles, keyword co-occurrence networks enable researchers to understand domain-specific conceptual structures and patterns (Shkundalov & Vilutienė, 2021). This is a type of web analysis that requires raw keywords to be cleaned and normalized before analysis is performed. The data were cleaned by substituting the author keywords with synonyms, altering singular and plural numbers, etc.; 258 keywords were eventually acquired.

To provide a clear co-occurrence network based on author keywords, we set the minimum frequency of keywords in VOSviewer to 2, and a total of 47 author keywords were generated. The co-occurrence network of author keywords with at least two or more occurrences is depicted in Figure 6. The circular size reflects the number of keyword occurrences, the arc represents links between keywords, and the thickness of the line represents the link strength (Wang et al., 2019). The color-coded circular nodes denote various groupings. As shown in the figure, the red clusters are primarily reflected in construction contract, information management, construction supply chain, trust, collaboration, and digital twin; the green clusters are primarily reflected in Internet of Things, supply chain management, digital transformation, big data, modular construction, and sustainability; and the yellow clusters are primarily reflected in construction, infrastructure, sensors, security, monitoring, and digital technologies. Furthermore, in addition to the BIM and blockchain technologies, other technologies such as the Internet of Things (IoT), smart contracts, artificial intelligence (AI) and big data have been included in the results.

Figure 7 depicts the temporal evolution of keywords co-occurrence. These author keywords are divided into three periods. The initial research focused on concepts or functions, such as building information management, trust, collaboration, security, monitoring, etc.; the subsequent research was gradually diversified, for example, smart contracts, construction contract, decentralization, Internet of Things, information security, asset information model, construction supply chains, circular economy, etc.; recent research is primarily reflected in the digital construction, modular construction, sustainability, common data environment, big data, life cycle, supply chain management, etc.

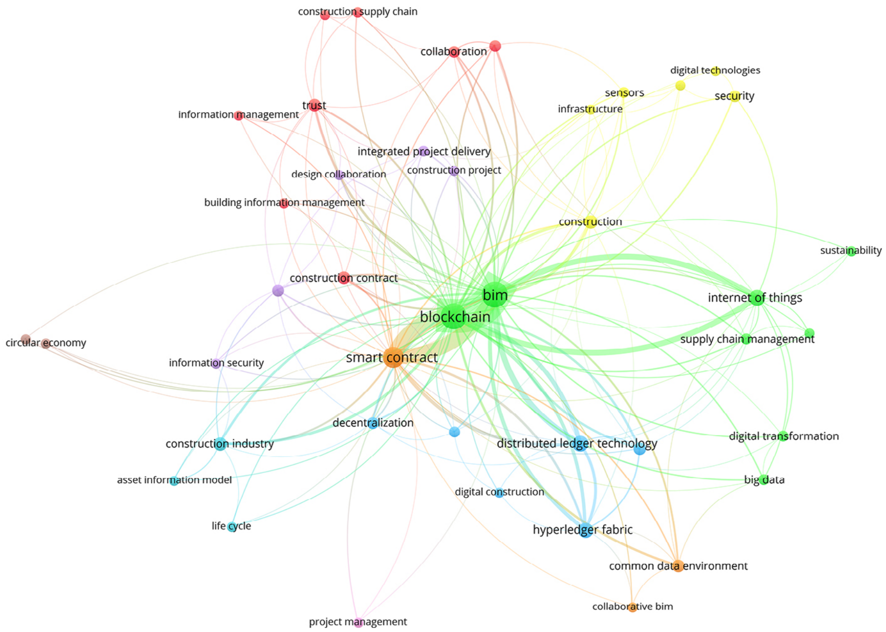

Figure 6. Analysis of co-occurrence network

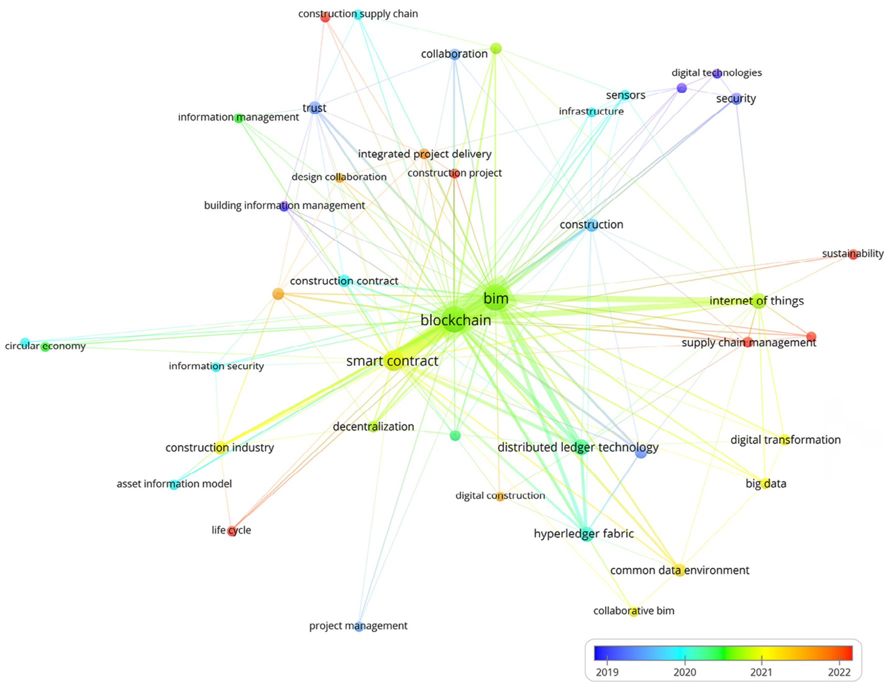

Figure 7. Timeline view of keyword co-occurrence network

4. Content analysis

Although the keyword co-occurrence network can reflect the focus of related research to a certain extent, it is not comprehensive. Therefore, this stage of review adopted content analysis to identify key research themes by summarizing the key research questions of 103 articles (review articles excluded) and, more importantly, considering managerial implications from the integrated BIM and blockchain as the main reference. The review process revolved around managerial strategies and technological inferences for project performance according to the development of integrated BIM and blockchain in the AECO industry. The results are shown in Figure 8 (see Appendix for classification basis), five managerial implications were identified: (a) design and collaboration, (b) financial management, (c) information management, (d) construction management, and (e) integration management (with other cutting-edge technologies). Analysis of the selected documents showed that the design phase was mentioned 31 times, the construction phase was mentioned 50 times, while the operations and maintenance phases were not widely mentioned (see Appendix for details). Therefore, the design and construction phases were identified as the two key phases of integrated BIM and blockchain. Information management was identified as a field with high interaction with other fields, which essentially reflects the driving force of the integrated BIM and blockchain. Additionally, this section summarizes the challenges of integrated BIM and blockchain from technical, organizational, and environmental perspectives.

4.1. Key managerial implications of the integrated BIM and blockchain

4.1.1. Design and collaboration

In the field of design and collaboration, the focus is primarily on collaborative BIM design and design liability control. Existing collaborative BIM design platforms have a centralized system structure, which can be vulnerable to cyberthreats in terms of design data tampering and the absence of rights. These threats can result in data loss, reduced design productivity, and project delays (Tao et al., 2021). Liu et al. (2019) studied the potential functions of the integrated BIM and blockchain in the architectural design phase. Singh and Ashuri (2019) developed a blockchain system for tracking the design lifecycle using block-chaining design directives and events. Zheng et al. (2019) investigated a feasible use of blockchain under a BIM-based design and indicated that blockchain may offer a credible source of BIM data. Srećković et al. (2021) presented a modeling method based on blockchain that would enable an autonomous procedure for analyzing and confirming BIM data at various design stages. Gao and Zhong (2022) proposed a blockchain-based architecture for administrating both automatic and manual processes for compliance review in a BIM setting. Dounas et al. (2019) integrated a blockchain and BIM to solve design-oriented problems. Subsequently, Dounas et al. (2021) presented a conceptual architecture for a BIM design solution, including blockchain, detailing four tiers of connectivity between the BIM system and blockchain. However, fully integrated BIM and blockchain can expose sensitive information, and blockchain is not practical for storing large BIM data, which limits the ability of blockchain to protect the integrity of BIM data. Tao et al. (2021) proposed two frameworks to address these concerns: a distributed common data environment (CDE) framework for solving storage problems, and a confidentiality-minded framework that provides an access-controlled working environment during the design and collaboration processes (Tao et al., 2022). Erri Pradeep et al. (2021) used blockchain and BIM to resolve the challenges of design liability control and information security.

4.1.2. Financial management

Despite repeated probes and gradual reforms, financial management, including payment concerns, still exists in the construction industry (Chong & Diamantopoulos, 2020). In recent years, BIM and blockchain have been used as solutions for project cash flow management and payment security. Elghaish et al. (2020) developed a toolkit that combines BIM and blockchain to provide an automated finance system for integrated project delivery. This system extracts scheduling data from a 4D BIM model, automated payments, and work done using the smart contract. Subsequently, Elghaish et al. (2022) proposed an interconnected financial control system based on a hyperledger fabric and chain code solutions. The system enabled team members to trigger transactions throughout the life cycle of a project, and they estimated the transaction value and payments using 4D and 5D BIM models.

Under project payments, Chong and Diamantopoulos (2020) established a complete framework for project payments that integrates BIM and blockchain to address payment security challenges in construction projects. Ye et al. (2020) presented a framework for simplifying and automating payments by integrating BIM, linked data, smart contracts, and blockchain. By integrating blockchain and BIM, Sigalov et al. (2021) investigated automated payments between clients and contractors. Hamledari and Fischer (2021) presented an automated payment management approach that used blockchain-based smart contracts with robotic reality-capturing technologies. An as-built BIM was used with sensing and machine intelligence to collect, assess, and document the construction progress. Under construction projects, Sonmez et al. (2022) proposed an integrated BIM and smart contract progress payment management platform that uses blockchain to connect the built BIM to the actual world, potentially improving the traditional payment process.

4.1.3. Information management

The information management of the integrated BIM and blockchain runs through the entire project life cycle for

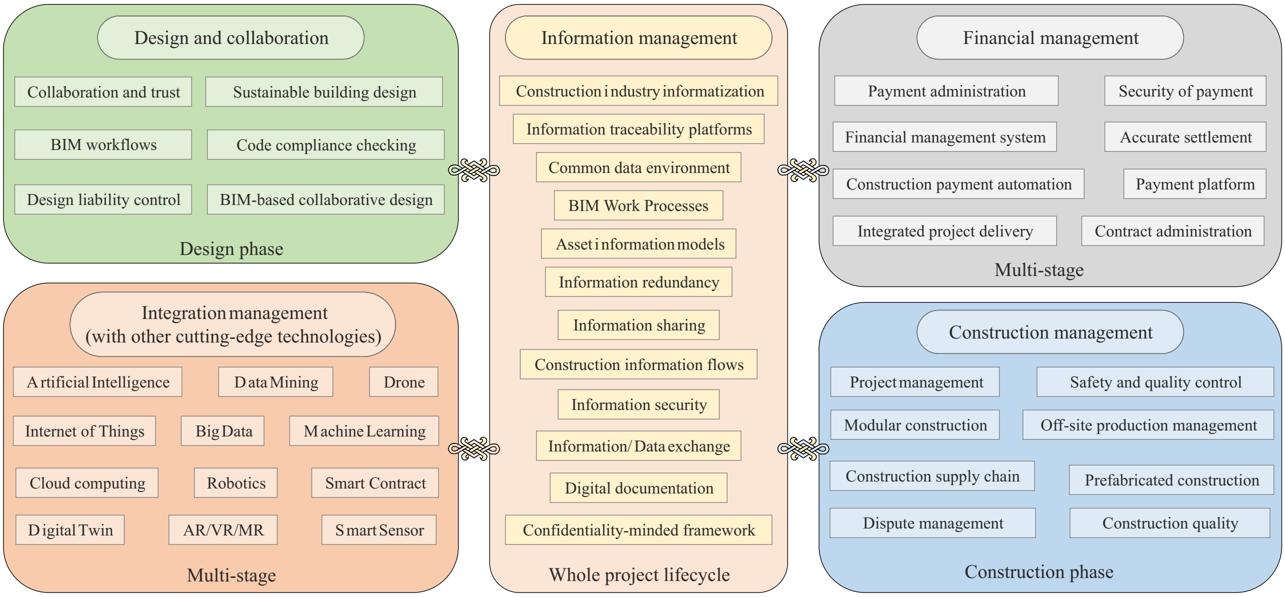

Figure 8. Key managerial implications from the integrated BIM and blockchain

new methods of storing, updating, and moving data over networks (Le, 2021; Ganter & Lützkendorf, 2019). Blockchain is a new and promising solution to the problem of information tampering caused by centralization (Turk & Klinc, 2017). Combining BIM and blockchain creates a new paradigm for collecting building data, resulting in a fully live BIM (Harty, 2019). Das et al. (2021) examined BIM flaws and proposed that blockchain can reduce the danger of information tampering owing to centralization. Zheng et al. (2019) created the "bcBIM" system in which team members shared blockchain hash values for BIM models. Although the system was effective in preventing data breaches, team members could not obtain source design data from or through the blockchain. Erri Pradeep et al. (2021) studied the process of changing BIM records via an online system into which relevant stakeholders submit design records to govern liability. Blockchain services, such as Ethereum, in addition to web-based platforms, have been used to connect BIM datasets. Tao et al. (2021) also integrated blockchain with the CDE for a BIM collaborative design workflow, but the blockchain network functioned as several CDE containers to share, publish, and achieve data safely. Raslan et al. (2020a) observed that the association between asset information models, BIM, and blockchain is intriguing because each technology can fill the gaps in the others. Subsequently, Raslan et al. (2020b) introduced a conceptual framework for assembling and protecting asset information models using blockchain at the asset management level. In addition, combining blockchain with BIM increases information sharing and boosts transparency among project stakeholders. Lee et al. (2021) combined IoT and blockchain with BIM to propose a system for information-sharing in construction management. According to Ciotta et al. (2021), the integration of BIM and blockchain can reduce human errors because it can boost the dependability and transparency of structural systems throughout construction processes. Celik et al. (2023b) proposed a Blockchain-based BIM data provenance model to support information exchange in construction projects.

4.1.4. Construction management

Integrated BIM and blockchains in construction management are primarily used for project safety and quality control, as well as for construction supply chain management. Project safety and quality management have always been challenging problems at construction sites. Zhong et al. (2020) used an alliance blockchain network to verify the proposed construction quality information management using an integrated BIM and blockchain. By fusing BIM, optical character recognition, and blockchain, Khan et al. (2020) created a fire safety rule-based approach to installing portable firefighting equipment, shifting the top-down inspection approach to a bottom-up voluntary method for suitable, transparent, and automated safety check information delivery. Li et al. (2021b) designed a smart construction project safety control system that integrates blockchain and BIM. Alvarez et al. (2021) identified BIM, IoT, and blockchain as technologies capable of controlling and supervising airport pavement management and indicated that the integration of these technologies can promote the integration of stakeholders in construction.

By extracting information from a 3D BIM model, BIM and blockchain have also been used to streamline the construction supply chain process (Shojaei et al., 2020). Fitriawijaya and Hsin-Hsuan (2019) explained how blockchain and BIM can be applied to supply chain management to support the activities of AEC industries. Li et al. (2021a) created a platform-based intelligent prefabricated building product-service system; that is, the use of blockchain, IoT, cyber-physical systems, and BIM in tandem to spark new types of smart construction. Subsequently, Lee et al. (2021) developed an integrated IoT-BIM with a blockchain architecture to enable accountable information exchange in the construction industry. Wu et al. (2022b) created a blockchain-enabled IoT-BIM framework for off-site production planning in modular construction to address single-point failures in IoT networks and sources of BIM updates. Li et al. (2022) presented a new service-oriented system architecture of a blockchain-enabled IoT-BIM platform for data information-knowledge-driven modular supply chain operations. Ni et al. (2021) explored the integration of BIM and blockchain in construction projects and built a blockchain-based BIM digital project management mechanism. Incorporating BIM and blockchain into construction projects can provide new concepts for whole-life-cycle construction (Ni et al., 2021).

4.1.5. Integration management

The integration of emerging advanced technologies into the construction industry has recently attracted significant interest from practitioners and scholars. Integration management refers to the proper coordination of integrated technologies to satisfy project requirements and expectations. The convergence of BIM with blockchain makes it easier to integrate with other technologies. As shown in Figure 9, as a subsidiary technology of blockchain, smart contracts have received the most interest. Integrating BIM and blockchain has accelerated the application of smart contracts in the AECO sector for progress payment management (Sonmez et al., 2022), contract management (Shojaei et al., 2020), workflow execution (Hunhevicz et al., 2022), change information management (Ciotta et al., 2021), and other applications. Another important technology is the IoT; the combination of BIM, blockchain, and IoT provides more possibilities for the AECO industry. Siountri et al. (2019b) proposed a system architecture that uses blockchain as a measure to secure and control BIM coupled with the IoT. Wu et al. (2022b) created a blockchain-enabled IoT-BIM platform with an IoT module and user interface to capture correct data from daily production activities and store it in a blockchain BIM while enabling user interaction. To clarify the relationships between blockchain, BIM, and IoT, Ye et al. (2018) posited the cup-of-water theory, in which BIM is considered to be the bottom of the cup for managing digital information, blockchain is considered to be the cup wall to reshape the approach of containers, and IoT is considered to be the water in the cup as an entity of object and data. Lokshina et al. (2019) viewed blockchain, BIM, and IoT as complementary technologies that operate together to enable the safe storage and monitoring of building project data and information.

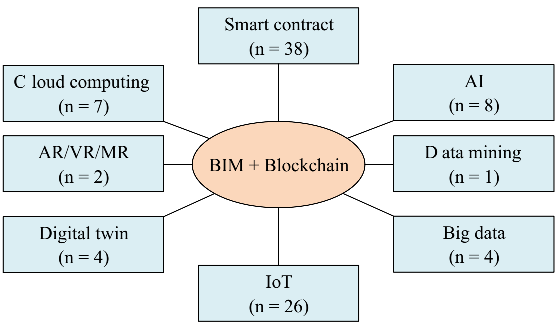

Figure 9. Other cutting-edge technologies in integrated BIM and blockchain

In addition, as artificial intelligence (AI) techniques advance, more academics are focusing on BIM-AI integration to promote the building sector (Zhang et al., 2022). Technologies, such as robotics, cloud computing, big data, digital twins, and data mining, have also attracted interest in integrated BIM and blockchain research. According to Aleksandrova et al. (2019), the integration of technologies such as cloud computing, IoT, specialized mobile applications, BIM, unmanned vehicles, big data, additive technologies, and blockchain is the foundation for digitalization. Li et al. (2021b) established a software intelligent system based on BIM, blockchain, AI, and data-mining technologies to address trace and tracking problems in safety and quality management processes. Hamledari and Fischer (2021) introduced an autonomous payment management solution that uses camera-equipped drones and unmanned ground vehicles equipped with laser scanners to capture, analyze, and document construction progress. Celik et al. (2021) presented the use of BIM and blockchain to facilitate the creation and deployment of digital twins for construction projects. Honcharenko et al. (2021) proposed an innovative scheme for a systematic method of digital modeling of a construction company's design, which consists of BIM, cloud computing, big data, IoT, and blockchain.

4.2. Challenges of the integrated BIM and blockchain

Integrating BIM and blockchain has had a far-reaching impact on the research and practice of the AECO industry. Although most studies have emphasized the potential and advantages of the integrated BIM and blockchain, the integration of the two is still in its infancy, and many challenges remain for large-scale implementation. To better promote the integrated BIM and blockchain, we summarize the challenges of integrating the, which can be considered as opportunities for future research. Three categories of challenges were identified, namely, the technological, organizational, and environmental levels, as shown in Table 4.

In terms of technology, integrating blockchain with BIM encounters significant difficulty in information redundancy (Xue & Lu, 2020). Because blockchain is inherently unsuitable for storing large design files such as BIM models, it is unable to protect BIM data integrity (Tao et al., 2021). The storage of duplicated building information in decentralized ledgers has already created redundancy, and the scenario worsens as the BIM model develops and is utilized (Xue & Lu, 2020). Furthermore, although blockchain, as a new distributed technology, ensures the authenticity and integrity of data by storing it in an immutable and traceable manner, direct integration of BIM and blockchain can result in the leakage of sensitive data (Tao et al., 2022).

Table 4. Main challenges of the integrated BIM and blockchain

Challenges of the integrated BIM and blockchain		Reference
Technological Level	Information redundancy	Li et al. (2022), Wu et al. (2022b), Gao and Zhong (2022), Hamledari and Fischer (2021), Tao et al. (2021), Xue and Lu (2020), Zhong et al. (2020), Turk and Klinc (2017)
	Compatibility	Hamledari and Fischer (2021), Pattini et al. (2021), Ng (2021), Shojaei et al. (2020), Bukunova and Bukunov (2019), Hijazi et al. (2019), Turk and Klinc (2017)
	Sensitive data security	Tao et al. (2022, 2023a), Li et al. (2019), Celik et al. (2023b), Chong and Cheng (2023)
	Infrastructure and technology maturity level	Elghaish et al. (2022), Hunhevicz et al. (2022), Raco et al. (2021), Lee et al. (2021), Dounas et al. (2021), Hijazi et al. (2019), Zhang et al. (2023), Yu et al. (2024)
Organizational Level	Lack of skilled technicians	Wu et al. (2022b), Li et al. (2021a), Pattini et al. (2020, 2021), Alvarez et al. (2021), Raslan et al. (2020a), Di Giuda et al. (2020), Prakash and Ambekar (2020), Zhong et al. (2020), Ganter and Lützkendorf (2019), Nawari and Ravindran (2019c), Sarkar et al. (2023), Selvanesan and Satanarachchi (2023)
	Stakeholder skepticism	Wu et al. (2022b), Hamledari and Fischer (2021), Pattini et al. (2021), Celik et al. (2023a), Singh and Kumar (2024)
	Uncertainty of initial investment cost and return	Wu et al. (2022b), Sonmez et al. (2022), Raco et al. (2021), Raslan et al. (2020a), Chong and Diamantopoulos (2020), Prakash and Ambekar (2020), Zhong et al. (2020), Nawari and Ravindran (2019c), Hijazi et al. (2019), Zhang et al. (2023), Selvanesan and Satanarachchi (2023)
	Top management support	Wu et al. (2022b), Raslan et al. (2020a), Nawari and Ravindran (2019c), Selvanesan and Satanarachchi (2023)
	Barriers to industry change	Wu et al. (2022b), Gao and Zhong (2022), Raco et al. (2021), Pattini et al. (2020), Di Giuda et al. (2020), Prakash and Ambekar (2020), Zhong et al. (2020), O'Reilly and Mathews (2019)
	Complexity of the project network	Li et al. (2019, 2022), Sonmez et al. (2022), Celik et al. (2021), Pattini et al. (2021), Sigalov et al. (2021), Alvarez et al. (2021), Ye et al. (2020), Zhong et al. (2020), Singh and Kumar (2024), Selvanesan and Satanarachchi (2023)
Environmental Level	Supervision	Wu et al. (2022b), Raco et al. (2021), Pattini et al. (2020), Zhong et al. (2020), Li et al. (2019), Hijazi et al. (2019, 2023a), Dounas and Lombardi (2018), Singh and Kumar (2024)
	Laws and regulations	Sonmez et al. (2022), Di Giuda et al. (2020), Erri Pradeep et al. (2020), Zhong et al. (2020), Nawari and Ravindran (2019c), Li et al. (2019), Hijazi et al. (2019, 2023a), Chong and Cheng (2023)
	Governmental support	Wu et al. (2022b), Gao and Zhong (2022), Nawari and Ravindran (2019c)

Because blockchain is a transparent network, shared data can then be exposed to all members without access control. Another problem is the limited compatibility between BIM and blockchain technologies (Bukunova & Bukunov, 2019). The adoption of blockchain for use in BIM technology requires data standards and interoperability (Bukunova & Bukunov, 2019). Considering the uncertainties and changes in construction projects, the immutability of blockchain and smart contracts can be considered a disadvantage when integrating BIM and blockchain for an automated and secure payment process. Finally, the integration of BIM and blockchain is considered a low-maturity field (Dounas et al., 2021), and the related infrastructure and technical maturity levels of various departments are not high, which hinders the integrated application and promotion of BIM and blockchain to a certain extent.

At the organizational level, because the construction industry has a history poorly adopting novel solutions, the deployment of integrated BIM and blockchain can be hampered by knowledge, attitude, industrial, financial, and procedural restrictions (Wu et al., 2022b). Most parties (clients, general contractors, primary subcontractors, and financial institutions) must buy into the novel processes created by the integrated BIM and blockchain (Hamledari & Fischer, 2021). Similarly, construction companies are hesitant to offer ledger access to all stakeholders because they have kept their corporate ledger confidential for decades (Zhong et al., 2020). Practitioners are skeptical of blockchain-enabled BIM (Hamledari & Fischer, 2021). This is primarily owing to the lack of actual applications. A technically feasible solution does not necessarily imply that it should be adopted. Technology acceptance will be slow or non-existent unless its usefulness in aiding construction management duties is clearly defined in projects. Furthermore, the main limitation of BIM integration with blockchain is the lack of knowledge among all stakeholders as well as cost (Raslan et al., 2020a). However, the integration of BIM and blockchain is still insufficiently developed. In the AECO industry, there is a considerable shortage of personnel who have received adequate blockchain training. A lack of understanding of how to integrate BIM and blockchain for more efficient and transparent business models can hinder stakeholders from adopting emerging innovations. Additionally, it can result in clients being reluctant to adopt new technologies in their businesses and projects. The deployment cost of the integrated BIM and blockchain mostly occurs in the early stage, and the return on investment of BIM and blockchain is still unclear in the interests of owners (Raslan et al., 2020a).

In terms of the environment, constraints primarily result from supervision, laws and regulations, and government support. The policy environment regarding blockchain has not been fully developed, including the relevant rules, laws, and standards (Zhong et al., 2020). The question of how to create a legislative environment to promote the integration of blockchain and BIM technologies remains unanswered. BIMCHAIN, for example, can indicate the authenticity and date of digital copyright, but its assertion that proofs are admissible in court is not supported by evidence (Erri Pradeep et al., 2020). Furthermore, data privacy must be embedded in any application with blockchain as it will promote information interchange and uphold privacy regulations (Zhong et al., 2020).

5. Discussions and conclusions

This paper conducted a state-of-the-art review of integrated BIM and blockchain in the AECO industry on its managerial implications and challenges based on current research and development. In total, 117 papers published between 2017 and 2023 were identified and reviewed. The results show that the integrated BIM and blockchain is still in the early exploration stage but has offered new managerial implications in projects. These managerial implications serve as the main contribution of this research because of their potential to revolutionize industry management practices and decision-making processes. They extend the current limited literature on integrating BIM and blockchain (Xu et al., 2022; Zhang et al., 2022). The design and construction phases have been identified as the two key phases of the integrated BIM and blockchain, whereas the operations and maintenance phases have not been widely mentioned. Information management has been identified as an area with strong interaction with other fields, which is essentially reflected as the main driving force of the integrated BIM and blockchain. In addition, the challenges of the current integrated BIM and blockchain are indicated from three aspects, leading toward opportunities for future studies from the dual perspectives of management and technology. The trend of digital transformation has become unavoidable. Technology integration, as a vital means of achieving and accelerating digital transformation, requires greater interest from technology and management researchers.

5.1. Opportunities from the management perspectives

Currently, most research on integrated BIM and blockchain is conducted from a technical perspective, but technical feasibility does not mean that it can be adopted in actual projects. Although some scholars have analyzed the feasibility of integrating the two, how to better promote the adoption of the integrated BIM and blockchain in the AECO industry, particularly from a management perspective, requires further exploration. Stakeholder management is the main area of opportunity for future research. Many stakeholders (such as architects, engineers, clients, contractors, developers, financial institutions, and government departments) will significantly influence and shape the adoption of an integrated BIM and blockchain framework for their projects. Global recognition of the significance of stakeholders' roles in the AECO industry has been increasing as construction projects consist of many social interactions among numerous stakeholders. In addition, the question of whether individuals will adopt a specific technology has been a subject of extensive research in numerous disciplines. As a result, a thorough understanding of the perspectives of all stakeholders is required for the successful integration of BIM and blockchain. Next, according to the state-of-the-art review, no previous study has investigated stakeholders' mixed perceptions during the implementation process of the integrated BIM and blockchain. For example, future studies should synchronize their levels of awareness and expertise based on the current capabilities and functions of the integrated BIM and blockchain. In addition, stakeholders' collaborative working environments or behavioral attitudes should be investigated during the implementation process, particularly from the perspective of value co-creation (Vijayeta, 2021).

The integration of BIM and blockchain is still in its infancy stage (Hijazi et al., 2019). The lack of real-world implementations makes it interesting to investigate its effects on project performance. From the perspective of their respective capabilities and features, blockchain can provide trust, traceability, auditability, data integrity, etc., whereas BIM can provide visualization, coordination, dativization, etc. However, the effective integration of the capabilities of BIM and blockchain, how well the integration matches, and what effects will be produced remain unclear. The effects and capabilities of blockchain and BIM technologies, as well as their potential new interactions for productivity improvement, must be explored. Furthermore, impact assessments are vital for clarifying the combination of enthusiasm and pessimism resulting from these technologies. Thus, future research should conduct longitudinal case studies or empirical studies to verify the effect of the integrated BIM and blockchain and to provide a clear answer on the effect of the integrated BIM and blockchain on the construction industry.

5.2. Opportunities from the technological perspective

Those who attempt to integrate BIM and blockchain rapidly encounter formidable obstacles to information redundancy (Xue & Lu, 2020). From the perspective of the Industry Foundation Classes (IFC) format, the information volume in BIM increases dramatically and creates a significant concern for its redundancy in the blockchain. Although some scholars have made some improvements in addressing the information redundancy of BIM integration with blockchain, blockchain is still slow when processing large BIM models. Future research could improve the forms of integrated BIM and blockchain. For example, an open format or BIM cloud services, including some signatures of IFC objects, can be used to reduce information redundancy when integrating BIM and blockchain. In addition, to promote integrated BIM and blockchain, future research should focus on developing effective IFCXML modules and new plug-ins for various BIM platforms (Lee et al., 2021).

Constraints, risks, and disruptions in construction projects are complicated, whereas the current smart contracts are nearly immutable. The incompatibility will become increasingly apparent, particularly regarding integrated BIM and blockchain for automated progress payments in complex construction projects. The payments for construction projects are often not achieved overnight, and uncertain processes occur, such as various project changes or claims. Most existing research is based on the framework of traditional project payment methods (for example, lump-sum, cost-plus, and target cost), and uncertainty remains about whether non-traditional procurement systems (e.g., public-private partnerships) are suitable for this integrated method. Therefore, matching the payment model of a project with the integrated BIM and blockchain in terms of technology will be a worthwhile study. Semi-automation appears to be a good compromise to provide a legally permissible and viable solution. However, more research in this area is required to streamline the project delivery process in the future.

The link between off-chain and on-chain reality is another important research direction for integrating BIM and blockchain. A major disadvantage of BIM and blockchain (including smart contracts) integration is that they are disconnected from the physical reality of the workplace (Hamledari & Fischer, 2021). Owing to their reliance on massive amounts of data from humans, hardware, and software, blockchain oracles have significant opportunities for improving real-time project management, which have yet to be thoroughly studied in the AECO industry (Lu et al., 2021). Some studies have proposed that IoT (Lokshina et al., 2019; Li et al., 2019), big data (Aleksandrova et al., 2019), or AI (Hamledari & Fischer, 2021; Li et al., 2021c) can be fused into the integration of BIM and blockchain to capture secure and accurate data in real-time. However, effective solutions in terms of data security, data style, etc., are lacking. Therefore, future research should develop multi-sensory systems with better reality capture features to record geometric and appearance-based changes from the project, ensuring that work progress and quality are more precisely communicated in the ecosystem.

6. Limitations and future work

Based on previous research, this study provides valuable insights into the integration of BIM and blockchain, especially in terms of the challenges and management implications of their integration. However, this study has some limitations. First, this study used data obtained from the Web of Science and Scopus databases, covering only journal and conference papers published in English, which may limit the scope of the study or result in less precision. Therefore, in future research, the search database on this topic needs to be expanded to achieve a more comprehensive search of the literature. Secondly, in addition to key management implications, some scattered research on the integration of BIM and blockchain may also be important research points in the future, but this study did not discuss this in detail. Future research should incorporate the Project Management Body of Knowledge (PMBOK) framework into the research of BIM and blockchain integration to further explore the role of BIM and blockchain integration for project management. Finally, this study reviewed integrated BIM and blockchain from the perspective of academic papers and did not involve industry reports or practical application cases. Future studies should include such materials to supplement the research on the integration of BIM and blockchain from both academic and industrial perspectives. Additionally, case study and expert interview methods should be used for triangulation in future studies to provide more valuable theoretical and practical references to practitioners.

References

Abrishami, S., & Elghaish, F. (2019). Revolutionising AEC financial system within project delivery stages: A permissioned blockchain digitalised framework. In B. Kumar, F. Rahimian, D. Greenwood, & T. Hartmann (Eds.), *36th CIB W78 2019* (pp. 199–210), Newcastle, UK.

Akbarieh, A., Carbone, W., Schäfer, M., Waldmann, D., & Teferle, F. N. (2020). Extended producer responsibility in the construction sector through blockchain, BIM and smart contract technologies. In *The World Congress on Sustainable Technologies* (*WCST-2020*) (pp. 190–196). https://doi.org/10.20533/WCST.2020.0004

Akhavan, P., Ravanshadnia, M., & Shahrayini, A. (2021). Blockchain technology in the construction industry: Integrating BIM in project management and IoT in supply chain management. In *2nd International Conference on Knowledge Management, Blockchain & Economy*, Iran.

Aleksandrova, E., Vinogradova, V., & Tokunova, G. (2019). Integration of digital technologies in the field of construction in the Russian Federation. *Engineering Management in Production and Services*, *11*(3), 38–47. https://doi.org/10.2478/emj-2019-0019

Alizadehsalehi, S., & Yitmen, I. (2023). Digital twin-based progress monitoring management model through reality capture to extended reality technologies (DRX). *Smart and Sustainable Built Environment*, *12*(1), 200–236. https://doi.org/10.1108/SASBE-01-2021-0016

Alvarez, A. P., Ordieres-Meré, J., Loreiro, Á. P., & de Marcos, L. (2021). Opportunities in airport pavement management: Integration of BIM, the IoT and DLT. *Journal of Air Transport Management*, *90*, Article 101941. https://doi.org/10.1016/j.jairtraman.2020.101941

Amaludin, A., & Bin Taharin, M. (2018). Prospect of blockchain technology for construction project management in Malaysia. *ASM Science Journal*, *11*, 199–205.

Baldawa, S., Kondaka, L., Iyer, R. S., & Thiruganan, D. (2023). Blockchain-based construction management system. In *Proceedings of the 7th International Conference on Trends in Electronics and Informatics* (pp. 597–603). IEEE. https://doi.org/10.1109/ICOEI56765.2023.10125997

Bohner, E., Vehmas, T., Laikari, A., Okkonen, M., Kiviniemi, M., Lahdenperä, P., & Ferreira, M. (2019). Digitalisation of the quality control of concrete manufacturing and construction. In *FIB Symposium 2019: Concrete-Innovations in Materials, Design and Structures* (pp. 1435–1442), Krakow, Poland.

Brandín, R., & Abrishami, S. (2021). Information traceability platforms for asset data lifecycle: Blockchain-based technologies. *Smart and Sustainable Built Environment*, *10*(3), 364–386. https://doi.org/10.1108/SASBE-03-2021-0042

Bukunova, O. V., & Bukunov, A. S. (2019). Tools of data transmission at building information modeling. In *2019 International Science and Technology Conference "EastConf"*. IEEE. https://doi.org/10.1109/EastConf.2019.8725373

Celik, Y., Petri, I., & Rezgui, Y. (2021). Leveraging BIM and blockchain for digital twins. In *2021 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*. IEEE. https://doi.org/10.1109/ICE/ITMC52061.2021.9570246

Celik, Y., Petri, I., & Rezgui, Y. (2023a). Integrating BIM and Blockchain across construction lifecycle and supply chains. *Computers in Industry*, *148*, Article 103886. https://doi.org/10.1016/j.compind.2023.103886

Celik, Y., Petri, I., & Barati, M. (2023b). Blockchain supported BIM data provenance for construction projects. *Computers in Industry*, *144*, Article 103768. https://doi.org/10.1016/j.compind.2022.103768

Chong, H. Y., & Cheng, M. (2023). Smart contract implementation in building information modeling–enabled projects: Approach to contract administration. *Journal of Construction Engineering and Management*, *149*(5), Article 05023004. https://doi.org/10.1061/JCEMD4.COENG-13216

Chong, H. Y., & Diamantopoulos, A. (2020). Integrating advanced technologies to uphold security of payment: Data flow diagram. *Automation in Construction*, *114*, Article 103158. https://doi.org/10.1016/j.autcon.2020.103158

Ciotta, V., Mariniello, G., Asprone, D., Botta, A., & Manfredi, G. (2021). Integration of blockchains and smart contracts into construction information flows: Proof-of-concept. *Automation in Construction*, *132*, Article 103925. https://doi.org/10.1016/j.autcon.2021.103925

Cocco, L., Tonelli, R., & Marchesi, M. (2022). A system proposal for information management in building sector based on BIM, SSI, IoT and blockchain. *Future Internet*, *14*(5), Article 140. https://doi.org/10.3390/fi14050140

Das, M., Tao, X., & Cheng, J. C. (2021). BIM security: A critical review and recommendations using encryption strategy and blockchain. *Automation in Construction*, *126*, Article 103682. https://doi.org/10.1016/j.autcon.2021.103682

Di Giuda, G. M., Giana, P. E., & Pattini, G. (2020). The shortening and the automation of payments: The potentiality of smart contract in the AECO sector. *In Fifth Australasia and South-East Asia Structural Engineering and Construction Conference*. ISEC Press. https://doi.org/10.14455/ISEC.2020.7(2).CON-12

Dounas, T., & Lombardi, D. (2018). A CAD-blockchain integration strategy for distributed validated digital design-connecting the blockchain. In *Proceedings of 36th Education and Research in Computer Aided Architectural Design in Europe (eCAADe) Conference 2018: Computing for a Better Tomorrow* (pp. 223–230), Łódź, Poland. https://doi.org/10.52842/conf.ecaade.2018.1.223

Dounas, T., Lombardi, D., & Jabi, W. (2019). Towards blockchains for architectural design consensus mechanisms for collaboration in BIM. In *Blucher Design Proceedings* (pp. 267–274), San Paulo, Brazil. https://doi.org/10.5151/proceedings-ecaadesigradi2019_296

Dounas, T., Jabi, W., & Lombardi, D. (2020). Smart contracts for decentralised building information modelling. In *Proceedings of 38th Education and Research in Computer Aided Architectural Design in Europe (eCAADe) Conference 2020: Anthropologic: Architecture and Fabrication in the Cognitive Age* (pp. 565–574), Berlin, Germany. https://doi.org/10.52842/conf.ecaade.2020.2.565

Dounas, T., Lombardi, D., & Jabi, W. (2021). Framework for decentralised architectural design BIM and blockchain integration. *International Journal of Architectural Computing*, *19*(2), 157–173. https://doi.org/10.1177/1478077120963376

Elghaish, F., Abrishami, S., & Hosseini, M. R. (2020). Integrated project delivery with blockchain: An automated financial system. *Automation in Construction*, *114*, Article 103182. https://doi.org/10.1016/j.autcon.2020.103182

Elghaish, F., Hosseini, M. R., Matarneh, S., Talebi, S., Wu, S., Martek, I., Poshdar, M., & Ghodrati, N. (2021). Blockchain and the 'Internet of Things' for the construction industry: Research trends and opportunities. *Automation in Construction*, *132*, Article 103942. https://doi.org/10.1016/j.autcon.2021.103942

Elghaish, F., Rahimian, F. P., Hosseini, M. R., Edwards, D., & Shelbourn, M. (2022). Financial management of construction projects: Hyperledger fabric and chaincode solutions. *Automation in Construction*, *137*, Article 104185. https://doi.org/10.1016/j.autcon.2022.104185

Elghaish, F., Hosseini, M. R., Kocaturk, T., Arashpour, M., & Ledari, M. B. (2023). Digitalised circular construction supply chain: An integrated BIM-Blockchain solution. *Automation in Construction*, *148*, Article 104746. https://doi.org/10.1016/j.autcon.2023.104746

Erri Pradeep, A. S., Yiu, T. W., & Amor, R. (2019). Leveraging blockchain technology in a BIM workflow: A literature review. In *International Conference on Smart Infrastructure and Construction 2019 (ICSIC): Driving Data-Informed Decision-Making* (pp. 371–380). ICE Publishing. https://doi.org/10.1680/icsic.64669.371

Erri Pradeep, A. S., Amor, R., & Yiu, T. W. (2020). Blockchain improving trust in BIM data exchange: A case study on BIMCHAIN. In *Construction Research Congress 2020* (pp. 174–183). https://doi.org/10.1061/9780784482865.124

Erri Pradeep, A. S., Yiu, T. W., Zou, Y., & Amor, R. (2021). Blockchain-aided information exchange records for design liability control and improved security. *Automation in Construction*, *126*, Article 103667. https://doi.org/10.1016/j.autcon.2021.103667

Faraji, A., Homayoon Arya, S., Ghasemi, E., Rashidi, M., Perera, S., Tam, V., & Rahnamayiezekavat, P. (2024). A conceptual framework of decentralized blockchain integrated system based on building information modeling to steering digital administration of disputes in the IPD contracts. *Construction Innovation*, *24*(1), 384–406. https://doi.org/10.1108/CI-01-2023-0008

Fitriawijaya, A., & Hsin-Hsuan, T. (2019). A blockchain approach to supply chain management in a BIM-enabled environment. In *Intelligent and Informed – Proceedings of the 24th International Conference on Computer-Aided Architectural Design Research in Asia* (pp. 411–420), Bangkok, Thailand. https://doi.org/10.52842/conf.caadria.2019.2.411

Ganter, M., & Lützkendorf, T. (2019). Information management throughout the life cycle of buildings-basics and new approaches such as blockchain. *IOP Conference Series: Earth and Environmental Science*, *323*(1), Article 012110. https://doi.org/10.1088/1755-1315/323/1/012110

Gao, H., & Zhong, B. (2022). A blockchain-based framework for supporting BIM-based building code compliance checking workflow. *IOP Conference Series: Materials Science and Engineering*, *1218*(1), Article 012016. https://doi.org/10.1088/1757-899X/1218/1/012016

Hadavi, A., & Alizadehsalehi, S. (2024). From BIM to metaverse for AEC industry. *Automation in Construction*, *160*, Article 105248. https://doi.org/10.1016/j.autcon.2023.105248

Hamledari, H., & Fischer, M. (2021). Construction payment automation using blockchain-enabled smart contracts and robotic reality capture technologies. *Automation in Construction*, *132*, Article 103926. https://doi.org/10.1016/j.autcon.2021.103926

Hargaden, V., Papakostas, N., Newell, A., Khavia, A., & Scanlon, A. (2019). The role of blockchain technologies in construction engineering project management. In *2019 IEEE International Conference on Engineering*, *Technology and Innovation* (*ICE/ITMC*). IEEE. https://doi.org/10.1109/ICE.2019.8792582

Harty, J. (2019). Rewarding performance in construction. *WIT Transactions on the Built Environment*, *192*, 15–20. https://doi.org/10.2495/BIM190021

Hijazi, A. A., Perera, S., Al-Ashwal, A. M., & Neves Calheiros, R. (2019). Enabling a single source of truth through BIM and blockchain integration. In *Proceedings of the 2019 International Conference on Innovation*, *Technology*, *Enterprise and Entrepreneurship* (*ICITEE 2019*), Kingdom of Bahrai.

Hijazi, A. A., Perera, S., Calheiros, R. N., & Alashwal, A. (2021). Rationale for the integration of BIM and blockchain for the construction supply chain data delivery: A systematic literature review and validation through focus group. *Journal of Construction Engineering and Management*, *147*(10), Article 03121005. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002142

Hijazi, A. A., Perera, S., Alashwal, A. M., & Calheiros, R. N. (2023a). Developing a BIM single source of truth prototype using blockchain technology. *Buildings*, *13*(1), Article 91. https://doi.org/10.3390/buildings13010091

Hijazi, A. A., Perera, S., Calheiros, R. N., & Alashwal, A. (2023b). A data model for integrating BIM and blockchain to enable a single source of truth for the construction supply chain data delivery. *Engineering*, *Construction and Architectural Management*, *30*(10), 4645–4664. https://doi.org/10.1108/ECAM-03-2022-0209

Honcharenko, T., Kyivska, K., Serpinska, O., Savenko, V., Kysliuk, D., & Orlyk, Y. (2021). Digital transformation of the construction design based on the building information modeling and internet of things. In *CEUR Workshop Proceedings* (Vol. 3039, pp. 267–279), Ternopil, Ukraine.

Hsu, C. L., Wang, J. T., & Hou, H. Y. (2023). A blockchain-based parametric model library for knowledge sharing in building information modeling collaboration. *Journal of Construction Engineering and Management*, *149*(11), Article 04023107. https://doi.org/10.1061/JCEMD4.COENG-13060

Hunhevicz, J. J., Motie, M., & Hall, D. M. (2022). Digital building twins and blockchain for performance-based (smart) contracts. *Automation in Construction*, *133*, Article 103981. https://doi.org/10.1016/j.autcon.2021.103981

Husin, A. E., & Priyawan, P. (2023). Implementation the Last Indonesian Minister Regulation of 2022 uses SEM-PLS and Blockchain-BIM to green cost efficiency. *Journal of Sustainable Architecture and Civil Engineering*, *33*(2), 96–112. https://doi.org/10.5755/j01.sace.33.2.34229

Husin, A. E., Priyawan, P., Kussumardianadewi, B. D., Pangestu, R., Prawina, R. S., Kristiyanto, K., & Arif, E. J. (2023). Renewable energy approach with Indonesian Regulation Guide uses Blockchain-BIM to green cost performance. *Civil Engineering Journal*, *9*(10), 2486–2502. https://doi.org/10.28991/CEJ-2023-09-10-09

Javaherikhah, A., Valiente Lopez, M., & Mohandes, S. R. (2023). Developing an inspector-centric blockchain-enabled conceptual framework for BIM management in Mars buildings. *Buildings*, *13*(11), Article 2858. https://doi.org/10.3390/buildings13112858

Jia, J., Zhang, M., & Yang, G. (2022). Factors influencing BIM integration with emerging technologies: Knowledge coupling perspective. *Journal of Management in Engineering*, *38*(2), Article 04022001. https://doi.org/10.1061/(ASCE)ME.1943-5479.0001018

Jiang, H., Yun, L., & Li, B. (2022). Framework for blockchain-enabled building information modeling. In K. Arai (Ed.), *Lecture notes in networks and systems: Vol 438*. *Advances in information and communication*. *FICC 2022* (pp. 832–842). Springer, Cham. https://doi.org/10.1007/978-3-030-98012-2_58

Kamel, M. A., Bakhoum, E. S., & Marzouk, M. M. (2023). A framework for smart construction contracts using BIM and blockchain. *Scientific Reports*, *13*(1), Article 10217. https://doi.org/10.1038/s41598-023-37353-0

Kang, J. (2022). Convergence analysis of BIM & blockchain technology in construction industry informatization. In *2022 4th International Conference on Smart Systems and Inventive Technology* (*ICSSIT*) (pp. 256–259). IEEE. https://doi.org/10.1109/ICSSIT53264.2022.9716352

Kankanamge, D., & Ruparathna, R. (2023). Adopting ecolabels in the construction industry via blockchain. In R. Gupta, M. Sun, S. Brzev, M. S. Alam, K. T. W. Ng, J. Li, A. El Damatty, & C. Lim (Eds.), *Lecture notes in civil engineering: Vol. 363*. *Proceedings of the Canadian Society of Civil Engineering Annual Conference 2022*. *CSCE 2022* (pp. 655–672). Springer, Cham. https://doi.org/10.1007/978-3-031-34593-7_40

Khan, N., Lee, D., Baek, C., & Park, C. S. (2020). Converging technologies for safety planning and inspection information system of portable firefighting equipment. *IEEE Access*, *8*, 211173–211188. https://doi.org/10.1109/ACCESS.2020.3039512

Khanna, M., Elghaish, F., McIlwaine, S., & Brooks, T. (2021). Feasibility of implementing IPD approach for infrastructure projects in developing countries. *Journal of Information Technology in Construction*, *26*, 902–921. https://doi.org/10.36680/j.itcon.2021.048

Le, H. T. (2021). Blockchain for building information modeling in construction industry. In *AIP Conference Proceedings*, *2406*(1), Article 020033. AIP Publishing LLC. https://doi.org/10.1063/5.0067158

Lee, D., Lee, S. H., Masoud, N., Krishnan, M. S., & Li, V. C. (2021). Integrated digital twin and blockchain framework to support accountable information sharing in construction projects. *Automation in Construction*, *127*, Article 103688. https://doi.org/10.1016/j.autcon.2021.103688

Li, J., & Kassem, M. (2021). Applications of distributed ledger technology (DLT) and Blockchain-enabled smart contracts in construction. *Automation in Construction*, *132*, Article 103955. https://doi.org/10.1016/j.autcon.2021.103955

Li, Q., & Wang, Y. (2021). Blockchain's role in supporting circular supply chains in the built environment. In *2021 IEEE International Conference on Blockchain* (*Blockchain*) (pp. 578–583). IEEE. https://doi.org/10.1109/Blockchain53845.2021.00087

Li, J., Kassem, M., Ciribini, A. L. C., & Bolpagni, M. (2019). A proposed approach integrating DLT, BIM, IOT and smart contracts: Demonstration using a simulated installation task. In *International Conference on Smart Infrastructure and Construction 2019* (*ICSIC*)*: Driving Data-Informed Decision-Making* (pp. 275–282). ICE Publishing. https://doi.org/10.1680/icsic.64669.275

Li, C. Z., Chen, Z., Xue, F., Kong, X. T., Xiao, B., Lai, X., & Zhao, Y. (2021a). A blockchain-and IoT-based smart product-service system for the sustainability of prefabricated housing construction. *Journal of Cleaner Production*, *286*, Article 125391. https://doi.org/10.1016/j.jclepro.2020.125391

Li, J., Wang, J., Ji, W., Liu, J., Sun, H., Xu, Y., & Wu, B. (2021b). Research on safety and quality control intelligent systems of engineering project based on blockchain and BIM technologies. *Journal of Physics: Conference Series*, *2044*(1), Article 012199. https://doi.org/10.1088/1742-6596/2044/1/012199

Li, W., Duan, P., & Su, J. (2021c). The effectiveness of project management construction with data mining and blockchain consensus. *Journal of Ambient Intelligence and Humanized Computing*. https://doi.org/10.1007/s12652-020-02668-7

Li, X., Lu, W., Xue, F., Wu, L., Zhao, R., Lou, J., & Xu, J. (2022). Blockchain-enabled IoT-BIM platform for supply chain management in modular construction. *Journal of Construction Engineering and Management*, *148*(2), Article 04021195. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002229

Li, C. Z., Zhen, Y., Wu, H., Chen, Z., Xiao, B., & Tam, V. W. (2023). The application of BIM in the AECO industry. *Journal of Civil Engineering and Management*, *29*(3), 202–222. https://doi.org/10.3846/jcem.2023.18076

Liu, Z., Jiang, L., Osmani, M., & Demian, P. (2019). Building information management (BIM) and blockchain (BC) for sustainable building design information management framework. *Electronics*, *8*(7), Article 724. https://doi.org/10.3390/electronics8070724

Liu, Z., Chi, Z., Osmani, M., & Demian, P. (2021). Blockchain and building information management (BIM) for sustainable building development within the context of smart cities. *Sustainability*, *13*(4), Article 2090. https://doi.org/10.3390/su13042090

Lokshina, I. V., Greguš, M., & Thomas, W. L. (2019). Application of integrated building information modeling, IoT and blockchain technologies in system design of a smart building. *Procedia Computer Science*, *160*, 497–502. https://doi.org/10.1016/j.procs.2019.11.058

Loo, B. P., & Wong, R. W. (2023). Towards a conceptual framework of using technology to support smart construction: The case of modular integrated construction (MiC). *Buildings*, *13*(2), Article 372. https://doi.org/10.3390/buildings13020372

Lu, W., Li, X., Xue, F., Zhao, R., Wu, L., & Yeh, A. G. (2021). Exploring smart construction objects as blockchain oracles in construction supply chain management. *Automation in Construction*, *129*, Article 103816. https://doi.org/10.1016/j.autcon.2021.103816

Luo, X., Mao, H., Wang, F., Li, Y., Ji, H., & Meng, H. (2021). Development and application of three-dimensional visualization system for substation construction control based on "BIM+ Smart site" technology. In *2021 4th International Symposium on Traffic Transportation and Civil Architecture* (*ISTTCA*) (pp. 410–417). IEEE. https://doi.org/10.1109/ISTTCA53489.2021.9654628

Mason, J. (2019). BIM Fork: Are smart contracts in construction more likely to prosper with or without BIM?. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *11*(4), Article 02519002. https://doi.org/10.1061/(ASCE)LA.1943-4170.0000316

Mathews, M., Robles, D., & Bowe, B. (2017). BIM+blockchain: A solution to the trust problem in collaboration. In *CITA BIM Gathering 2017*, Gallway, Ireland. https://doi.org/10.21427/D73N5K

Meng, Q., Zhang, Y., Li, Z., Shi, W., Wang, J., Sun, Y., Xu, L., & Wang, X. (2020). A review of integrated applications of BIM and related technologies in whole building life cycle. *Engineering*, *Construction and Architectural Management*, *27*(8), 1647–1677. https://doi.org/10.1108/ECAM-09-2019-0511

Nawari, N. O. (2021). Blockchain technologies: Hyperledger fabric in BIM work processes. In E. Santos Toledo, & S. Scheer (Eds.), *Lecture notes in civil engineering: Vol 98. Proceedings of the 18th International Conference on Computing in Civil and Building Engineering. ICCCBE 2020* (pp. 813–823). Springer, Cham. https://doi.org/10.1007/978-3-030-51295-8_56

Nawari, N. O., & Ravindran, S. (2019a). Blockchain technology and BIM process: Review and potential applications. *Journal of Information Technology in Construction*, *24*(12), 209–238.

Nawari, N. O., & Ravindran, S. (2019b). Blockchain and building information modeling (BIM): Review and applications in post-disaster recovery. *Buildings*, *9*(6), Article 149. https://doi.org/10.3390/buildings9060149

Nawari, N. O., & Ravindran, S. (2019c). Blockchain and the built environment: Potentials and limitations. *Journal of Building Engineering*, *25*, Article 100832. https://doi.org/10.1016/j.jobe.2019.100832

Nawari, N. O., & Ravindran, S. (2019d). Blockchain technologies in BIM workflow environment. In *Computing in Civil Engineering 2019: Visualization*, *Information Modeling*, *and Simulation* (pp. 343–352). American Society of Civil Engineers. https://doi.org/10.1061/9780784482421.044

Ng, P. (2021). 21E8: Coupling generative adversarial neural networks (GANS) with blockchain applications in building information modelling (BIM) systems. In *Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia* (*CAADRIA*) (Vol. 2, pp. 111–120), Hong Kong, China. https://doi.org/10.52842/conf.caadria.2021.2.111

Ni, Y., Sun, B., & Wang, Y. (2021). Blockchain-based BIM digital project management mechanism research. *IEEE Access*, *9*, 161342–161351. https://doi.org/10.1109/ACCESS.2021.3130270

O'Reilly, A., & Mathews, M. (2019). Incentivising multidisciplinary teams with new methods of procurement using BIM + blockchain. In *CITA BIM Gathering 2019*, Gallway, Ireland. https://doi.org/10.21427/14aq-jn02

Oraee, M., Hosseini, M. R., Edwards, D. J., Li, H., Papadonikolaki, E., & Cao, D. (2019). Collaboration barriers in BIM-based construction networks: A conceptual model. *International Journal of Project Management*, *37*(6), 839–854. https://doi.org/10.1016/j.ijproman.2019.05.004

Orani, C., & Mathews, M. (2022). *A BIM+ blockchain approach to ensure transparency in the strategic housing development planning system*. Technological University Dublin. https://doi.org/10.21427/52HT-9396

Pan, Y., & Zhang, L. (2023). Integrating BIM and AI for smart construction management: Current status and future directions. *Archives of Computational Methods in Engineering*, *30*(2), 1081–1110. https://doi.org/10.1007/s11831-022-09830-8

Pattini, G., Di Giuda, G. M., & Tagliabue, L. C. (2020). Blockchain application for contract schemes in the construction industry. In Y. Vacanas, C. Danezis, A. Singh, S., & Yazdani (Eds.), *Proceedings of International Structural Engineering and Construction. Holistic Overview of Structural Design and Construction* (pp. AAE-21-1–AAE-21-6). ISEC Press. https://doi.org/10.14455/ISEC.res.2020.7(1).AAE-21

Pattini, G., Seghezzi, E., & Di Giuda, G. M. (2021). Digitalization in construction: Blockchain applicability in the industry. In S. El Baradei, A. Abodonya, A. Singh, & S. Yazdani (Eds.), *Proceedings of International Structural Engineering and Construction* (Vol. 8(1), pp. AAE-06-1–AAE-06-6). ISEC Press. https://doi.org/10.14455/ISEC.2021.8(1).AAE-06

Perera, S., Nanayakkara, S., Rodrigo, M. N. N., Senaratne, S., & Weinand, R. (2020). Blockchain technology: Is it hype or real in the construction industry?. *Journal of Industrial Information Integration*, *17*, Article 100125. https://doi.org/10.1016/j.jii.2020.100125

Prakash, A., & Ambekar, S. (2020). Digital transformation using blockchain technology in the construction industry. *Journal of Information Technology Case and Application Research*, *22*(4), 256–278. https://doi.org/10.1080/15228053.2021.1880245

Raco, F., Stefani, M., Balzani, M., & Ferrari, L. (2021). Towards effective project documentation, transparency, and data-driven decision-making through BIM-blockchain based applications. *The International Archives of Photogrammetry*, *Remote Sensing and Spatial Information Sciences*, *XLVI-4/W5-2021*, 437–444. https://doi.org/10.5194/isprs-archives-XLVI-4-W5-2021-437-2021

Raslan, A., Kapogiannis, G., Cheshmehzangi, A., Tizani, W., & Towey, D. (2020a). Blockchain: Future facilitator of asset information modelling and management?. In *2020 IEEE 44th Annual Computers*, *Software*, *and Applications Conference* (*COMPSAC*) (pp. 523–528). IEEE. https://doi.org/10.1109/COMPSAC48688.2020.0-199

Raslan, A., Kapogiannis, G., Cheshmehzangi, A., Tizani, W., & Towey, D. (2020b). A framework for assembling asset information models (AIMs) through permissioned blockchain. In *2020 IEEE 44th Annual Computers*, *Software*, *and Applications Conference* (*COMPSAC*) (pp. 529–534). IEEE. https://doi.org/10.1109/COMPSAC48688.2020.0-198

Saah, A. E. N., & Choi, J. H. (2023). Blockchain technology in the AEC industry: Scientometric analysis of research activities. *Journal of Building Engineering*, *72*, Article 106609. https://doi.org/10.1016/j.jobe.2023.106609

Safa, M., Baeza, S., & Weeks, K. (2019). Incorporating blockchain technology in construction management. *Strategic Direction*, *35*(10), 1–3. https://doi.org/10.1108/SD-03-2019-0062

Sari, M., Berawi, M. A., & Zagloel, T. Y. (2023). A research review on the integration of BIM and blockchain in the AEC industry. *AIP Conference Proceedings*, *2594*, Article 030002. https://doi.org/10.1063/5.0109126

Sarkar, D., Dhaneshwar, D., & Raval, P. (2023). Automation in monitoring of construction projects through BIM-IoT-Blockchain model. *Journal of The Institution of Engineers* (*India*)*: Series A*, *104*(2), 317–333. https://doi.org/10.1007/s40030-023-00727-8

Selvanesan, H., & Satanarachchi, N. (2023). Potential for synergetic integration of building information modelling, blockchain and supply chain management in construction industry. *Journal of Information Technology in Construction*, *28*(35), 662–691. https://doi.org/10.36680/j.itcon.2023.035

Shkundalov, D., & Vilutienė, T. (2021). Bibliometric analysis of building information modeling, geographic information systems and web environment integration. *Automation in Construction*, *128*, Article 103757. https://doi.org/10.1016/j.autcon.2021.103757

Shojaei, A., Flood, I., Moud, H. I., Hatami, M., & Zhang, X. (2020). An implementation of smart contracts by integrating BIM and blockchain. In K. Arai, R. Bhatia, & S. Kapoor (Eds.), *Advances in intelligent systems and computing: Vol. 1070. Proceedings of the Future Technologies Conference. FTC 2019* (pp. 519–527). Springer, Cham. https://doi.org/10.1007/978-3-030-32523-7_36

Shu, P., Binti Za'Ba, N. I. L., & Ya'Acob, M. R. B. (2023). Framework design of smart contracts-based building information modeling contracts management in material supply chain. *International Journal of Communication Networks and Information Security*, *15*(1), 49–58. https://doi.org/10.17762/ijcnis.v15i1.5737

Sigalov, K., Ye, X., König, M., Hagedorn, P., Blum, F., Severin, B., Hettmer, M., Hückinghaus, P., Wölkerling, J., & Groß, D. (2021). Automated payment and contract management in the construction industry by integrating building information modeling and blockchain-based smart contracts. *Applied Sciences*, *11*(16), Article 7653. https://doi.org/10.3390/app11167653

Singh, S., & Ashuri, B. (2019). Leveraging blockchain technology in AEC industry during design development phase. In *Computing in Civil Engineering 2019: Visualization*, *Information Modeling*, *and Simulation* (pp. 393–401). Reston, VA: American Society of Civil Engineers. https://doi.org/10.1061/9780784482421.050

Singh, A. K., & Kumar, V. P. (2024). Analyzing the barriers for blockchain-enabled BIM adoption in facility management using best-worst method approach. *Built Environment Project and Asset Management*, *14*(2), 164–183. https://doi.org/10.1108/BEPAM-04-2023-0080

Siountri, K., Skondras, E., & Vergados, D. D. (2019a). Towards a smart museum using BIM, IoT, blockchain and advanced digital technologies. In *ICVISP 2019: Proceedings of the 3rd International Conference on Vision*, *Image and Signal Processing*, Article 23. https://doi.org/10.1145/3387168.3387196

Siountri, K., Skondras, E., Mavroeidakos, T., & Vergados, D. D. (2019b). The convergence of blockchain, internet of things (IoT) and building information modeling (BIM): The smart museum case. In *WTS 2019 – Wireless Telecommunications Symposium*, New York, USA.

Siountri, K., Skondras, E., & Vergados, D. D. (2020). Developing smart buildings using blockchain, internet of things, and building information modeling. *International Journal of Interdisciplinary Telecommunications and Networking*, *12*(3), 1–15. https://doi.org/10.4018/IJITN.2020070101

Sonmez, R., Ahmadisheykhsarmast, S., & Güngör, A. A. (2022). BIM integrated smart contract for construction project progress payment administration. *Automation in Construction*, *139*, Article 104294. https://doi.org/10.1016/j.autcon.2022.104294

Srećković, M., Šibenik, G., Breitfuß, D., Preindl, T., & Kastner, W. (2021). Analysis of design phase processes with BIM for blockchain implementation. In *ECPPM 2021 – eWork and eBusiness in Architecture*, *Engineering and Construction* (pp. 125–131). CRC Press. https://doi.org/10.1201/9781003191476-17

Suliman Eissa Mohammed, H., & Jamal Salem Alharthi, W. (2022). Blockchain technology and the future of construction industry in the Arab region: Applications, challenges, and future opportunities. *Engineering Research Journal*, *173*, 411–441. https://doi.org/10.21608/erj.2022.223618

Suliyanti, W. N., & Sari, R. F. (2019). Blockchain-based building information modeling. In *2019 2nd International Conference on Applied Engineering* (*ICAE*). IEEE. https://doi.org/10.1109/ICAE47758.2019.9221744

Suliyanti, W. N., & Sari, R. F. (2021). Blockchain-based implementation of building information modeling information using hyperledger composer. *Sustainability*, *13*(1), Article 321. https://doi.org/10.3390/su13010321

Suliyanti, W. N., & Sari, R. F. (2023). Blockchain-based double-layer byzantine fault tolerance for scalability enhancement for building information modeling information exchange. *Big Data and Cognitive Computing*, *7*(2), Article 90. https://doi.org/10.3390/bdcc7020090

Tan, J. H., Loo, S. C., Zainon, N., Aziz, N. M., & Mohd Rahim, F. A. (2023). Potential functionality and workability of blockchain within a building information modelling (BIM) environment. *Journal of Facilities Management*, *21*(4), 490–510. https://doi.org/10.1108/JFM-10-2021-0131

Tao, X., Das, M., Liu, Y., & Cheng, J. C. (2021). Distributed common data environment using blockchain and interplanetary file system for secure BIM-based collaborative design. *Automation in Construction*, *130*, Article 103851. https://doi.org/10.1016/j.autcon.2021.103851

Tao, X., Liu, Y., Wong, P. K. Y., Chen, K., Das, M., & Cheng, J. C. (2022). Confidentiality-minded framework for blockchain-based BIM design collaboration. *Automation in Construction*, *136*, Article 104172. https://doi.org/10.1016/j.autcon.2022.104172

Tao, X., Das, M., Zheng, C., Liu, Y., Wong, P. K. Y., Xu, Y., Liu, H., Gong, X., & Cheng, J. C. (2023a). Enhancing BIM security in emergency construction projects using lightweight blockchain-as-a-service. *Automation in Construction*, *150*, Article 104846. https://doi.org/10.1016/j.autcon.2023.104846

Tao, X., Wong, P. K. Y., Xu, Y., Liu, Y., Gong, X., Zheng, C., Das, M., & Cheng, J. C. (2023b). Smart contract swarm and multi-branch structure for secure and efficient BIM versioning in blockchain-aided common data environment. *Computers in Industry*, *149*, Article 103922. https://doi.org/10.1016/j.compind.2023.103922

Turk, Ž., & Klinc, R. (2017). Potentials of blockchain technology for construction management. *Procedia Engineering*, *196*, 638–645. https://doi.org/10.1016/j.proeng.2017.08.052

Vijayeta, M. (2021). BIM: blockchain interface framework for the construction industry. *International Journal of Sustainable Real Estate and Construction Economics*, *2*(1), 46–60. https://doi.org/10.1504/IJSRECE.2021.10038966

Wang, H., Pan, Y., & Luo, X. (2019). Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis. *Automation in Construction*, *103*, 41–52. https://doi.org/10.1016/j.autcon.2019.03.005

Wang, J., Shen, Y., Xiong, X., Wang, X., & Fang, X. (2022). Research on multi-person collaborative design of BIM drawing based on blockchain. *Scientific Reports*, *12*(1), Article 16312. https://doi.org/10.1038/s41598-022-20321-5

Wu, P., Jin, R., Xu, Y., Lin, F., Dong, Y., & Pan, Z. (2021). The analysis of barriers to BIM implementation for industrialized building construction: A China study. *Journal of Civil Engineering and Management*, *27*(1), 1–13. https://doi.org/10.3846/jcem.2021.14105

Wu, H., Zhang, P., Li, H., Zhong, B., Fung, I. W., & Lee, Y. Y. R. (2022a). Blockchain technology in the construction industry: Current status, challenges, and future directions. *Journal of Construction Engineering and Management*, *148*(10), Article 03122007. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002380

Wu, L., Lu, W., Xue, F., Li, X., Zhao, R., & Tang, M. (2022b). Linking permissioned blockchain to internet of things (IoT)-BIM platform for off-site production management in modular construction. *Computers in Industry*, *135*, Article 103573. https://doi.org/10.1016/j.compind.2021.103573

Xu, Y., Chong, H. Y., & Chi, M. (2021). A review of smart contracts applications in various industries: a procurement perspective. *Advances in Civil Engineering*, *2021*, Article 5530755. https://doi.org/10.1155/2021/5530755

Xu, Y., Chong, H. Y., & Chi, M. (2022). Blockchain in the AECO industry: Current status, key topics, and future research agenda. *Automation in Construction*, *134*, Article 104101. https://doi.org/10.1016/j.autcon.2021.104101

Xue, F., & Lu, W. (2020). A semantic differential transaction approach to minimizing information redundancy for BIM and blockchain integration. *Automation in Construction*, *118*, Article 103270. https://doi.org/10.1016/j.autcon.2020.103270

Ye, X., & König, M. (2020). Framework for automated billing in the construction industry using BIM and smart contracts. In E. Santos Toledo, & S. Scheer (Eds.), *Lecture notes in civil engineering: Vol 98. Proceedings of the 18th International Conference on Computing in Civil and Building Engineering. ICCCBE 2020* (pp. 824–838). Springer, Cham. https://doi.org/10.1007/978-3-030-51295-8_57

Ye, X., Sigalov, K., & König, M. (2020). Integrating BIM-and cost-included information container with blockchain for construction automated payment using billing model and smart contracts. In *Proceedings of the 37th International Symposium on Automation and Robotics in Construction* (*ISARC 2020*) (pp. 1388–1395). IAARC Publications. https://doi.org/10.22260/ISARC2020/0192

Ye, Z., Yin, M., Tang, L., & Jiang, H. (2018). Cup-of-Water theory: A review on the interaction of BIM, IoT and blockchain during the whole building lifecycle. In *Proceedings of the 35th International Symposium on Automation and Robotics in Construction* (*ISARC 2018*) (pp. 478–485). IAARC Publications. https://doi.org/10.22260/ISARC2018/0066

Yu, J., Zhong, H., & Bolpagni, M. (2024). Integrating blockchain with building information modelling (BIM): A systematic review based on a sociotechnical system perspective. *Construction Innovation*, *24*(1), 280–316. https://doi.org/10.1108/CI-04-2023-0082

Zhang, F., Chan, A. P., Darko, A., Chen, Z., & Li, D. (2022). Integrated applications of building information modeling and artificial intelligence techniques in the AEC/FM industry. *Automation in Construction*, *139*, Article 104289. https://doi.org/10.1016/j.autcon.2022.104289

Zhang, T., Doan, D. T., & Kang, J. (2023). Application of building information modeling-blockchain integration in the Architecture, Engineering, and Construction/Facilities Management industry: A review. *Journal of Building Engineering*, *77*, Article 107551. https://doi.org/10.1016/j.jobe.2023.107551

Zheng, R., Jiang, J., Hao, X., Ren, W., Xiong, F., & Ren, Y. (2019). bcBIM: A blockchain-based big data model for BIM modification audit and provenance in mobile cloud. *Mathematical Problems in Engineering*, *2019*, Article 5349538. https://doi.org/10.1155/2019/5349538

Zhong, B., Wu, H., Ding, L., Luo, H., Luo, Y., & Pan, X. (2020). Hyperledger fabric-based consortium blockchain for construction quality information management. *Frontiers of Engineering Management*, *7*(4), 512–527. https://doi.org/10.1007/s42524-020-0128-y

Zhong, B., Pan, X., Ding, L., Chen, Q., & Hu, X. (2023). Blockchain-driven integration technology for the AEC industry. *Automation in Construction*, *150*, Article 104791. https://doi.org/10.1016/j.autcon.2023.104791

APPENDIX

Summary of selected publications

No.	Authors (Year)	Application stage	Topic classification	Source type	Research method	Other technologies	Cited by
1	Kamel et al. (2023)	Construction phase	Payment automation	Scientific Reports	Conceptual framework/ Case study	Smart contract	0
2	Hijazi et al. (2023b)	Construction and operation phase	Construction supply chain/ Data delivery	Engineering Construction and Architectural Management	Proof of concept/ Survey	NA	18
3	Javaherikhah et al. (2023)	Whole life cycle	Information security	Buildings	Conceptual framework	Smart contract	0
4	Hsu et al. (2023)	Design and construction phase	Design and collaboration/ Knowledge sharing	Journal of Construction Engineering and Management	Conceptual framework	NA	0
5	Husin and Priyawan (2023)	Whole life cycle	Green cost performance	Journal of Sustainable Architecture and Civil Engineering	Survey	NA	0
6	Zhang et al. (2023)	NA	NA	Journal of Building Engineering	Literature review	NA	2
7	Husin et al. (2023)	Whole life cycle	Green cost performance	Civil Engineering Journal	Survey	NA	0
8	Tan et al. (2023)	NA	NA	Journal of Facilities Management	Literature review	NA	7
9	Tao et al. (2023b)	Design phase	Design and collaboration	Computers in Industry	Proof of concept	NA	3
10	Suliyanti and Sari (2023)	Whole life cycle	Information exchange	Big Data and Cognitive Computing	Proof of concept	NA	1
11	Tao et al. (2023a)	Design phase	Design and collaboration/ Data security	Automation in Construction	Proof of concept/ Case study	NA	6
12	Sarkar et al. (2023)	Construction phase	Payment process	Journal of The Institution of Engineers (India): Series A	Proof of concept/ Case study	IoT\ Smart contract	4
13	Celik et al. (2023a)	Whole life cycle	Construction supply chain/ Data exchange	Computers in Industry	Insight/Case study	Smart contract	15
14	Sari et al. (2023)	NA	NA	Conference paper	Literature review	NA	0
15	Elghaish et al. (2023)	Construction phase	Construction supply chain	Automation in Construction	Proof of concept	Smart contract	31
16	Loo and Wong (2023)	Construction phase	Modular integrated construction	Buildings	Conceptual framework/Case study	IoT/Cloud computing/ AI	5
17	Singh and Kumar (2024)	Construction phase	Construction management/ Facility management	Built Environment Project and Asset Management	Delphi method	NA	0
18	Faraji et al. (2024)	Construction phase	Dispute management	Construction Innovation	Conceptual framework\ Interviews	NA	0
19	Selvanesan and Satanarachchi (2023)	NA	NA	Journal of Information Technology in Construction	Insight\Literature review	NA	0

No.	Authors (Year)	Application stage	Topic classification	Source type	Research method	Other technologies	Cited by
20	Kankanamge and Ruparathna (2023)	Procurement and construction phase	Green procurement	Conference paper	Conceptual framework	NA	0
21	Yu et al. (2024)	NA	NA	Construction Innovation	Literature review	NA	1
22	Shu et al. (2023)	Construction phase	Contract administration	International Journal of Communication Networks and Information Security	Conceptual framework	Smart contract	0
23	Baldawa et al. (2023)	Construction phase	Project management/Share data	Conference paper	Conceptual framework	Smart contract	0
24	Hijazi et al. (2023a)	Construction phase	Construction supply chain/ Data delivery	Buildings	Proof of concept	NA	1
25	Celik et al. (2023b)	Construction phase	Information management/ Data provenance	Computers in Industry	Proof of concept\ Case study	NA	38
26	Chong and Cheng (2023)	Construction phase	Contract administration	Journal of Construction Engineering and Management	Survey/Case study	Smart contract	1
27	Wang et al. (2022)	Design phase	Design and collaboration	Scientific Reports	Conceptual framework	NA	8
28	Cocco et al. (2022)	Whole life cycle	Information management/ Integration management	Future Internet	Conceptual framework	IoT	8
29	Elghaish et al. (2022)	Design and construction phase	Financial management	Automation in Construction	Proof of concept/ Case study	Smart contract	32
30	Tao et al. (2022)	Design phase	Design and collaboration	Automation in Construction	Proof of concept/ Case study	Smart contract	46
31	Li et al. (2022)	Construction phase	Modular construction/ Supply chain management/ Integration management	Journal of Construction Engineering and Management	Proof of concept/ Case study	IoT/Smart contract	100
32	Wu et al. (2022b)	Construction phase	Modular construction/ Off-site production management/ Integration management	Computers in Industry	Proof of concept/ Case study	IoT/Smart contract	65
33	Jiang et al. (2022)	Whole life cycle	Information management	Conference paper	Conceptual framework	NA	3
34	Hunhevicz et al. (2022)	Whole life cycle	Digitize performance contracts/ Integration management	Automation in Construction	Proof of concept	Digital twin/ IoT/Smart contract	82
35	Gao and Zhong (2022)	Design phase	Code compliance checking	Conference paper	Conceptual framework	NA	6
36	Orani and Mathews (2022)	Design phase	Strategic housing development	Conference paper	Conceptual framework/Case study	Smart contract	0
37	Kang (2022)	Construction phase	Information management	Conference paper	Conceptual framework	NA	4
38	Sonmez et al. (2022)	Construction phase	Progress payment administration	Automation in Construction	Proof of concept/ Case study/Survey	Smart contract	33
39	Suliman Eissa Mohammed and Jamal Salem Alharthi (2022)	Whole life cycle	Information management	Engineering Research Journal	Insight/Interviews	NA	4

No.	Authors (Year)	Application stage	Topic classification	Source type	Research method	Other technologies	Cited by
40	Raco et al. (2021)	Whole life cycle	Digital documentation/ Integration management	Conference paper	Conceptual framework	Big data/ Smart contract/ IoT/ Cloud computing	3
41	Hamledari and Fischer (2021)	Construction phase	Construction payment automation/ Integration management	Automation in Construction	Proof of concept\ case study	Smart contract/AI	132
42	Ciotta et al. (2021)	Construction phase	Documentation management/ Integration management	Automation in Construction	Proof of concept	IoT/AI	54
43	Brandín and Abrishami (2021)	Whole life cycle	Information traceability platform/ Integration management	Smart and Sustainable Built Environment	Conceptual framework	Smart contract IoT/ AI	33
44	Khanna et al. (2021)	Construction phase	Integrated project delivery/ Integration management	Journal of Information Technology in Construction	Interviews	Cloud computing/ IoT/MR	10
45	Li et al. (2021b)	Construction phase	Safety and quality control/ Integration management	Conference paper	Conceptual framework	AI/Data mining	0
46	Tao et al. (2021)	Design phase	Design and collaboration	Automation in Construction	Proof of concept/ Case study	Smart contract	74
47	Hijazi et al. (2021)	NA	NA	Journal of Construction Engineering and Management	Literature review/ Focus groups	Smart contract	56
48	Le (2021)	Whole life cycle	Information management	Conference paper	Conceptual framework	NA	3
49	Lee et al. (2021)	Construction phase	Information sharing/ Stakeholder collaboration	Automation in Construction	Proof of concept/ Case study	Digital twin/ IoT	232
50	Celik et al. (2021)	Whole life cycle	Design collaboration/ Digital twin/ Integration management	Conference paper	Proof of concept/ Case study	Smart contract/ Digital twin/ Cloud computing	11
51	Erri Pradeep et al. (2021)	Design phase	Design and collaboration/ Information exchange/ Design liability control	Automation in Construction	Proof of concept/ Case study	NA	72
52	Das et al. (2021)	NA	NA	Automation in Construction	Literature review	NA	89
53	Dounas et al. (2021)	Design phase	Design and collaboration	International Journal of Architectural Computing	Conceptual framework	AI	85
54	Li et al. (2021a)	Construction phase	Prefabricated construction/ Integration management	Journal of Cleaner Production	Conceptual framework/Case study	IoT	141
55	Liu et al. (2021)	NA	NA	Sustainability	Literature review	NA	80
56	Li and Wang (2021)	Design and construction phase	Circular supply chain/ Sustainable performance	Conference paper	Insight	Cloud computing	3
57	Luo et al. (2021)	Construction phase	Accurate settlement/ Integration management	Conference paper	Conceptual framework/case study	IoT	3
58	Honcharenko et al. (2021)	Design phase	Integration management	Conference paper	Conceptual framework	IoT/Big data/Cloud computing	15
59	Ni et al. (2021)	Whole life cycle	Project management	IEEE Access	Insight	Smart contract	24

No.	Authors (Year)	Application stage	Topic classification	Source type	Research method	Other technologies	Cited by
60	Pattini et al. (2021)	Whole life cycle	Information management/ Process automation/ Collaborative environment	Conference paper	Insight	Smart contract	4
61	Ng (2021)	NA	NA	Conference paper	Conceptual framework\Case study	NA	2
62	Sigalov et al. (2021)	Construction phase	Automated payment/ Contract management	Applied Sciences	Conceptual framework\Case study	Smart contract	60
63	Li et al. (2021c)	Design and construction phase	Project management/ Integration management	Journal of Ambient Intelligence and Humanized Computing	Conceptual framework/Case study	AI	19
64	Suliyanti and Sari (2021)	Whole life cycle	Information exchange	Sustainability	Conceptual framework	NA	26
65	Vijayeta (2021)	Whole life cycle	Data management	International Journal of Sustainable Real Estate and Construction Economics	Survey	NA	4
66	Srećković et al. (2021)	Design phase	Design and collaboration	Conference paper	Conceptual framework	NA	18
67	Alvarez et al. (2021)	Construction phase	Airport pavement management/ Integration management	Journal of Air Transport Management	Conceptual framework/Case study	IoT	22
68	Akhavan et al. (2021)	Design and construction phase	Project management/ Supply chain management/Integration management	Conference paper	Conceptual framework	IoT	5
69	Xue and Lu (2020)	Whole life cycle	Information redundancy	Automation in Construction	Proof of concept/ Case study	NA	154
70	Raslan et al. (2020b)	Whole life cycle	Asset information management	Conference paper	Conceptual framework	NA	18
71	Raslan et al. (2020a)	NA	NA	Conference paper	Literature review	NA	15
72	Elghaish et al. (2020)	Construction phase	Automated financial system/ Integrated project delivery	Automation in Construction	Proof of concept/ Case study	Smart contract	201
73	Chong and Diamantopoulos (2020)	Construction phase	Security of payment/ Integration management	Automation in Construction	Survey/Case study	Smart contract/ IoT	101
74	Pattini et al. (2020)	Whole life cycle	Information management/ Contract management	Conference paper	Insight	Smart contract	22
75	Di Giuda et al. (2020)	Design phase	Automation of payment	Conference paper	Insight	Smart contract	11
76	Prakash and Ambekar (2020)	Whole life cycle	Smart asset management/ Single source of truth	Journal of Information Technology Case and Application Research	Interviews\Case study	NA	29
77	Ye et al. (2020)	Construction phase	Construction automated payment	Conference paper	Conceptual framework	Smart contract	36
78	Khan et al. (2020)	Construction phase	Safety inspection	IEEE Access	Conceptual framework/Case study	NA	10
79	Erri Pradeep et al. (2020)	Whole life cycle	Data exchange	Conference paper	Case study	NA	28

No.	Authors (Year)	Application stage	Topic classification	Source type	Research method	Other technologies	Cited by
80	Shojaei et al. (2020)	Design and construction phase	Construction project contract/ Updating the payment amounts	Conference paper	Conceptual framework	Smart contract	85
81	Nawari (2021)	Design and construction phase	BIM work process	Conference paper	Conceptual framework	Smart contract	18
82	Zhong et al. (2020)	Construction phase	Construction quality information management	Frontiers of Engineering Management	Conceptual framework	Smart contract/ IoT	122
83	Akbarieh et al. (2020)	Whole life cycle	Construction and demolition waste management	Conference paper	Conceptual framework	Smart contract	9
84	Siountri et al. (2020)	Design and construction phase	Integration management	International Journal of Interdisciplinary Telecommunications and Networking	Conceptual framework	IoT	35
85	Dounas et al. (2020)	Design phase	Design and collaboration	Conference paper	Conceptual framework	Smart contract	17
86	Ye and König (2020)	Construction phase	Automated billing	Conference paper	Conceptual framework	Smart contract	47
87	Abrishami and Elghaish (2019)	Construction phase	Financial system/ Project delivery	Conference paper	Conceptual framework	Smart contract	18
88	Mason (2019)	Construction phase	Integration management/ Construction management/ Payment arrangements	Journal of Legal Affairs and Dispute Resolution in Engineering and Construction	Insight	Smart contract	45
89	Suliyanti and Sari (2019)	Whole life cycle	Information system security	Conference paper	Insight	NA	11
90	Safa et al. (2019)	Construction phase	Construction management	Strategic Direction	Insight	NA	59
91	Ganter and Lützkendorf (2019)	Whole life cycle	Information management	Conference paper	Insight	NA	20
92	Aleksandrova et al. (2019)	Whole life cycle	Integration management	Engineering Management in Production and Services	Insight	Cloud computing/ IoT/ AI/Big data/AR/VR	51
93	Nawari and Ravindran (2019c)	NA	NA	Journal of Building Engineering	Literature review	NA	207
94	Siountri et al. (2019a)	Construction and operation phase	Integration management	Conference paper	Conceptual framework	IoT	25
95	Liu et al. (2019)	Design phase	Sustainable building design/ Information management	Electronics	Conceptual framework	NA	102
96	Hargaden et al. (2019)	Construction phase	Project Management	Conference paper	Insight	NA	91
97	Nawari and Ravindran (2019a)	NA	NA	Journal of Information Technology in Construction	Literature review	NA	157
98	Bukunova and Bukunov (2019)	Whole life cycle	Information security	Conference paper	Insight	NA	15
99	Erri Pradeep et al. (2019)	NA	NA	Conference paper	Literature review	NA	64
100	Harty (2019)	Whole life cycle	Rewarding performance	Conference paper	Insight	NA	6

No.	Authors (Year)	Application stage	Topic classification	Source type	Research method	Other technologies	Cited by
101	Li et al. (2019)	Construction phase	Integration management	Conference paper	Proof of concept	IoT/Smart contract	67
102	Lokshina et al. (2019)	Design phase	Integration management	Conference paper	Conceptual framework	IoT	104
103	Nawari and Ravindran (2019b)	NA	NA	Buildings	Literature review/ Case study	NA	134
104	Nawari and Ravindran (2019d)	Design and construction phase	BIM Workflow	Conference paper	Insight	NA	39
105	Singh and Ashuri (2019)	Design phase	Design and collaboration/ Information exchange	Conference paper	Conceptual framework	NA	39
106	Fitriawijaya and Hsin-Hsuan (2019)	Whole life cycle	Supply chain management	Conference paper	Proof of concept	IoT	32
107	Bohner et al. (2019)	Construction phase	Construction quality control	Conference paper	Insight	IoT	5
108	Zheng et al. (2019)	Design and construction phase	Information security	Mathematical Problems in Engineering	Proof of concept	Big data	165
109	Dounas et al. (2019)	Design phase	Design and collaboration	Conference paper	Insight	NA	23
110	O'Reilly and Mathews (2019)	Design phase	Team collaboration/ Procurement	Conference paper	Proof of concept	NA	17
111	Hijazi et al. (2019)	Construction phase	Construction supply chain/ Single source of truth	Conference paper	Insight	NA	20
112	Siountri et al. (2019b)	Operation phase	Integration management	Conference paper	Conceptual framework\Case study	IoT	9
113	Ye et al. (2018)	NA	NA	Conference paper	Literature review	NA	80
114	Amaludin and Bin Taharin (2018)	Design and construction phase	Project management	ASM Science Journal	Insight	NA	22
115	Dounas and Lombardi (2018)	Design phase	Design and collaboration	Conference paper	Proof of concept	NA	22
116	Turk and Klinc (2017)	Whole life cycle	Information management	Conference paper	Insight	NA	489
117	Mathews et al. (2017)	Design and construction phase	Trust/Collaboration	Conference paper	Insight	NA	153

Note: NA – not available.