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Review

Critical success factors for implementing blockchain technology in construction

Weihao Sun [a], Maxwell Fordjour Antwi-Afari [a,*], Imran Mehmood [b], Shahnawaz Anwer [b], Waleed Umer [c]

[a] Department of Civil Engineering, College of Engineering and Physical Sciences, Aston University, Birmingham B4 7ET, United Kingdom
[b] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong Special Administrative Region
[c] Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne NE7 7YT, United Kingdom

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ABSTRACT

In recent years, blockchain technology has attracted momentous attention in the construction industry. However, a state-of-the-art review of critical success factors (CSFs) for implementing blockchain technology in the construction industry is unexplored. In addition, there is no stage framework or a common set of CSFs for blockchain technology in the extant literature. Therefore, this review study aims to develop a stage framework and identify a common set of CSFs for successful blockchain technology implementation by analyzing published articles related to the studied domain. This review study adopted a systematic literature review and a science mapping approach to objectively identify a common set of CSFs, research gaps, and future research directions. Focusing on 78 journal articles retrieved from the Scopus database, influential journals, keywords, countries/regions, and documents in the domain of CSFs for blockchain technology in construction were analyzed. The results revealed that countries like China, USA, UK, and Australia have made the most contributions to this domain. Of the 22 CSFs, five main common sets for blockchain technology were (1) decentralized system (protocol), (2) transparency in data information for construction lifecycle processes, (3) ensuring data immutability, (4) increasing data security and reliability, and (5) providing full traceability of prefabrication. In the stage framework of CSFs for blockchain technology, some CSFs play an essential role throughout the entire construction life cycle processes (e.g., CSF#1 decentralized system and CSF#2 transparency in data information for construction life cycle processes). Four key research gaps and future research directions are proposed. They include (1) digital innovation, (2) smart contracts and information management, (3) intelligent construction, and (4) data analytics methods and techniques. Overall, the findings and checklist of CSFs for blockchain technology would be beneficial for successful exploration and practice in this field.

1. Introduction

The global construction market was projected to reach US$12.4 trillion by 2022 from US$ 10.4 trillion in 2017 [58]. With the rise in finance and computing, traditional industries like construction have slowly developed as compared to unconventional industries [107]. This is because the construction industry has not been able to quickly embrace advanced digital technologies [58]. However, it is gradually adopting advanced digital technologies such as building information modeling (BIM) and wearable sensing technologies [8,26]. Recently, blockchain technology, an advanced digital technology, has been regarded as an advanced database mechanism to transform many global industries including construction [58]. Therefore, there is a need to adopt blockchain technology in the construction industry to improve information sharing and database management.

Blockchain is a novel decentralized infrastructure and distributed computing paradigm that uses a chained data structure for verification, storage, and distributed consensus algorithms to generate and update data [53]. Blockchain technology has established new and advanced features for the business and industrial sectors [101]. The decentralization and transparency of blockchain technology also ensure data security, thereby increasing trust among users [27,83,125]. It incorporates

* Corresponding author.
E-mail addresses: 220258164@aston.ac.uk (W. Sun), m.antwiafari@aston.ac.uk (M.F. Antwi-Afari), imran.mehmood@connect.polyu.hk (I. Mehmood), shahnawaz.anwer@polyu.edu.hk (S. Anwer), waleed.umer@northumbria.ac.uk (W. Umer).

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various techniques to support a shared ledger among users (e.g., organizations, individuals, etc.), thus enabling consensus, steady, and secured transactions [3]. Blockchain technology can promote the development of industries like construction because it has many critical success factors (CSFs). CSFs comprise the areas/activities in which blockchain technology can be effectively implemented in construction projects. These areas/activities relate to the key characteristics and/or benefits of blockchain technology such as decentralization, autonomy, peer-to-peer relationships, and immutability [9]. These characteristics of blockchain technology play important roles in improving time efficiency, reducing costs, increasing trust among users, data security and transparency, and development of international projects.

Previous review studies about blockchain technology in construction [49,58,76] were based on manual reviews, which may be prone to subjectivity or bias. Li et al. [58] studied the challenges and opportunities of blockchain technology in the engineering field, proposing a multi-dimensional conceptual model to improve its application in the construction industry. Olawumi et al. [76] reviewed several digital tools and technologies and explored the potential of blockchain technology as an enabler for modular integrated construction projects. Taken together, these existing review articles discussed the current state of blockchain technology in construction. However, there is no state-of-the-art research on CSFs for implementing blockchain technology in the construction industry. In addition, the integration of a methodological approach based on a systematic literature review and science mapping approach has not been used in extant literature. Furthermore, identifying a common set of CSFs or developing a stage framework for implementing blockchain technology has not yet been explored. The essence of this review study would not only help other researchers to understand the critical factors needed for advancing research in blockchain technology but also help practitioners to prioritize the CSFs which may lead to improved information sharing and database management in construction. To fill these gaps, this review study adopted a systematic literature review and science mapping approach to conduct state-of-the-art research on the CSFs for implementing blockchain technology in the construction industry, improve current practices and recommend further studies.

Therefore, the present review study aims to develop a stage framework and identify a common set of CSFs for successful blockchain technology implementation in the construction industry and to recommend research gaps and future research directions. To achieve this goal, the objectives of this review study are to: (1) identify the annual publication trends of CSFs for implementing blockchain technology in the construction industry; (2) apply a science-mapping approach to analyze influential journals, keywords, countries/regions, and documents in the studied domain; (3) discuss the main common set of CSFs for successful blockchain technology implementation; and (4) develop a stage framework and propose future research directions of CSFs for implementing blockchain technology in construction.

The remaining sections of this review study are organized as follows. Section 2 discusses previous review studies on blockchain technology across several sectors and blockchain technology in the construction industry. Section 3 elaborates on the research methods based on a systematic literature review and a science mapping review. The results of annual publication trends, selection of peer-reviewed journals, co-occurrence of keywords analysis, countries/regions co-occurrence analysis, and documents analysis are presented in Section 4. In Section 5, the common set of CSFs, stage framework showing the identified CSFs across the different lifecycle stages of a construction project, recommendations for future research directions, study implications, limitations, and further studies are discussed. Finally, the conclusions of this review study are summarized in Section 6.

2. Previous studies

2.1. Review studies on blockchain technology across different sectors

Blockchain emerged as a promising technology with the introduction and wide use of cryptocurrency [30]. In recent years, it has shown a rapid growth and been applied in many applications across different sectors [3]. Patel et al. [79] reviewed the influential aspects (e.g., trending topics, authors, and target journals) of blockchain technology in the banking and finance sector and identified the main literature streams and future research agenda. Pandey et al. [78] showcased the significance of blockchain technology in food supply chains by examining and analyzing the existing studies using a bibliometric analysis approach. Wong et al. [117] conducted a systematic literature review of integrating blockchain technology into smart sustainable city developments, finding that smart sustainable cities can leverage blockchain technology in areas such as governance, mobility, assets, utility, healthcare, and logistics. Alshareef [4] focused on the value of blockchain investment in the education sector. Jabbar et al. [44] studied blockchain technology applications in intelligent transportation systems. Table 1 summarizes review articles on blockchain technology across different sectors.

2.2. Review studies on blockchain technology in the construction industry

Blockchain technology is a relatively new advanced digital technology in the construction industry, as such, its application in construction is still in its infancy [31]. One of the main issues hindering the modernization of the construction industry is its inability to embrace technological advancements in comparison with the successes seen in the logistics, automotive, and mechanical engineering industries [13]. To address this situation, recent empirical and review studies on blockchain technology have been conducted in the architecture, construction, and engineering (AEC) sector [2,5,23,52,90,95]. Scott et al. [95] reviewed blockchain technology in the construction industry and classified its application into seven subject areas: (1) procurement and supply chain, (2) design and construction, (3) operations and life cycle, (4) smart cities, (5) intelligent systems, (6) energy and carbon footprint, and (7) decentralized organizations. Wang et al. [113] studied the adoption of digital technology in off-site construction, finding the current practices and applications of these digital technologies as well as their limitations. Kiu et al. [49] conducted a systematic literature review to analyze the potential of blockchain technology in the construction industry. Olawumi et al. [76] and Liu et al. [62] adopted a science mapping and systematic analysis to automate the modular construction process and smart construction, respectively. Table 2 presents review

Table 1
Summary of review articles on blockchain technology across different sectors.

Source	Timespan	Research method	Research domain
Kubler et al. [51]	2018–2021	Systematic literature review	Decision support System
Patel et al. [79]	2009–2021	Meta-bibliometric review	Banking and Finance
Wong et al. [117]	Not Specified	Systematic literature review	Smart sustainable City
Alshareef [4]	2017–2020	Systematic literature review	Education sector
Jabbar et al. [44]	2015–2022	Systematic literature review	Intelligent Transportation systems
Saeed et al. [91]	2018–2021	Systematic literature review	Healthcare
Pandey et al. [78]	2016–2021	Literature review and bibliometric analysis	Food supply chain
Rana et al. [85]	Not Specified	Systematic literature review	Tourism industry

Table 2
Summary of review articles on blockchain technology in the construction industry.

Source	Timespan	Research method	Research direction
Wang et al. [113]	2010–2020	Systematic literature review	Digital technology adoption in off-site construction
Kiu et al. [49]	2015–2020	Systematic literature review	Potentials of blockchain in Construction
Scott et al. [95]	2017–2020	Exploratory literature review	Literature review of blockchain in construction
Olawuni et al. [76]	2010–2020	Science mapping and systematic analysis	Automating the modular construction process
Liu et al. [62]	2016–2022	Bibliometric analysis and systematic qualitative review	Smart construction

articles on blockchain technology in the construction industry.

Based on the aforementioned studies, it was revealed that blockchain technology had been studied across different sectors in recent years. Although numerous studies have explored blockchain technology in the construction industry, there is no state-of-the-art research on the common set of CSFs and a stage framework for successful blockchain technology implementation. To fill these research gaps, this review study aims to develop a stage framework and identify a common set of CSFs for successful blockchain technology implementation by analyzing published articles retrieved from the Scopus database.

3. Research methods

This review study adopted a "mixed-method approach", which consists of both a science mapping review (i.e., quantitative approach) and a systematic literature review (i.e., qualitative approach). The science mapping review is the quantitative method that consists of bibliometric and scientometric analyses using VOSviewer of the targeted research domain. This systematic literature review provides an in-depth qualitative discourse by identifying a common set of CSFs, developing a stage framework, and proposing future research directions of CSFs for implementing blockchain technology in the construction industry. The adopted mixed-method approach can help eliminate subjectivity, and it is divided into four parts. An overview of the research methods is presented in Fig. 1.

3.1. Articles retrieval

The process of retrieving relevant articles involves conducting a keyword search in the Scopus database, which covers a wider range of journals and recent publications in comparison to other databases like Web of Science [20]. The keywords "blockchain" and "construction" and "critical" OR "success" OR "factor" OR "impact" OR "influence" were used to search for literature samples in Scopus with no restrictions on time period. Overall, 375 documents were initially identified. Subsequently, these documents were further screened based on specific criteria, including the subject area (engineering), document type (article), publication stage (final), and language (English). The search string used in the Scopus database was TITLE-ABS-KEY (blockchain AND construction AND critical OR success OR factor OR impact OR influence) AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO

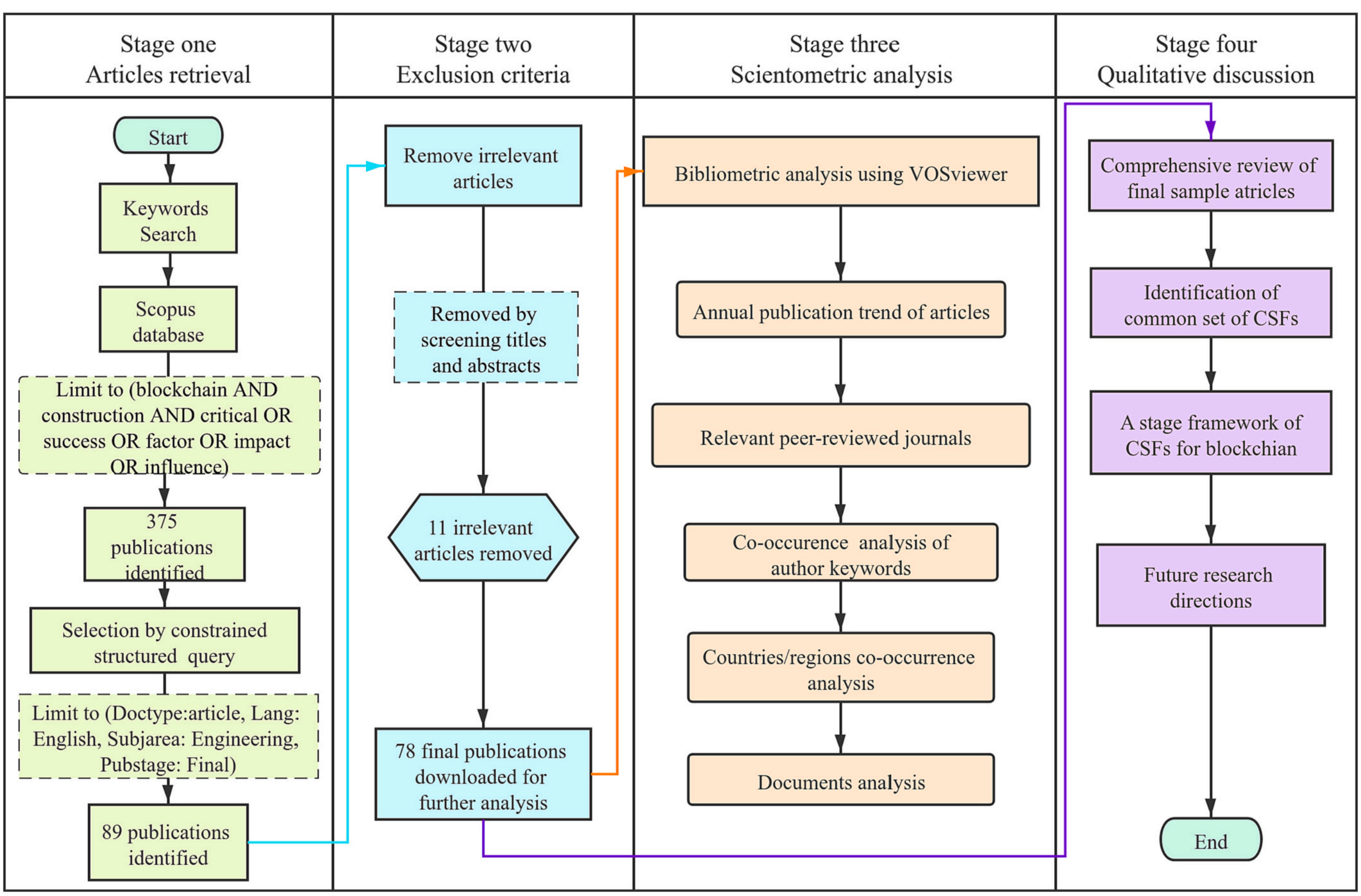

Fig. 1. Overview of research methods.

(LANGUAGE, “English”)). The search was conducted in March 2023. Conference papers were excluded because they contain less valuable information than journal articles [16]. After the second screening, 89 articles were retained for further evaluation.

3.2. Exclusion criteria

Articles were excluded by reading the titles and abstracts of the remaining 89 articles. Some articles such as Wang et al. [114], Su et al. [99], and Çevikbaş and Işık [19] did not include the keyword “blockchain” in the title or abstract, and these articles did not focus on CSFs for blockchain technology, thus, they were excluded. Some articles, although using the term “blockchain” in the abstract, did not focus on the CSFs for blockchain. For example, Fang et al. [35] mainly analyzed key behavioral events that occurred in teachers' past teaching work to determine the outstanding competence of teaching or scientific project criteria. Khanna et al. [47] investigated the feasibility of implementing an integrated project delivery (IPD) approach and applying its principles. Furthermore, articles that did not focus on CSFs for blockchain technology in the construction industry were removed. After the final round of screening, 11 articles were removed, and 78 journal articles were ultimately retained for scientometric analysis.

3.3. Scientometric analysis

After the final screening, 78 articles were extracted from the Scopus database and fed into VOSviewer for scientometric analysis. Scientometric analysis can eliminate problems from the traditional review process such as a lack of in-depth analysis or rigor, and allows for objective visualization of the research database [69]. The first part of the analysis was to understand the trends of publications over the years and analyze relevant peer-reviewed journals. Second, scientometric analysis in this study was performed using VOSviewer software. VOSviewer creates distance-based visualizations of networks, where the distances between nodes indicate the level of closeness among them [108]. It is suitable for visualizing larger networks with special text-mining features [109]. Furthermore, the data indexed in VOSviewer can be visualized and the results were reported on the keywords co-occurrence analysis, countries/regions co-occurrence analysis, and document analysis.

3.4. Qualitative discussion

The qualitative discussion comprised of comparing concepts, themes, theories, developments, and research findings [28]. Based on the keyword and document analyses in the prior step [7,46], the qualitative discussion aimed to provide a list of 22 CSFs identified from 78 articles retrieved from Scopus database. This review study also classified the identified CSFs into three major lifecycle stages of a construction project. In addition, future research directions of CSFs for implementing blockchain technology in the construction industry are thoroughly discussed based on keyword analysis.

4. Results

4.1. Annual publication trend of articles

In total, 78 articles were included in this review study, spanning from 2019 to 2023 (until the end of March 2023). Fig. 2 shows the annual distribution of the selected articles. It is observed that no article about CSFs for blockchain technology in the construction industry was published before 2019. The highest number of articles, i.e., 31, was published in 2022. Only eight articles were published in 2023, because this study was conducted at the end of March 2023. It is expected that more research will be published in the “blockchain in construction” which is a completely new research domain for digital transformation in the construction industry.

4.2. Relevant peer-reviewed journals analysis

Table 3 illustrates the peer-reviewed journals in which articles related to CSFs for blockchain technology in construction were published. Not all journals that were screened are shown in Table 3, but only journals with 2 or more published articles during the studied period. It was found that “*Buildings*” has the highest number of articles (i.e., 9 articles) published in this domain. Next, “*Automation in Construction*” and “*IEEE Access*” journals were ranked second and third places with 8 and 7 articles, respectively. About 29 articles, comprising 37.18%, were separately published as a single article in respective journals. Moreover, it was found that the included articles retrieved from Scopus had 44 different journals, which illustrates the diversity and extant of published articles on CSFs for blockchain technology.

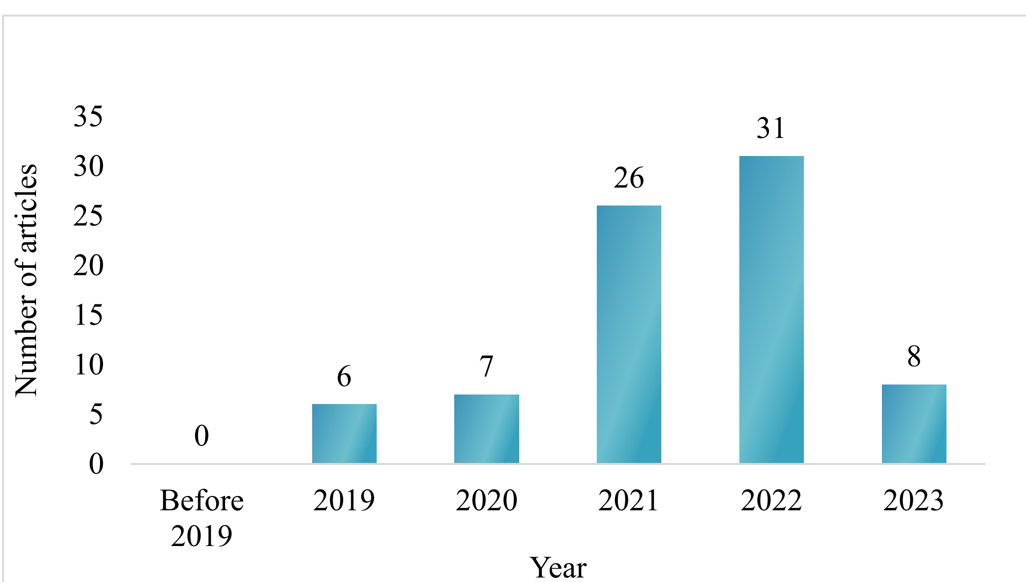

Fig. 2. Annual distribution of selected articles from 2019 to 2023 (March 2023).

Table 3
Selection of relevant peer-reviewed journals.

Journal sources	Number of articles	% of total publications
Buildings	9	11.54
Automation in Construction	8	10.26
IEEE Access	7	8.97
Mathematical Problems in Engineering	4	5.13
Engineering, Construction and Architectural Management	3	3.85
Journal of Construction Engineering and Management	3	3.85
Journal of Management in Engineering	3	3.85
Computers in Industry	2	2.56
Construction Innovation	2	2.56
Electronics (Switzerland)	2	2.56
Expert Systems with Applications	2	2.56
Journal of Cleaner Production	2	2.56
Wireless Communications and Mobile Computing	2	2.56
Others	29	37.18
Total	78	100

4.3. *Keywords co-occurrence analysis*

By using “author keywords” in VOSviewer and by setting the minimum occurrence of keywords at 2, 38 out of the 244 author keywords were initially selected. Further analysis was performed to remove general keywords, such as “blockchain”, “construction”, and “construction industry”. Other keywords with similar semantic meaning such as “internet of things” and “internet of things (iot)”, “smart contracts” and “smart contract, “bim” and “building information modeling (bim)” were combined. Finally, 32 keywords were generated from VOSviewer, as shown in Fig. 3.

The keywords that were frequently used in this research include “smart contract”, “Industry 4.0”, “digital twin”, “decentralization”, “supply chain management”, and “big data”. The connection lines in Fig. 3 show the interrelationship between a pair of keywords. For example, “smart contracts” are closely related to “big data” and they cover studies that focus on the critical function of big data in smart contracts. The keywords in Fig. 3 were divided into several clusters. Keywords within the same cluster generally have close internal relationships [46]. For example, security has often been co-studied with data privacy in the same article. In addition, “prefabrication” was generally aligned with “information integration”, “e-commerce”, and “supply chain” in similar articles. The distances and connection lines between keywords in Fig. 3 indicate their interrelatedness [46]. For example, “building information modeling” and “construction projects” were found to have a close relationship with “supply chain management”, “trust”, and “information asymmetry”. The font size indicates the frequency of keywords in the selected articles. The most frequently studied keywords include “smart contracts”, “Industry 4.0”, “digital twins”, and “big data”. Table 4 shows the quantitative summary of keywords co-occurrence analysis in CSFs for implementing blockchain technology in the construction industry.

The keywords listed in Table 4 show the rankings of the average normalized citations. It can be observed that keywords with the highest occurrence do not necessarily have the highest average citation or average normalized citation. Although “modular construction” appeared only twice, it had the highest average normalized citations. “Smart contract” appears most frequently with 10 occurrences, but its' average normalized citation was 1.11. The average publication year shows the recentness of the keywords studied. From Table 4, the most author keywords were from 2021 to 2022.

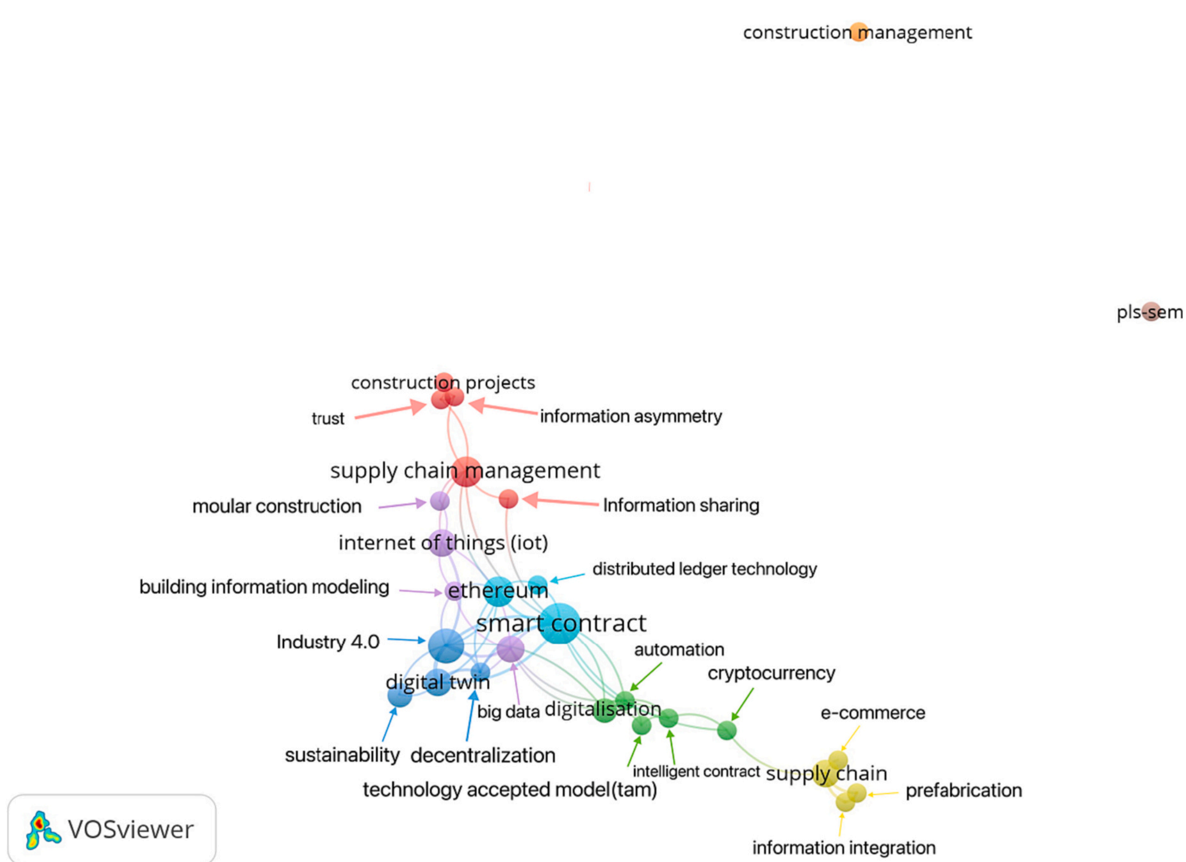

Fig. 3. Visualization of co-occurrence of keywords from the literature samples.

Table 4
Quantitative summary of co-occurrence analysis of keywords.

Keywords	Occurrence	Average publication year	Average citation	Average normalized citation
Modular construction	2	2022	22.5	7.42
Building information modeling (BIM)	2	2022	18	5.94
Supply chain management	5	2021	38	3.63
Trust	2	2021	36	1.90
Automation	2	2021	39.5	1.57
Sustainability	3	2022	20.7	1.46
Ethereum	5	2021	37	1.22
Big data	4	2021	17	1.18
Smart contract	10	2021	31.7	1.11
Digitalization	3	2020	26.7	1.06
Industry 4.0	7	2021	8	0.89
IoT (Internet of things)	6	2022	7.7	0.87
Digital twin	4	2022	9.3	0.77
Distributed ledger technology	2	2022	11.5	0.75
Information sharing	2	2022	26	0.59
Intelligent contract	2	2021	17	0.38
Technology accepted model (TAM)	2	2021	17	0.38
Construction management	2	2021	13	0.34
Supply chain	4	2021	4.3	0.33
Cryptocurrency	2	2022	1	0.33
E-commerce	2	2019	9	0.30
Decentralization	2	2022	4.5	0.24
Information integration	2	2022	4.5	0.24
Prefabrication	2	2022	4.5	0.24
PLS-SEM	2	2022	0.5	0.16
Construction projects	2	2022	0	0.00
Information asymmetry	2	2022	0	0.00

4.4. Countries/regions co-occurrence analysis

The countries/regions were identified to explore the distribution of articles on CSFs for blockchain technology in construction. Fig. 4 shows the geospatial distribution of the selected articles. The results showed that scholars from 21 countries/regions have conducted relevant research and published papers in this field.

Among these countries/regions, China has published the largest number of research articles (i.e., 26) in this field. Both the United Kingdom and Australia had the second highest number of articles (i.e., 8) in this field. The United States of America, Hong Kong SAR, and India ranked third with five published articles each.

A network was created with VOSviewer to provide a clearer picture of the research contributions and scientific collaborations of the countries/regions, which can help identify countries that are highly engaged in the specific research field [28]. The type of analysis was "co-authorship", the unit of analysis was "countries", and the values of 1 and 5 were defined as the minimum numbers of publications and citations, respectively. Under these criteria, 19 out of 28 countries/regions were selected and visualized, as shown in Fig. 5.

Fig. 5 illustrates that the countries/regions are divided into several nodes with the largest node obtained by China. Within this collaboration network, China, Australia, United States of America, United Kingdom, and Hong Kong SAR were the top five countries/regions in the studied research domain.

Table 5 presents the summary of countries/regions' contribution to CSFs for implementing blockchain technology in the construction industry. With most (31%) of published articles emerging from China, a strong relationship with other countries/regions is expected. In terms of citations, China ranks first with 332 citations, followed by the United Kingdom with 273 citations. Regarding the average publication year, the countries/regions in this research field are South Africa, Qatar, and Hong Kong SAR, whose publications are generally published around 2022. According to the average normalized citations, Hong Kong SAR received the highest value (2.74), indicating that its outcomes had the most considerable influence on the development of CSFs for blockchain technology in construction research.

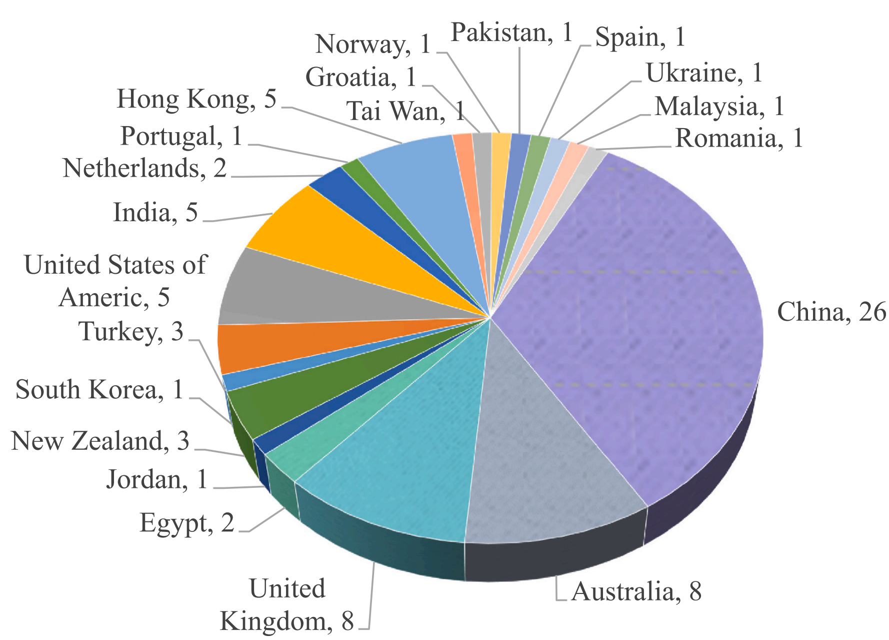

Fig. 4. Distributions of countries/regions.

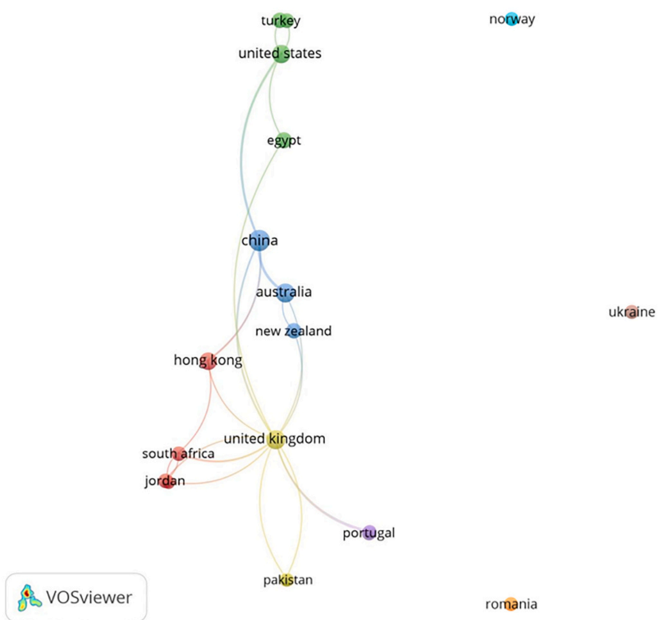

Fig. 5. Visualization of countries/regions co-occurrence network.

4.5. Document analysis

By setting the minimum number of citations for a document to 20, 19 out of 78 documents met the threshold. The most influential articles in terms of normalized citations are listed in Table 6. It can be seen that not all articles after screening are shown in the list, but only those with normalized citations over 2.00. For example, articles such as Berglund et al. [14] and Liu et al. [65], have relatively high total citations, but their normalized citations were below 2.00. Other articles such as Li et al. [59], although their total citations are not outstanding, the normalized citations rank first. Consequently, a study by Li et al. [59] which focused on blockchain-enabled platforms for supply chains in modular construction received the highest normalized citations. Table 6 indicates that the most influential articles were generally applied to the field of supply chain (e.g., blockchain platforms for supply chain management). Other articles represent more traditional research on blockchain- and IoT-based smart product-service systems [55], smart contracts [41], and blockchain-based big data models [132].

5. Discussion

5.1. Critical success factors (CSFs) for implementing blockchain technology in the construction industry

CSFs are the few key areas of activity in which favorable results are crucial for managers to reach their goals [88]. They also constitute powerful project management tools for minimizing project failures [121]. CSFs for blockchain technology in the construction industry can be defined as a set of key characteristics and areas that promote rapid progress in the industry [21]. In this study, CFSs for blockchain technology refer to areas or activities in a construction company or project that promote the renewal, information sharing, iteration, and database management. To implement blockchain technology successfully, researchers and practitioners need to identify the CSFs in order to take measures to ensure their effective implementation in these key areas. Table 7 shows 22 CSFs that have three or more occurrences/citations retrieved from the 78 included articles. The remaining eight CFSs, with one or two occurrences, are not shown in Table 7. A full list of all 30 CSFs is presented in Table 8. These CSFs for implementing blockchain technology in construction are cross-referenced with the extant literature. This review study discusses five common sets of the most frequently occurred/cited CSFs because they are crucial elements for successful blockchain technology implementation in the construction industry. They are (1) decentralized system (protocol), (2) transparency in data information for construction lifecycle processes, (3) ensuring data immutability, (4) increasing data security and reliability, and (5) providing full traceability of prefabrication and other construction sources.

5.1.1. Decentralized system (protocol)

Decentralization is a key feature of blockchain technology, which refers to the distribution of power and decision-making across a network of nodes or participants rather than being controlled by a central authority or system [10]. Decentralization provides robustness while eliminating many-to-one traffic flows to avoid delays and single points of failure [82]. Various studies have identified how a decentralized blockchain system can significantly improve the construction process. Saviour and Samiappan [93] stated that blockchain technology offers characteristics like a shared, decentralized database that keeps track of all transactions made on a given distributed network. Lee et al. [52] discussed a decentralized and distributed digital ledger of transactions that enables parties who do not fully trust each other to maintain a set of guaranteed recording states. Similarly, Figueiredo et al. [36] and San et al. [92] reported the significance of a decentralized system that

Table 5
Quantitative summary of countries/regions' contribution.

Country/Region	Documents	Citations	Average publication year	Average citations	Average normalized citations
Hong Kong SAR	8	174	2022	21.8	2.74
Qatar	1	8	2022	8	2.64
Sweden	1	31	2021	31	1.64
United Kingdom	11	273	2021	24.8	1.53
Jordan	2	8	2022	4	1.32
South Africa	2	8	2023	4	1.32
Australia	12	293	2021	24.4	1.27
Norway	1	52	2020	52	1.17
Romania	1	22	2021	22	1.16
Portugal	2	54	2021	27	1.08
China	29	332	2021	11.4	0.84
Turkey	3	18	2021	6	0.79
Egypt	4	9	2022	2.3	0.74
United States of America	9	83	2022	9.2	0.58
New Zealand	3	32	2021	10.7	0.56
Pakistan	1	8	2021	8	0.42
Saudi Arabia	1	8	2021	8	0.42
South Korea	2	35	2022	17.5	0.39
Ukraine	1	6	2019	6	0.20

Table 6
Summary of highly cited articles related to the studied research domain.

Articles	Title	Total citations	Normalized citations
Li et al. [59]	Blockchain-Enabled IoT-BIM Platform for Supply Chain Management in Modular Construction	35	11.30
Qian and Papadonikolaki [84]	Shifting trust in construction supply chains through blockchain technology	72	3.79
Li et al. [55]	A blockchain- and iot-based smart product-service system for the sustainability of prefabricated housing construction	58	3.05
Yang et al. [124]	Public and private blockchain in construction business process and information integration	132	2.94
Hamledari and Fischer [41]	Role of blockchain-enabled smart contracts in automating construction progress payments	55	2.89
Zheng et al. [132]	A blockchain-based big data model for bim modification audit and provenance in mobile cloud	80	2.59
McNamara and Sepasgozar [72]	Intelligent contract adoption in the construction industry: concept development	45	2.37

excludes the need for a trusted third party or trust management middleman role. Other studies such as Celik et al. [18] and Teisserenc and Sepasgozar [104], concluded that the decentralized system is a secure alternative to information storage and data integrity. Ratnasabapathy et al. [86] placed a core emphasis on blockchain technology as a decentralized data management technology that can considerably improve waste data management practices including waste data collection, reporting, and auditing, and contribute to driving a shift towards the circular economy through the circularity of waste information.

5.1.2. *Transparency in data information for construction lifecycle processes*

Construction professionals gravitate towards blockchain technology because of the benefits of transparency [66]. Transparency can be defined as a blockchain that orders and sends transactions to all members in an apparent manner [2]. Ameyaw et al. [5] proposed that blockchain-based smart contracts are an innovative technology for automating construction contract processes and show the potential to enhance the performance and efficiency of construction projects by ensuring transparency. Celik et al. [18] and Li et al. [,59] acknowledged that a transparent blockchain approach would promote confidence among construction stakeholders and guarantee secure payments for construction projects. With further application of blockchain technology in the construction industry, transparency can help stakeholders strengthen risk identification and reduce risk document loss or data manipulation, which, in turn, improves quality accountability [52,104,110]. The transparent nature of blockchain technology can also help establish trust and accountability among all parties involved in a construction project by providing a tamper-proof and transparent record of all transactions and interactions [55,60]. Transparency also facilitates payment management. Das et al. [25] affirmed that blockchain technology can be used to automate payments which can be transparently monitored based on pre-determined criteria. Transparency makes the payment process more efficient and reduces the risk of fraud or dispute. Other studies such as Sunny et al. [100], have mainly focused on the application of tracking resources in the supply chain in a transparent environment.

Table 7
Summary of related articles on CSFs for implementing blockchain technology in the construction industry.

Item	Critical success factors	References	Total	Rank
1	Decentralized system (protocol)	Ameyaw et al. [5], Saviour and Samiappan [93], Tian et al. [106], Chen and Chang [22], Lee et al. [52], Celik et al. [18], Escobar et al. [34], Raval et al. [87], Teisserenc and Sepasgozar [104], Van Groesen and Pauwels [110], Ibrahim et al. [43], Amiri Ara et al. [6], Xihua and Goyal [122], Pan et al. [77], Li et al. [54], Lian [61], Li et al. [56], Bakhtiarizadeh et al. [11], Elbashbishy et al. [31], Li et al. [59], Teisserenc and Sepasgozar [102], Bakhtiarizadeh et al. [12], Jiang et al. [45], Wu et al. [118], Zaidi et al. [129], Wu et al. [120], Fu et al. [37], Zhang et al. [131], Tezel et al. [105], Qian and Papadonikolaki [84], Hamledari and Fischer [41], Ni et al. [75], Peng [81], Yuan et al. [128], Du et al. [29], Cioara et al. [24], Kim et al. [48], Rodrigo et al. [89], Wan et al. [111], Liu et al. [65], Wang et al. [115], Adel et al. [2]	42	1
2	Transparency in data information for construction life cycle processes	Ameyaw et al. [5], Tian et al. [106], Xu et al. [123], Lee et al. [52], Celik et al. [18], Magdy et al. [68], Lou and Lu [66], Li et al. [54], Teisserenc and Sepasgozar [104], Van Groesen and Pauwels [110], Amiri Ara et al. [6], Adel et al. [2], Wu et al. [119], Xihua and Goyal [122], Nabeeh et al. [74], Pan et al. [77], Li et al. [56], Cheng and Chong [23], Bakhtiarizadeh et al. [11], Elbashbishy et al. [31], Li et al. [59], Singh and Kumar [97], Teisserenc and Sepasgozar [102], Bakhtiarizadeh et al. [12], Jiang et al. [45], Wu et al. [118], Fu et al. [37], Qian and Papadonikolaki [84], Ni et al. [75], Peng [81], Liu et al. [63], Du et al. [29], Yang et al. [124], Kim et al. [48], Rodrigo et al. [89], Wan et al. [111], Song et al. [98], Wang et al. [115], Chen and Chang [22]	39	2
3	Ensuring data immutability	Ameyaw et al. [5], Tian et al. [106], Chen and Chang [22], Lee et al. [52], Magdy et al. [68], Raval et al. [87], Lou and Lu [66], Li et al. [54], Teisserenc and Sepasgozar [104], Van Groesen and Pauwels [110], Patruni and	36	3

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Table 7 (*continued*)

Item	Critical success factors	References	Total	Rank
		Saraswathi [80], Amiri Ara et al. [6], Adel et al. [2], Wu et al. [119], Xihua and Goyal [122], Nabeeh et al. [74], Pan et al. [77], Li et al. [56,], Cheng and Chong [23], Lian [61], Li et al. [57], Elbashbishy et al. [31], Li et al. [59], Singh and Kumar [97], Jiang et al. [45], Wu et al. [118], Zaidi et al. [129], Fu et al. [37], Tezel et al. [105], Qian and Papadonikolaki [84], Yuan et al. [128], Cioara et al. [24], Rodrigo et al. [89], Liu et al. [65], Wang et al. [115], Zheng et al. [132]		
4	Increasing data security and reliability	Ameyaw et al. [5], Saviour and Samiappan [93], Chen and Chang [22], Xu et al. [123], Lee et al. [52], Magdy et al. [68], Raval et al. [87], Li et al. [54], Ibrahim et al. [43], Patruni and Saraswathi [80], Amiri Ara et al. [6], Elghaish et al. [32], Adel et al. [2], Xihua and Goyal [122], Nabeeh et al. [74], Pan et al. [77], Saygili et al. [94], Li et al. [56], Bakhtiarizadeh et al. [11], Elbashbishy et al. [31], Li et al. [59], Teisserenc and Sepasgozar [102], Bakhtiarizadeh et al. [12], Jiang et al. [45], Tezel et al. [105], Li et al. [60], Qian and Papadonikolaki [84], Hamledari and Fischer [42], Ni et al. [75], Peng [81], Du et al. [29], Rodrigo et al. [89]	32	4
5	Providing full traceability of prefabrication and other construction sources	Ameyaw et al. [5], Chen and Chang [22], Xu et al. [123], Lee et al. [52], Celik et al. [18], Lou and Lu [66], Li et al. [54,56], Teisserenc and Sepasgozar [104], Van Groesen and Pauwels [110], Elghaish et al. [32], Adel et al. [2], Wu et al. [119], Nabeeh et al. [74], Li et al. [57], Bakhtiarizadeh et al. [11], Elbashbishy et al. [31], Li et al. [59], Singh and Kumar [97], Ge et al. [39], Teisserenc and Sepasgozar [102], Bakhtiarizadeh et al. [12], Jiang et al. [45], Wu et al. [118], Li et al. [55], Qian and Papadonikolaki [84], Ni et al. [75], Du et al. [29], Cioara et al. [24], Yang et al. [124], Liu et al. [65]	31	5
6	Generating (Increasing) trust through the disclosure of information	Ameyaw et al. [5], Lee et al. [52], Raval et al. [87], Li et al. [54], Teisserenc and Sepasgozar [104], Elghaish et al. [32], Xihua and Goyal [122], Pan et al. [77], Li et al. [56], Lian [61], Bakhtiarizadeh et al. [11], Elbashbishy et al. [31], Li et al. [59], Teisserenc and Sepasgozar [102], Teisserenc and Sepasgozar [103], Bakhtiarizadeh et al. [12], Fu et al. [37], Du et al. [29], Rodrigo et al. [89]	19	6
7	Peer-to-peer relationship (network)	Ameyaw et al. [5], Saviour and Samiappan [93], Lee et al. [52], Li et al. [54], Teisserenc and Sepasgozar [104], Van Groesen and Pauwels [110], Patruni and Saraswathi [80], Adel et al. [2], Nabeeh et al. [74], Elbashbishy et al. [31], Brandín and Abrishami [15], Fu et al. [37], Zhang et al. [130], Tezel et al. [105], Li et al. [60], Peng [81], Yang et al. [124], Rodrigo et al. [89]	18	7
8	Reducing costs	Ameyaw et al. [5], Tian et al. [106], Lee et al. [52], Raval et al. [87], Patruni and Saraswathi [80], Amiri Ara et al. [6], Elghaish et al. [32], Wu et al. [119], Saygili et al. [94], Lian [61], Elbashbishy et al. [31], Du et al. [29], Kim et al. [48], Zheng et al. [132]	14	8
9	Enhancing the efficiency of construction progress	Ameyaw et al. [5], Tian et al. [106], Xu et al. [123], Raval et al. [87], Amiri Ara et al. [6], Pan et al. [77], Teisserenc and Sepasgozar [102], Teisserenc and Sepasgozar [103], Wu et al. [118], Ni et al. [75], Du et al. [29], Yang et al. [124], Elbashbishy et al. [31]	13	9
10	Combining data from BIM to enhance the efficiency of smart asset management	Celik et al. [18], Raval et al. [87], Lu and Zhang [67], Li et al. [59], Cheng and Chong [23], Das et al. [26], McNamara and Sepasgozar [72], Hamledari and Fischer [42], Ni et al. [75], Yang et al. [124], McNamara and Sepasgozar [71], Zheng et al. [132]	12	10
11	Ability to make transaction anonymously	Ameyaw et al. [5], Xu et al. [123], Magdy et al. [68], Li et al. [54], Nabeeh et al. [74], Lian [61], Bakhtiarizadeh et al. [11], Li et al. [59], Rodrigo et al. [89], Wang et al. [115]	10	11
12	Improving working collaboration, effective communication between practitioners	Ameyaw et al. [5], Lee et al. [52], Celik et al. [18], Li et al. [56], Teisserenc and Sepasgozar [104], Cheng and Chong [23], Bakhtiarizadeh et al. [11], Li et al. [59], Teisserenc and Sepasgozar [102], Wan et al. [111]	10	11
13	Facilitating automation in construction	Lee et al. [52], Celik et al. [18], Ibrahim et al. [43], Amiri Ara et al. [6], Wu et al. [119], Xihua and	10	11

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Table 7 (*continued*)

Item	Critical success factors	References	Total	Rank
		Goyal [122], Pan et al. [77], Cheng and Chong [23], Wu et al. [118], Hamledari and Fischer [41]		
14	Improving supply chain management	Ameyaw et al. [5], Tian et al. [106], Lee et al. [52], Gurgun et al. [40], Cheng and Chong [23], Ge et al. [39], Bakhtiarizadeh et al. [12], Fu et al. [37], Qian and Papadonikolaki [84]	9	14
15	Authentication and authorization of identity to ensure data is recorded securely	Ameyaw et al. [5], Tian et al. [106], Chen and Chang [22], Lee et al. [52], Celik et al. [18], Escobar et al. [34], Lou and Lu [66], Xihua and Goyal [122], Pan et al. [77]	9	14
16	Promoting information sharing, information accuracy, and information management	Xu et al. [123], Elbashbishy et al. [31], Jiang et al. [45], Celik et al. [18], Wu et al. [119], Rodrigo et al. [89], Pan et al. [77], Teisserenc and Sepasgozar [103], Ameyaw et al. [5]	9	14
17	Openness of ledger structure	Li et al. [56,59], Ni et al. [75], Du et al. [29], Song et al. [98], Zheng et al. [132], Ameyaw et al. [5], Teisserenc and Sepasgozar [104]	8	17
18	Reducing disputes and risks	Ameyaw et al. [5], Lee et al. [52], Adel et al. [2], Cheng and Chong [23], Lian [61], Li et al. [59]	6	18
19	Having auditability	Li et al. [59], Adel et al. [2], Zaidi et al. [129], Rodrigo et al. [89], Wang et al. [115]	5	19
20	Facilitating data integrity in document management	Celik et al. [18], Teisserenc and Sepasgozar [104], Patruni and Saraswathi [80], Teisserenc and Sepasgozar [102], Kim et al. [48]	5	19
21	Data encryption	Tian et al. [106], Li et al. [59], Li et al. [60], Yuan et al. [128]	4	21
22	Reducing consumption of energy	Escobar et al. [34], Li et al. [59], Teisserenc and Sepasgozar [103]	3	22

5.1.3. *Ensuring data immutability*

Data recorded in a blockchain are considered unchangeable [89], which is referred to as the immutability of the blockchain. The immutability of blockchain technology can provide significant benefits to the construction industry by improving accountability, supply chain management, and regulatory compliance [102]. Li et al. [54,56,57,59] identified that the chances of fraud are reduced due to the blockchain's immutability. With immutable information recording, Wu et al. [118] reported that it could be reliable evidence for efficient quality accountability so that disputes and guarded behaviors such as cutting corners would decline. Furthermore, immutability of blockchain technology ensures that energy transactions, once registered in the distributed ledger, are not modified [24], which can improve trust and confidence among stakeholders. Because blockchain provides immutability, transparency, and traceability of historical transactions, the proposed 7D smart contract framework allows for enhanced monitoring of the consumption patterns of tokenized green assets throughout their lifecycles [104]. With the immutability of blockchain, data integrity, which plays an important role, can also be easily achieved [89].

Table 8
A stage framework of CSFs for implementing blockchain technology in construction.

Item	CSFs for blockchain technology	Lifecycle stages of a construction project		
		Pre-construction	Construction	Post-construction
1.	Decentralized system (protocol)	✓	✓	✓
2.	Transparency in data information for construction life cycle processes	✓	✓	✓
3.	Ensuring data immutability	✓	✓	✓
4.	Increasing data security and reliability	✓	✓	✓
5.	Providing full traceability of prefabrication and other construction sources		✓	
6.	Generating (Increasing) trust through the disclosure of information	✓	✓	✓
7.	Peer-to-peer relationships (networks)	✓		
8.	Reducing costs		✓	
9.	Enhancing the efficiency of construction progress		✓	
10.	Combining data from BIM to enhance the efficiency of smart asset management	✓	✓	✓
11.	Ability to make transactions anonymously			✓
12.	Improving working collaboration, effective communication between practitioners	✓	✓	✓
13.	Facilitating automation in construction		✓	
14.	Improving supply chain management		✓	
15.	Authentication and authorization of identity to ensure data is recorded securely			✓
16.	Promoting information sharing, information accuracy, and information management	✓	✓	✓
17.	Openness of ledger structure			✓
18.	Reducing disputes and risks	✓	✓	✓
19.	Having auditability			✓
20.	Facilitating data integrity in document management	✓		✓
21.	Data encryption			✓
22.	Reducing consumption of energy		✓	
23.	Creating theoretical conditions for smart contracts	✓		
24.	Integrating with big data for managing construction contracts	✓		
25.	Supporting different kinds of services			✓
26.	Optimize the salvage value of components reusing in their lifecycle		✓	
27.	Improving the efficiency of the contract administration process	✓		

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Table 8 (*continued*)

Item	CSFs for blockchain technology	Lifecycle stages of a construction project		
		Pre-construction	Construction	Post-construction
28.	Avoiding or minimizing the requirement for intermediaries and duplication of effort		✓	
29.	Minimal changes			✓
30.	Having multiparty maintenance			✓

5.1.4. Increasing data security and reliability

Blockchain security and reliability refer to the blockchain records secured through cryptography, and users across networks exchange their private and public keys to transactions and act as a personal digital signature [74]. Chen and Chang [22] created three operation modes and standards for big data security management in blockchains to ensure confidentiality, integrity, and availability. As disruptive innovative technologies, Xu et al. [123] and Li et al. [54,56,59] identified that blockchain can guarantee secure payments by providing secure data. Lee et al. [52] demonstrated how the hybrid on-chain and off-chain blockchain systems can help secure traceable information sharing. With the convergence of AI and blockchain technology in a single ecosystem, trusted decentralized artificial intelligence (TDAI) can enable securing, auditing, and validating learning data to avoid the development of mistaken or biased AI models [2]. Pan et al. [77] reported that data security and authenticity of blockchain technology can improve trust, efficiency, and transparency in information sharing between participants, which has the potential to promote a paradigm shift in the CESIM (construction equipment security information management) towards information transparency and accountability change.

5.1.5. Providing full traceability of prefabrication and other construction sources

Bakhtiarizadeh et al. [11] reported that traceability was taken as the second critical attribute of information that helps the development of an efficient prefabrication supply chain. This is known as the ability to track and trace information [17]. Li et al. [54,56,57,59] acknowledged that blockchain technology can provide traceable communication for the network, which not only helps network administrators to query historical resources at any time but also deters the attempts of malicious users to create resource usage. Blockchain traceability can be applied to logistics information systems and food safety systems [39]. Owing to the long-term lifecycle of building management, historical data need to be traced for the maintenance of the building, which can be achieved by blockchain [45]. One of the most prominent benefits of blockchain technology is its ability to provide traceability for clients/customers wishing to trace the origins of their materials in supply chain management. In the blockchain platform, suppliers and clients can verify mutual immutable qualifications and track previous records through the supply chain for value co-creation. Meanwhile, specific products/services can be monitored in real-time, which facilitates the smart management of prefabricated housing construction [12,55]. Additionally, Liu et al. [65] identified that the traceability of blockchain technology can also reduce fraud and improve trust and accountability among stakeholders.

5.2. Stage framework of the CSFs for implementing blockchain technology in construction

The implementation of blockchain technology in construction is not limited to a discrete event. As such, it can be used for different lifecycle stages in a construction project. Efficient management of distinct stages is crucial for the successful implementation of blockchain technology in construction projects. Consequently, it is essential to delineate and classify CSFs for successful blockchain technology implementation across construction project lifecycle stages. Table 8 depicts a stage framework that shows the CSFs for implementing blockchain technology across construction project lifecycle stages. The construction project lifecycle stages consist of pre-construction, construction, and post-construction stages. In this review study, the pre-construction stage includes planning and conceptual design, permits and approvals, procurement, cost estimation/quantification, risk assessment, and contracting. The construction stage includes site preparation, resource allocation, on-site construction, and project management. The post-construction stage includes commissioning, document archiving, operations, and maintenance.

As shown in Table 8, the first lifecycle stage is the pre-construction stage, which is critical in construction projects. This typically refers to the period between project conception and the start of actual construction work [50]. During the pre-construction stage, a lot of planning and preparation takes place, which can significantly affect the success of the project. Throughout the pre-construction stages, the parties agree upon the project's contractual conditions, which include the mechanism of payments, retentions, etc. Blockchain technology provides a platform for these conditions to be coded for use as validation data [1,45] (CSF#24). Furthermore, blockchain technology can be used as an alternative to a central cloud-based data repository, sometimes referred to as a decentralized system (CSF#1). It provides end-to-end encryption, where data are shredded into small pieces called shards and stored in a global network of computers. This enables faster, cheaper, and more secure storage than centralized cloud services [33]. Considering the current path of progress of BIM towards level three maturity, stakeholders are expected to work on a single shared model with contributions related to their domain of work. At this stage, blockchain technology can help with stakeholder integration through multi-signature transactions and inter-organizational record-keeping with BIM (CSF#10) [58]. During the pre-construction stage, it is also essential to make data information transparent for construction life cycle processes (CSF#2), ensure data immutability (CSF#3), increase data security and reliability (CSF#4), and generate trust between participants (CSF#5).

The construction stage can also immensely benefit from the implementation of blockchain technology. For instance, the decentralized system (CSF#1), transparency in data information for construction lifecycle processes (CSF#2), ensuring data immutability (CSF#3), increasing data security and reliability (CSF#4), and generating (increasing) trust through the disclosure of information (CSF#6) are all important for the pre-construction, construction, and post-construction stages [33]. Full traceability for prefabrication and other construction sources (CSF#5) can ensure authentication by providing linearly chained immutable records with timestamps [66]. The success of this stage also requires enhancing the efficiency of construction progress (CSF#9) to meet the schedule, which can be achieved through effective communication and collaboration between practitioners (CSF#12) and the promotion of information sharing, information accuracy, and information management (CSF#16). During the construction stage, blockchain technology can also be used to improve the reliability (CSF#4) and authenticity of records, such as work performed, materials used, and other information that can be integrated into the BIM model (CSF#10). Additionally, at the end of the construction stage, it is also critical to optimize the salvage value of components reused in their lifecycle (CSF#26), which can help reduce the consumption of energy (CSF#22) and the cost (CSF#8).

Once the project is completed, blockchain technology can play a key role in the post-construction stage as an inherent issue in preparing historical data for construction projects [1,73]. During this stage, to perform transactions like payment or document archive, only private and public keys are required, without the need to reveal any related identity information [74], which also refers to CSF#11 (ability to make transactions anonymously). To ensure that the data are recorded securely in this stage, the blockchain authenticates and authorizes the user's identity (CSF#15). Furthermore, the openness of the ledger structure in blockchain technology (CSF#17) can also make the data environment more transparent to reduce disputes and risks (CSF#18) after construction [38]. After the construction project delivery, supporting different kinds of services (CSF#25) and multiparty maintenance (CSF#30) are also required for the project and clients. Blockchain technology can also offer better security of sensitive information collected during the operation stage, when sensors are deployed to collect various types of data [96] and facilitate data integrity in document management (CSF#20).

5.3. Future research directions

This review study aims to conduct state-of-the-art research on CSFs for implementing blockchain technology in construction, identifying a common set of CSFs, proposing a stage framework, and future research directions. It adopted a "mixed-method approach", comprising a science mapping review (i.e., quantitative approach) and a systematic literature review (i.e., qualitative approach). Based on the science mapping review, the impact of keywords, countries/regions, and documents related to CSFs for blockchain technology in construction were quantitatively analyzed. On the other hand, the systematic literature review reported five common sets of CSFs and a stage framework that shows the list of CSFs for blockchain technology across different lifecycle stages of a construction project.

Following the reported results on the co-occurrence of keywords analysis, and the common set of CSFs, it is therefore crucial to identify and explore relevant future research directions that would extend the research domain in CSFs for blockchain technology in construction. As such, Fig. 6 presents four major future research directions for the successful implementation of blockchain technology in the construction industry. They are (1) digital innovation, (2) smart contracts and information management, (3) intelligent construction, and (4) data analytics methods and techniques.

5.3.1. Digital innovation

Advanced digital technologies, such as building information modeling (BIM), IoT, big data, and digital twins under the concept of Industry 4.0, have potential benefits for construction projects through the application of blockchain technology [5]. Industry 4.0 can enhance industrial development by focusing on transitional factors for environmental conditions and related technologies to assist advancements in automatic industries [74], which can be easier to achieve using digital innovative technologies. Recent advances in BIM have provided new methods for data integration using open data formats, and process mapping [18]. The integration of BIM and blockchain technology can enable more transparent verification and storage of information related to the provenance of physical, digital, and application resources [18]. With features such as computing, communication, and sensing capabilities that are deployed in the field, IoTs have capabilities for sensing physical objects [70]. Zaidi et al. [129] and Yuan et al. [128] found that the combination of blockchain technology with IoT is more verifiable, decentralized, and secure; a reliable database can be established; and a distributed trust of billions of connected physical objects can also be achieved. Furthermore, by combining blockchain, IoT, and BIM, it inherits the merits of permissioned blockchain for supply chain management of modular construction in secure communication, accountable operations, traceable data, transparent information, and reliable knowledge compared with existing IoT-enabled BIM platforms [59,102]. Lu and Zhang [67] explained big data as the storage, management, processing, interpretation, and visualization of large amounts of data. Digital twins allow visualization of the current status of resources (e.g., human, equipment), as well as predicting trends by analyzing the manufacturing context via learned operating behavior patterns [74]. Additionally, Teisserenc and Sepasgozar [104] agreed that blockchain-based digital twins (BCDT) can strengthen information security throughout the lifecycle of projects by recording key project data related to seven BCDT dimensions: spatial (3D), time (4D), cost (5D), maintenance (6D), sustainability (7D), safety (8D), and contractual (cD). These advanced digital technologies can bring further progress after combining them with blockchain technology. In future work, blockchain scalability and performance, as well as its integration into the construction sector, should be analyzed and optimized by combining it with existing digital innovations. Moreover, cloud interactions should be improved and harmonized with BIM, IoT, digital twins, and other innovations to boost blockchain usage in the construction sector.

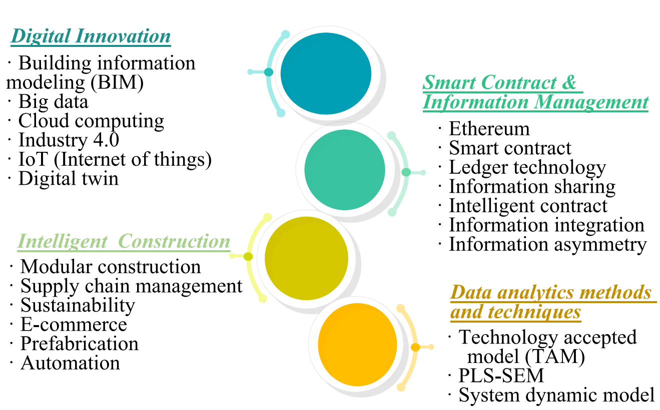

Fig. 6. Future research directions of CSFs for implementing blockchain technology in the construction industry.

5.3.2. Smart contracts and information management

Smart contracts are computerized transaction protocols that execute the terms of a contract [110]. It provides tools for improving a wide range of processes, automating them, and ultimately, making them more successful. Because of these properties, blockchain and smart contracts have been used in many complex industries, such as medical, energy, and insurance, as well as construction [43]. Some of these platforms (e.g., Ethereum) have been developed for the successful execution of smart contracts. Yang et al. [124] defined Ethereum as a generic blockchain platform (permissionless, public, and private), which can enable users to execute smart contracts more efficiently and develop cryptocurrency-related applications. The usage of smart contracts can also be combined with distributed ledger technology (DLT), and a digital execution plan (i.e., BIM), which can be deployed to automate some aspects of traditional contract clauses.

Several studies have reported that blockchain technology is beneficial for information management. For instance, Lee et al. [52], Wu et al. [119], Jiang et al. [45], and Wan et al. [111] reported that blockchain technology has had a positive effect on information sharing among stakeholders by providing an immutable digital footprint to all members in a network. The positive effect can add value to enhancing collaborative work in different types of supply chains, such as health and medical, construction, and smart cities. Bakhtiarizadeh et al. [12] and Yang et al. [124] emphasized blockchain as a secure information integration instrument that will bring numerous benefits, including reducing the high level of fragmentation of construction supply chains, decentralized data storage, reducing project time, improving scalability, and ensuring transparent, traceable, and accountable data storage and sharing. Blockchain technology can mitigate information asymmetry by distributing information to generate decentralized consensus building among various stakeholders involved and enhance trust between project participants [97]. In the future, optimization of the developed smart contracts can focus on the reduction of transaction costs [110], supplementing legislation and regulation governing smart contracts from a legal standpoint [97], and improving scalability in blockchain networks to enable faster transactions. In addition, information sharing with selective stakeholders should be part of future research directions in information management [111]. Moreover, future studies should consider improving the security and privacy of information when combining different types of innovative technologies.

5.3.3. Intelligent construction

Blockchain technology has potential applications in intelligent construction management, such as in modular construction [66], supply chain management [29,40,87], sustainability [45,55,60], e-Commerce [64], and prefabrication [11,12]. Construction project management requires several techniques to support the continual exchange of information across disciplines [18]. Lee et al. [52] discussed the impacts of information sharing among stakeholders in modular construction, which can reduce cost and improve safety, sustainability, productivity, and quality. Nabeeh et al. [74] and Teisserenc and Sepasgozar [103] argued that the implementation of blockchain technology for digital twins can achieve sustainability in the construction industry. Blockchain technology can offer integration in prefabrication and provide a secure decentralized database [112]. Additionally, the application of blockchain technology in supply chains has attracted the interest of various researchers. Amiri Ara et al. [6] identified a new blockchain system to reduce cost inefficiencies by 12.4% and operation lead-times by 36.5%. Qian and Papadonikolaki [84] used blockchain technology to estimate the product lifecycle by integrating products and services in an interconnected process. Blockchain technology also provides stakeholders with a traceable, transparent, effective, and reliable supply chain [11,12]. Solutions to reduce the cost of adopting blockchain technology in the construction supply chain can be the focus of future studies. Furthermore, the standards and interoperability of blockchain technology in the construction industry should also be further explored.

5.3.4. Data analytics methods and techniques

With regard to advanced digital technology in each industry, it is essential to understand the determinants of blockchain technology. In recent years, the technology acceptance model (TAM) has been widely used to understand the acceptance behavior of information technology. It is a conceptual model proposed by Davis in 1989, based on the theory of rational behavior (TRA) to study users' acceptance of information systems. It was initially proposed to explain the decisive factors of widespread acceptance of computers [116]. TAM has provided effective research methods to demonstrate the adoption of innovative technology. It can help businesses and organizations anticipate how users will respond to new technologies, make informed decisions about product development and marketing strategies, and be applied to a wide range of technologies. Additionally, partial least squares-structural equation modeling (PLS-SEM) is a method to assess the linear relationships and configuration effects of the variables, and not only contains both formative and reactive variables but is also a complex model consisting of latent variables; hence, the PLS-SEM method is well suited for this exploratory study [23]. Moreover, the system dynamic modeling approach (i.e., computer simulation model), which was proposed by Forrester in 1971, can also be used to analyze the relationships between the identified CSFs for implementing blockchain technology. The system dynamic modeling approach is particularly useful for examining the dynamic characteristics of systems, and their overall behaviors through interactions between the elements involved [126]. With the identified CSFs for implementing blockchain technology, a conceptual model (i.e., a causal loop diagram or the stock-flow diagram) should be developed to illustrate how these factors are interconnected within the lifecycle stages of a project. Subsequently, the validity and reliability of the developed conceptual model should be tested in real-world settings. Next, the process of model simulation and scenario analysis can be conducted by using the Vensim software package [127]. Taken together, it is recommended that a conceptual model should be developed, hypothesized, and validated in future research based on the identified CSFs, thus enabling their impact on practical application and influence of government policies.

5.4. Study implications, limitations, and further studies

The implementation of blockchain technology in the construction industry could be successful by identifying the CSFs needed for its adoption by practitioners, researchers, policymakers, etc. Undoubtedly, blockchain technology plays a significant role in the construction industry in embracing advanced digital innovation and transformation. Consequently, this review study was conducted to identify a common set of CSFs, develop a stage framework, and propose future research directions for implementing blockchain technology in the construction industry. The results reported five common sets of CSFs, a stage framework showing how the identified CSFs could be implemented in different lifecycle stages of a project and recommended four future research directions. The following sections discuss the theoretical and practical implications, limitations, and further studies.

5.4.1. Theoretical implications

This review study will encourage researchers to explore deeper applications of blockchain technology. Some of the theoretical implications of CSFs for blockchain technology include (1) data integrity, (2) cost reduction, and (3) scalability optimization.

First, the immutability of blockchain technology makes it an ideal platform for maintaining the integrity of research data. Researchers can create a tamper-proof system that ensures the authenticity of data and prevents data manipulation through blockchain. Researchers can also focus on hashing, a cryptographic process that converts any data into a unique and fixed-length string of characters. Blockchain technology uses hashing to ensure data integrity. However, in the case of tempering, the hash of the block changes, making it easy to detect any fraudulent activity. The protection of hashing can also be a part of future research.

Second, blockchain technology can hone the efficiency and effectiveness of construction projects, but the cost of blockchain technology reduction should not be overlooked. Since blockchain technology is still in its infancy, the cost of installation, implementation, integration, maintenance, and training are still high. Therefore, future studies could investigate how to optimize this cost and achieve value in the implementation of blockchain technology, such as by utilizing open-source software and collaborating with other companies.

Third, with the addition of nodes in the blockchain network, the time that the blockchain validates each transaction will also increase, leading to slower transaction processing times. The system can become congested and slow, resulting in longer confirmation times and higher transaction fees. Consequently, researchers can focus on optimizing scalability. For example, improvements in consensus algorithms can be part of future research.

5.4.2. Practical implications

This study has significant practical implications for the construction industry, especially from three key aspects: (1) implications for supply chain management, (2) implications for re-skilling and updating, and (3) implications for information efficiency.

First, the adoption of blockchain technology with its CSFs has implications for supply chain management, especially because transparency, security, and traceability characteristics can provide a single source of truth for all transactions, making it easier to track and trace materials and supplies throughout the supply chain. The construction industry should streamline payment processes by using blockchain technology. Payment processes can be automated, reducing the need for manual intervention and improving payment duration and accuracy. Smart contracts can be used to automatically release payments once certain conditions are met, such as the delivery of materials to the construction site. Furthermore, the construction industry should also improve inventory management by using blockchain technology, which can provide real-time visibility into inventory levels and locations. This would enable construction companies to better manage their inventories and avoid delays due to shortages or overstocking.

Second, the adoption of blockchain technology in the construction industry also has skills and updating implications for employees and stakeholders. Blockchain technology brings about frequent interactions between employees and machines, thus necessitating the need for workers to develop new skills or update existing skills to adapt to new roles. Additionally, with the integration of blockchain technology with other existing systems, employees should also learn and update their related skills. Consequently, construction companies are responsible for providing learning organizations to help employees understand the principle that blockchain technology affects their roles and responsibilities. Construction companies should also redefine their employees' job roles. The adoption of blockchain technology may change how certain tasks are carried out in the construction industry. Since blockchain technology relies on secure and immutable data storage, construction companies should emphasize the importance of data security to their employees and provide training on how to handle sensitive information securely.

Third, blockchain technology has a significant impact on information efficiency due to collaboration. Construction companies can develop blockchain-based platforms that allow different parties to access and share information securely. These platforms can be used to store project plans, contracts, invoices, and other relevant information. Furthermore, to ensure that all parties are comfortable using the blockchain platform, construction companies should provide training and support. This includes training sessions, tutorials, and technical support. Construction companies can also use smart contract-based blockchain technology to automate payment processes, track project milestones, and manage the delivery of materials to improve the information efficiency of construction progress.

5.4.3. Limitations and further studies

Like other reviews, this review study has some limitations. First, it may exclude some of the latest studies published after March 2023 and other relevant studies published in conference proceedings. Therefore, future studies should include conference articles and recently published articles. Second, the included articles were only retrieved from top-tier peer-reviewed journals in the Scopus database. As such, the findings of this review study cannot be generalized to other disciplines like medicine, automobile, etc. Future studies should include other peer-reviewed journal articles published in databases such as Web of Science, Science Direct, PubMed, etc.

6. Conclusions

Although the current state of blockchain technology has been discussed in the extant literature, there is no state-of-the-art research of CSFs for blockchain technology in the construction industry that summarizes a common set of CSFs to provide implications and directions for both practice and theory. The current review study aims to develop a stage framework and identify a common set of CSFs for successful blockchain technology implementation in the construction industry by analyzing research articles from 2019 to 2023 (years inclusive). By adopting a systematic literature review and science mapping review, the Scopus database was used to retrieve 78 relevant articles that were analyzed in this study.

It was found that, over the past five years, there has been a significant increase in publications on CSFs for blockchain technology in the construction industry, especially since 2022. In peer-reviewed journal analyses, most of the research articles have been published in *Buildings, Automation in Construction,* and *IEEE Access.* The co-occurrence of keyword analysis revealed mainstream topics within this domain, including smart contracts, Industry 4.0, IoTs, supply chain management, modular construction, and smart contracts. Among various countries/regions, China made the greatest contribution by publishing most related articles. The number of articles published in developed countries like the USA, Australia, and the UK, also accounted for a large proportion. In addition, the most influential articles on the studied domain were found to be related to supply chain management and information technologies (e.g., BIM, IoTs). The key findings proposed 22 CSFs for successful implementation of blockchain technology, while the five common sets of the most frequently occurred/cited CSFs were discussed. These include (1) decentralized system (protocol), (2) transparency in data information for construction lifecycle processes, (3) ensuring data immutability, (4) increasing data security and reliability, and (5) providing full traceability of prefabrication and other construction sources. This study also evaluated the CSFs across three major lifecycle stages of construction projects. This review also highlights and discusses four future research directions: (1) digital innovation, (2) smart contracts and information management, (3) intelligent construction, and (4) data analytics methods and techniques. The findings are expected to provide a useful reference for scholars and practitioners to understand research trends and the development of blockchain technology implementation and to further deepen their understanding of CSFs in construction project applications.

This review study contributes to both theory and practice. From a theoretical perspective, researchers should focus on the security of data and the protection of hashing. Furthermore, the reduction of the total cost of the blockchain technology should be investigated. Moreover, the optimization of blockchain scalability can be a part of future research. From practical contributions, the construction industry should streamline payment processes with blockchain technology to automate the transaction process, reduce the need for manual intervention, and improve payment duration and accuracy. Employees should develop new skills or update their existing skills to adapt to new roles under the guidance of the construction industry. Additionally, construction companies can develop blockchain-based platforms that allow different parties to securely access and share information.

Declaration of Competing Interest

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

Data availability

The datasets used in this study are available from the corresponding author upon request.

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