International Journal of Applied Logistics
Volume 13 • Issue 1

Blockchain Applications in Digital Construction Supply Chains

Chen Wang, Huaqiao University, China
Benben Cui, Huaqiao University, China*
Yutong Tang, Huaqiao University, China

ABSTRACT

This article takes the relevant construction supply chain (CSC) literature of the Web of Science Core Collection Database in the past 20 years and its construction supply chain - blockchain as the object, and then aims to identify and analyze the articles related to the application of blockchain technology in the CSC, and analyze the related problems and potential of the CSC in the application of blockchain technology. An analysis and exploration of a total of 395 articles was conducted. Through VOS viewer software, the author in collaboration network, key term co-occurrence network, and theme classification visualization network of the research field are extracted. The research status of blockchain technology in the CSC is analyzed, and the two key issues of the CSC are focused on through literature reading, so as to explore the application prospects of blockchain technology, and make relevant discussions and some application prospects for the application of blockchain technology in the future.

KEYWORDS

blockchain, collaboration, information sharing, integration, visualization map

1. INTRODUCTION

The construction industry is one of the largest in the world, accounting for 13% of the world's total gross domestic product (GDP) and 7% of the world's total employment population (Barbosa, Woetzel, & Mischke, 2017). With artificial intelligence (AI), Internet of Things (IoT), virtual reality (VR), geographic information systems (GIS), digital photogrammetry, building information modelling (BIM), 3D printing, laser scanning, global positioning system (GPS), radio frequency identification physical equipment (RFID), augmented reality (AR) sensors, robotics, big data management and a series of new and more mature digital (Bhattacharyya, Maitra, & Deb, 2021; Wang, Wang, Sepasgozar, & Zlatanova, 2020)the level of uniformization in the construction industry has been continuously improved, and the way information is shared in the CSC has also changed.

DOI: 10.4018/IJAL.322098 *Corresponding Author

The CSC is the means of delivering a construction project to the i.e., the project owner. It comprises a supply chain of materials, labor, and equipment involving multiple stakeholders, such as owners, general contractors (GCs), subcontractors, and various suppliers (Balasubramanian & Shukla, 2018; Butkovic, Kauric, & Mikulic, 2016; Fischer, Ashcraft, Reed, & Khanzode, 2017). Involves multi-stakeholder integration of supply chain processes, exchange of information and collaboration (J. C. Cheng, Law, Bjornsson, Jones, & Sriram, 2010; Fearne & Fowler, 2006; Hao, Du, Huang, Shao, & Yan, 2019). As a result, these lead to some of the problems in the CSC of the CSC, such as inefficient logistics and inventory management, extended delivery times, wasted resources and processes, product out-of-specs, and conflicts among stakeholders. At this stage, the BIM collaborative management cloud platform can provide an information platform for cross-departmental data integration and collaborative sharing in the project CSC involving owners, designers, contractors and other participants, such as Li et al. (C. Z. Li, Xue, Li, Hong, & Shen, 2018; G. Xu, Li, Chen, & Wei, 2018; Zhai et al., 2019; Zhong et al., 2017)co-developed a practical cloud platform for microcontrollers in prefabricated buildings by adopting building information modeling (BIM) and the Internet of Things (IoT). These multidimensional IoT-BIM platforms can help collect real-time data to improve visibility and traceability of production, logistics, and on-site installations. Different stakeholders can then track the cost and progress of the project (C. Z. Li et al., 2021)which greatly improves the efficiency of information sharing. However, there are some problems with the promotion process of cloud platforms. Building Information Modeling (BIM) is difficult to achieve real-time improvements in the Internet of Things (IoT) when it comes to making changes (Xue & Lu, 2020). Random errors, noise, or malicious data generated by IoT sensors can lead to a single point of failure in IoT networks, degrading the data quality of BIM, and negatively impacting the trustworthiness of IoT BIM (Lee, Lee, Masoud, Krishnan, & Li, 2021). The lack of an information security system seriously hinders the sharing of information between all parties. Data privacy, trust, and intellectual property are key issues in the digital transformation of the construction industry (Ahmed, Tezel, Aziz, & Sibley, 2017; Sadeghi, Wachsmann, & Waidner, 2015). A secure information assurance system and a trusting approach to information exchange help improve the efficiency of information sharing within the building supply chain and ensure the achievement of overall project performance objectives. As a result, blockchain technology has attracted the attention of practitioners and researchers as a solution to the drawbacks of existing information sharing in the construction industry.

Blockchain is a peer-to-peer (P2P) distributed data structure that cryptographically and securely stores a series of data information into the blockchain in chronological order (J. Li, Greenwood, & Kassem, 2019). Blockchain was introduced in 2008 in a white paper on Bitcoin, the world's first cryptocurrency, proposed by Satoshi Nakamoto (Nakamoto, 2008). Yoo (Yoo, 2017)argues that blockchain is an encrypted digital distributed ledger technology that is stored in public or private networks on many computers, allowing participants in the network to exchange various transaction data between them. This distributed database maintains an ever-growing list of information records in a decentralized manner, with each list on the network storing a copy of the chain and using a consensus mechanism to verify transactions to ensure the immutability of the chain, forming blocks that prevent tampering and adjustment (Bashir, 2017; Duan, Zhang, Gong, Brown, & Li, 2020; Nakamoto, 2008). Services and application platforms built through blockchain technology can be divided into public blockchains, private blockchains, and public-private consortium blockchains according to the level of accessibility(Al Barghuthi, Ncube, & Said, 2019; Corbet, Lucey, & Yarovaya, 2018; Mensi, Al-Yahyaee, & Kang, 2019; Oh & Shong, 2017; Scully & Höbig, 2019). Through these services and platforms, key product dimensions can be highlighted and detailed: nature, quality, quantity, location, and ownership (Saberi, Kouhizadeh, Sarkis, & Shen, 2019). Based on these characteristics, blockchain applications can at least play a role in reducing costs, accelerating the digitization of physical processes, increasing reliability, reducing risk, and enhancing sustainability in terms of chain management (Kshetri, 2018). For example: Turk and Klinc (Turk & Klinc, 2017)have studied the potential of blockchain technology in building information management, arguing that blockchain can improve the reliability and credibility of construction logs, the work performed and the number of materials recorded. In addition, the study shows that blockchain technology can also provide secure storage of privacy-sensitive sensor data during the facility maintenance phase (Turk & Klinc, 2017). Wang et (Z. Wang et al., 2020)has developed a blockchain-based information management framework for the supply chain of prefabricated construction projects that can improve the timely delivery of prefabricated components and enable stakeholders to track the cause of disputes in the supply chain. Xiong et al. (Xiong, Xiao, Ren, Zheng, & Jiang, 2019) A blockchain-based framework for information sharing in the building supply chain is proposed to eliminate intermediaries in transactions and enhance the security of transactions by designing private key distribution protocols. Both the above research and industry cases demonstrate the potential application value of blockchain in CSC management. Therefore, the purpose of this paper is to grasp the application status of blockchain technology in the building supply chain through the method of literature review, scientifically and quantitatively summarize and analyze the development of the green model of the building supply chain, determine the current technical level and examine the future challenges and opportunities. Explore new solutions that building supply chain management offers through blockchain technology and how these solutions can be adopted to improve performance, sustainability, and safety in the future. The structure of this article is as follows: Section 1 is the introduction, followed by section 2 Research Methods, and Part 3 Bibliometric Analysis. Parts 4 and 5 are an analytical discussion of the application of blockchain technology in the CSC. Section 5 is the conclusion and related outlook of the analysis of the application of blockchain technology.

2. RESEARCH METHODS

The overall methodological stance adopted for this study is a mixed philosophical stance of hermeneuticist and (Al-Saeed, Edwards, & Scaysbrook, 2020; Roberts, Pärn, Edwards, & Aigbavboa, 2018; Smith et al., 2021; Spellacy, Edwards, Roberts, Hayhow, & Shelbourn, 2020)systematically analyzing existing literature using a scientific metrology method using existing literature as a valuable data source (Aghimien et al., 2021; Chamberlain, Edwards, Lai, & Thwala, 2019; Edwards et al., 2021; Nazir et al., 2020). Reduce the potential impact of researcher bias by applying quantitative and qualitative data analysis methods (Bryman, 2016; Saunders, Lewis, & Thornhill, 2019). This paper provides a systematic review of literature through the visual exploration of VOSviewer software and the ability to create bibliometric networks (Van Eck & Waltman, 2020).

2.1 Database Selection

As a comprehensive academic information resource database, WOS Core Collection Database includes more than 12,000 authoritative and influential academic journals in the field, with strong academic representation. Therefore, the WOS Core Collections Database was chosen as the source of literature to investigate trends through a preliminary review of the WOS Database.

2.2 Search Rules and Control Criteria

1) The target literature was selected as an English paper published in the past 20 years.
2) Further cleaning and filtering of the sample is required to ensure that only relevant items are included in subsequent analyses. Apply specific criteria (including paper type, language, year, and journal) to filter search results and find the latest papers related to compatibility. That is: (ALL (“Blockchain”) AND ALL (“Construction Supply Chain”)) AND (EXCLUDE (DOCTYPE, “cp”)) AND (EXCLUDE (LANGUAGE, “German”) OR EXCLUDE (LANGUAGE, “Chinese”)) or exclude(language, “Lithuanian”) or exclude(language, “Portuguese”)).
3) In order to avoid differences between different research directions, the index journals are limited to journals related to the construction industry. For example: Journal of Architectural

Engineering and Management, Engineering Construction and Construction Management, Building Automation, etc.

Through the preliminary search of the WOS core collection database, 395 papers related to the CSC were retrieved, constituting the CSC literature. Figure 1 shows the distribution of papers in the journals searched. The further addition of the qualifier blockchain results in only 17 documents constituting the relevant building supply chain — blockchain literature,See Table 1 for details.

2.3. VOSviewer Software Visual Co-Occurrence Analysis

Contribution analysis of the CSC is carried out using a preliminary search database. A co-occurrence analysis of keywords was created using the titles and abstracts of the literature to understand the main keywords and topics used in the supply chain of the sample building. A co-author network is conducted using a complete counting method to showcase authors who contribute to the CSC. Since these analytical analyses do not provide insight into the literature, and since the application of blockchain technology in the construction industry is in its infancy, a content analysis is also carried out at the end.

3. RESULTS

Figure 2 shows a co-occurrence analysis graph of keywords created using the database literature from the preliminary search. The size of the node indicates the number of publications that contain these keywords, and the larger the number, so the larger the node, the larger the body of knowledge in the field. Different colors indicate the number of years the institute is in. Through the difference in color, we find that blockchain technology appears in a corner of the upper left corner of Figure 2 as the latest technology applied to the CSC. The application of blockchain technology as an emerging technology in the CSC is still in the exploratory stage, and there is a lack of relevant research.

Figure 3 shows a network of co-authors created using the full count method, which takes into account the weight of each co-author to the paper as "1". Therefore, the total weight of the article will be equal to the number of authors of the article (Perianes-Rodriguez, Waltman, & Van Eck, 2016) .

Figure 1.
Map of article distribution in the construction supply chain based on selected journals

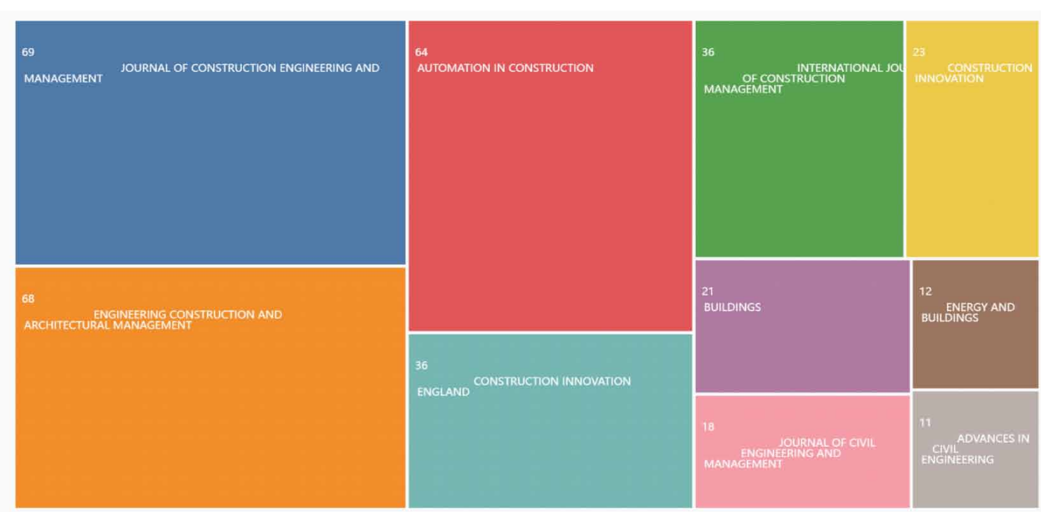


Table 1.
On the construction supply chain – blockchain journal search and results

Journal name	Thesis title
AUTOMATION IN CONSTRUCTION	Blockchain in the AECO industry: Current status, key topics, and future research agenda(Y. Xu, Chong, & Chi, 2022) Applications of distributed ledger technology (DLT) and Blockchain-enabled smart contracts in construction (J. Li & Kassem, 2021) Exploratory literature review of blockchain in the construction industry(Scott, Broyd, & Ma, 2021) Exploring smart construction objects as blockchain oracles in construction supply chain management (Lu et al., 2021) The application of blockchain-based crypto assets for integrating the physical and financial supply chains in the construction & engineering industry (Hamledari & Fischer, 2021) Blockchain-based framework for improving supply chain traceability and information sharing in precast construction (Z. Wang et al., 2020)
BUILDINGS	Exploring the Barriers against Using Cryptocurrencies in Managing Construction Supply Chain Processes (Gurgun, Genc, Koc, & Arditi, 2022) Blockchain and Information Integration: Applications in New Zealand's Prefabrication Supply Chain (Bakhtiarizadeh, Shahzad, Poshdar, Khalfan, & Rotimi, 2021) When Blockchain Meets the AEC Industry: Present Status, Benefits, Challenges, and Future Research Opportunities (M. Cheng, Liu, Xu, & Chi, 2021) Potential Application of Blockchain Technology for Embodied Carbon Estimating in Construction Supply Chains (M. N. N. Rodrigo, Perera, Senaratne, & Jin, 2020)
JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT	Blockchain-Enabled IoT-BIM Platform for Supply Chain Management in Modular Construction (X. Li et al., 2022) State-of-the-Art Review of Blockchain-Enabled Construction Supply Chain (Yoon, Pishdad-Bozorgi, & management, 2022) Rationale for the Integration of BIM and Blockchain for the Construction Supply Chain Data Delivery: A Systematic literature Review and Validation through Focus Group(Hijazi, Perera, Calheiros, & Alashwal, 2021)
ENGINEERING CONSTRUCTION AND ARCHITECTURAL MANAGEMENT	(M. Rodrigo, Perera, Senaratne, & Jin, 2021) Shifting trust in construction supply chains through blockchain technology (Qian & Papadonikolaki, 2020)
FRONTIERS IN BUILT ENVIRONMENT	Blockchain in Civil Engineering, Architecture and Construction Industry: State of the Art, Evolution, Challenges and Opportunities (Plevris, Lagaros, & Zeytinci)
INTERNATIONAL JOURNAL OF CONSTRUCTION MANAGEMENT	Exploring Blockchain-enabled smart contracts technology implementation within ready-mixed concrete plants industry in Saudi Arabia(Azmi, Sweis, Sweis, & Sammour, 2022)

Each circle in Figure 3 represents an author whose diameter size is equal to the number of publications of corresponding authors indexed in WOS. The approximate strength of a co-author link between corresponding authors is expressed by the distance between the two circles. Colors such as green or yellow indicate clusters of authors with strong co-author links. Figure 3 shows that there are 160 co-authors in the literature, with a minimum of 1. This clearly shows that there are many co-author sets that are not related to each other and that different subdomains may be studied in the literature.

3.1 Literature Exploration and Analysis

In order to further explore the application prospects of blockchain technology in the CSC, we will conduct a detailed review of the searched construction supply chain and construction supply chain- blockchain literature, and explore the role of blockchain technology in promoting the CSC in combination with other relevant research on blockchain technology. First of all, in order to identify the

Figure 2.
Keyword co-occurrence analysis graph created using literature analysis. Note: The minimum number of co-occurrences for keywords is 3. The network includes 1544 keywords

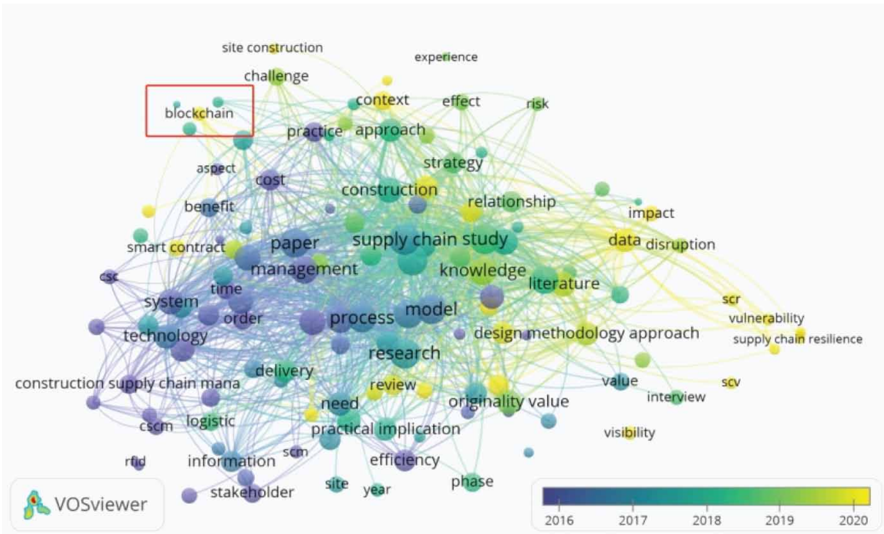
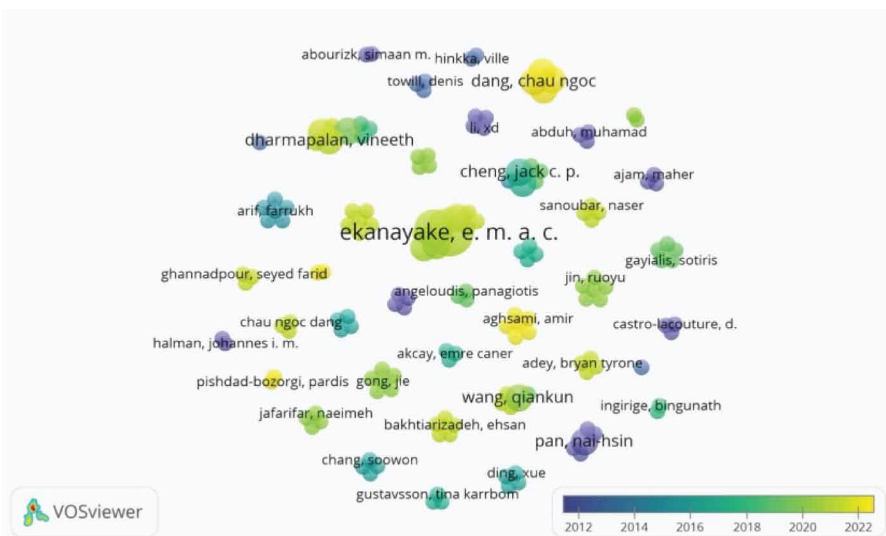


Figure 3.
Visualizes a network of 330 co-authors using the full count method. Note: The minimum number of articles published by the author is 1



key issues in the CSC, based on the searched CSC literature, we reviewed the abstracts and keywords of each article from 2010 to mid-2022, identified some high-frequency issues of CSC, sorted out the problems faced by the CSC, and integrated some characteristics of the CSC (see Table 2 for details). The most important issues in the CSC at present involve multi-stakeholder collaboration and integration, information sharing, green supply chain management and sustainability, etc. which are also partially reflected in the keyword co-occurrence analysis chart. Based on the advantages

Table 2.
Characteristics of the CSC in terms of organizational relationships, lead core, product characteristics, information flow, process management, supplier management, etc

Project	Construction supply chain
Organizational relationships	Multilateral two-way cross-network relationship, the supply chain is more complex, coordination is more difficult
Dominate the core of the supply chain	Dual leading core: the service core led by the owner, and the construction core led by the general contractor
Product features	Mainly to provide services, multi-single piece customization, temporary, rework is difficult, high cost
Information flow	The information is complex and large, and it needs two-way feedback, long-term preservation and sharing, and the organizations on the supply chain must provide information and use the information of multiple organizations on the chain, and the level of informatization is low
Process management	The chain is closely connected, the mutual influence is large, there are many hidden projects, process management is more important, and the construction period and quality and safety management are difficult
Vendor relationships	Supplier selection is carried out after undertaking the project, and the process may be changed at any time; the supplier relationship is unstable, discrete, and lack of mutual trust

of blockchain technology, we will focus on the two aspects of multi-stakeholder collaboration and integration and information sharing in the CSC

3.2 Collaboration and Integration

Collaboration and integration between different stakeholders in the CSC plays a vital role in green supply chain management (GSCM) and sustainable processes in the CSC. GSCM and sustainable processes are designed to reduce environmental damage to the construction industry. The net green outcome of a building project is the sum of the efforts of different stakeholders at all stages of the supply chain, from initial design to finish of-life demolition, and the GSCM approach was seen as a way to streamline the decentralization efforts of the green sector. In the GSCM process, focus is on green innovation, operation, evaluation and decision-making.

Some (Guo, Yu, & Gen, 2020; Long, Liu, Li, Chen, & Health, 2020; Yin, Li, & Xing, 2019; Zhu, Fang, Shi, Wang, & Li, 2018)supply chain processes by leveraging an evolutionary game approach to explore the impact of different stakeholders in the CSC, promoting shared values and incentives. In particular, governments play a vital role in the green transformation of the building supply chain, and collaboration and integration among other stakeholders can be fostered through government incentives and penalties. Collaboration and integration between different stakeholders (Akan, Dhavale, & Sarkis, 2017; Balasubramanian & Shukla, 2018; Dallasega & Rauch, 2017; Du et al., 2019; Gaur & Vazquez-Brust, 2019; Jiang, Lu, & Xu, 2019)helps to effectively implement GSCM and enhance sustainability in the CSC. Long-term collaborative collaboration among stakeholders in the CSC can significantly reduce emissions and improve the economic performance of the supply chain (Du et al., 2019; Jiang et al., 2019). The economic performance generated by working together to reduce emissions will create a positive and reinforcing cycle that continuously improves the sustainability of CSCs if they can be linked to shared values and incentives to improve sustainable processes. Long-term partnerships can better leverage the performance of proactive management in terms of clearly defined roles, initiative in project planning, regular performance measurement, and problem early warning (Meng, 2020). Collaboration in the supply chain enables stakeholders to identify root causes and solutions for rework and defects (Taggart, Koskela, & Rooke, 2014). Abedi et al. (Abedi, Rawai, Fathi, & Mirasa, 2014)leverages cloud computing technology to mitigate poor planning and scheduling, reduced design flexibility, long production lead times, problems such as heavy prefabricated components, and poor coordination in the field. Or facilitate collaboration by developing an information-sharing system (Isatto, Azambuja, & Formoso, 2015; London & Singh, 2013)to improve supply chain planning and management (Abedi et al., 2014).

3.3 Information Sharing

The sharing of information is also critical to reducing emissions and improving the sustainability of CSCs (Akan et al., 2017; Karlsson, Rootzén, & Johnsson, 2020; Kim, Woo, Rho, & Chung, 2016). The construction industry has long been plagued by the problem of information silos, lacking effective communication. The reason for the information island is that the construction project involves numerous participants, there are various information transactions, and there is not a full understanding between the different project participants. Therefore, there is a large number of information asymmetries in the entire large construction market environment. In the entire CSC management process, each participant cannot fully provide the information they have, and the participants will choose to hide the real information for their own interests, and even cover up the information that is unfavorable to themselves out of private interests. In addition, in addition to the participation in the main body of their own information asymmetry, information in the transmission process will gradually produce deviations, the supply chain of node enterprises often according to the adjacent upstream enterprises to implement the company's plan, due to the continuous distortion of information in the transmission process, downstream enterprises cannot grasp the real effective information, usually resulting in inconsistent with the requirements of upstream enterprises, which exacerbates the difficulty of information sharing in the CSC.

If information transparency can be enhanced, information flow can be effectively tracked, and participants' trust can be increased to fundamentally solve the problem of information silos, so as to determine a feasible GSCM solution. It will reduce emissions and enhance sustainability. In terms of reasonable incentives and punishments that can promote business cooperation and information sharing in the supply chain (Hao et al., 2019)mutual trust among stakeholders in the CSC is essential. A reliable communication platform can facilitate knowledge sharing among stakeholders. The decentralized nature of CSCs presents the challenge of sharing knowledge (Saini, Arif, & Kulonda, 2019). The main challenge is the traditional way of working with construction organizations. Challenges and obstacles are divided into technical, coordination, integration and organizational issues. Management factors, such as coordination and organizational issues, rather than technological development issues, are the main reasons for the excessive implementation period of information exchange. Reasonable rewards and punishments can stimulate stakeholder interest in sharing knowledge, thereby enhancing trust among stakeholders (Hao et al., 2019). While these studies can demonstrate that the main barriers to sharing tacit knowledge within the CSC are traditional methods and management factors that work in construction organizations, including coordination and organizational deficiencies. Despite these valuable findings, governance systems that provide reasonable rewards and punishments have not been studied. In addition, there is a lack of research on how to overcome the serious obstacles caused by traditional organizational structures.

3.4 Advantages of Applying Blockchain Technology in the CSC

Blockchain is a distributed ledger (J. Li et al., 2019)that mathematically stores blocks of data, coding and linking on multiple nodes(Abeyratne, Monfared, & Technology, 2016; Pala, Edum-Fotwe, Ruikar, Peters, & Doughty, 2016; Saini et al., 2019; Samaniego, Jamsrandorj, & Deters, 2016)to improve data security (Watanabe et al., 2015), traceability and transparency (Badzar, 2016; Tian, 2016). The technology provides a transparent, time-stamped chain of responsibility that enables authentication of products, services, transactions, documents (certificates) and information. At the heart of blockchain technology is the joint maintenance of transactions and databases by all currently participating nodes, making transactions based on cryptographic principles rather than trust. Technically, a block is a data structure that records transactions, mainly including two parts: the block head and the block body. The block body is mainly used to record transaction information, record all the computing nodes participating in the transaction on the main chain or part of the main chain, and then the transaction data is hashed to obtain the Merkel tree root value of the block body. In addition, blockchains allow for smooth data transfer, and for public blockchains, for the AEC industry data interoperability between different applications can be achieved. Blockchain makes shared data immutable and traceable. In addition, smart contracts enable construction stakeholders to establish digital rules or contracts using data stored in a blockchain network. By leveraging these two key advantages that differentiate blockchain technology from other IT technologies, the construction industry will be able to enhance sustainability and facilitate collaboration and information sharing in the supply chain (Betti, Khoury, Hallé, & Montreuil, 2019; Longo, Nicoletti, Padovano, d'Atri, & Forte, 2019; Zhang et al., 2020). Blockchain technology creates true sharing, which will eliminate the need for value generated between service providers and purchasers by third-party middlemen and middlemen. As a result, blockchain can help streamline procurement and payment processes and optimize the flow of materials, enhance trust between stakeholders, and create truly open purchasing arrangements based on accounting, which is necessary for collaboration and certification in the industry. In addition, the CSC has been committed to the application of various information technologies, such as cloud-based information sharing systems, to promote supply chain collaboration and information sharing. While these technologies can provide an effective platform for information sharing and management, they are not yet fully effective in enhancing sustainability and facilitating collaboration and information sharing. Lack of trust in data prevents stakeholders from collaborating and sharing information. In addition, since the data is not trustworthy, it cannot be used as a basis for implementing smart contracts to monitor and reward mutually agreed efforts to enhance sustainability and collaboration. Blockchain makes shared data immutable and traceable. In addition, smart contracts enable construction stakeholders to establish digital rules or contracts using data stored in a blockchain network. The benefits of tamper-proof and traceable information sharing and smart contracts can also enhance collaboration in the supply chain. Data authenticity, integrity, and traceability in blockchain promote trust among stakeholders such as systems and cognition-based trust (Qian & Papadonikolaki, 2020)and fast trust(Dubey, Gunasekaran, Bryde, Dwivedi, & Papadopoulos, 2020).

3.5 Disadvantages of Applying Blockchain Technology in CSCs

From the cognitive side of blockchain, since blockchain has a public chain and a private chain, the full potential of blockchain can only be achieved through public blockchain, because private blockchain is not much different from distributed databases in terms of data security (Tezel, Papadonikolaki, Yitmen, & Hilletofth, 2020). How to weigh the use of public chains and private chains requires a wise comparative analysis of the business types of the blockchain, so the advantages and disadvantages of the public chain and the private chain in the blockchain should be correctly communicated to the managers of the participating entities on the CSC. Managers in the current supply chain lack the motivation to use blockchain technology, and even if they adopt it, it is more to control the application of the blockchain than to improve the efficiency of transactions between all parties. From the performance point of view, the technical level of the blockchain has not yet reached a certain height, the number of transactions that can be processed per second on the blockchain is limited, and with the continuous advancement of construction projects, a large amount of transaction data will be generated in the supply chain, which will produce a series of performance problems. In addition, in the AEC industry, there are no substantial example use cases in blockchain-based asset tokenization, SCM, and procurement (Tezel et al., 2020). In addition, the development of blockchain technology has not yet formed a good interaction with the laws, regulations and management methods related to construction projects, and the lack of blockchain-based governance frameworks and mechanisms in the construction industry will affect the operability of the technology in the CSC.

4. DISCUSSION AND CONCLUSION

In the process of transformation and upgrading of the construction industry, it is necessary to promote the sharing of information in the CSC. Blockchain technology can enhance information sharing, and blockchain can improve supply chain transparency, ensuring information sharing and thus increasing trust among stakeholders. In addition to the collaboration and integration and information sharing presented in this article, the two core issues of the building supply chain, blockchain applications can potentially solve and improve other problems in the CSC: (1) green supply chain management and co-ownership Continuity, (2) tracking of material logistics, and (3) counterfeiting of information, etc. But in this article, we mainly analyze the two problems of collaboration and integration and information sharing, and analyze the potential of blockchain technology to solve problems. Blockchain technology because of its decentralized trust, prevention of tampering and other characteristics, the application of blockchain can have a significant impact on supply chain traceability and traceability, as well as anti-counterfeiting and product authenticity, in solving the problem of cooperation between various entities in the CSC Problems such as low integration, difficulty in information sharing, lack of trust, difficulty in regulatory traceability, and information security show great potential. In the future, with the further development and improvement of blockchain technology, we can build a mutually trusting building supply chain alliance with the help of the blockchain + smart contract model to achieve continuous value-added of the project value stream.

The first opportunity for the use of blockchain technology in the construction industry is related to the improvement of data systems and information flow, and blockchain can constitute a layer of trust on the Internet of various digital transactions in the construction industry, making those information technology-based industries the main beneficiaries, especially in facilities management, smart cities, digital twin creation, and material procurement management. For example, the optimization of decentralized procurement processes and the implementation of material sources in the construction industry increase the sustainability of the entire supply chain. If all material certificates and quality inspections during construction were stored and shared in a blockchain system, this would make measuring sustainability much easier. Second, blockchain can serve as a trusted communication medium between participating entities in the supply chain, promoting the creation of a decentralized public data environment in the future. At the same time, the digitalization of the construction industry is accelerated by overcoming major digital barriers related to trust, transparency, data traceability, etc. For example, systems with transparent chains of custody encourage good behavior and drive quality, which in turn sets high-quality products and trusted suppliers apart and establishes long-term partnerships. Finally, while the traceability and transparency features in blockchain are applicable to large public client organizations in the construction industry, small organizations can compete with large organizations by forming a trust-based procurement framework through blockchain. Leverage smart contracts to support automated payments, source tracking, contract management, disintermediation, data ownership and control, and trust-building procurement and supply chain activities. The value that blockchain technology can provide is deployed at the beginning of the procurement process and can facilitate collaboration among various stakeholders. All transactions completed by participants will be stored and recorded on the blockchain during procurement and delivery, providing oversight of deliveries and enhancing the regulatory system. As a result, blockchain technology can support new business models that can form a truly open ledger.

Given the increasing prevalence of over-hyping the concept of "blockchain" and related products, it is necessary to conduct a rational and systematic analysis of blockchain technology. Blockchain technology offers disruptive latest business solutions in multiple areas, including supply chain management, and managers on the supply chain currently lack the motivation to use blockchain technology, and even if the technology is adopted, it is more to control the application of the blockchain than to improve the efficiency of transactions between all parties. Future related research may be aimed at the following aspects: blockchain technology can improve product quality inspection and assurance, and studying the impact of blockchain technology on supply chain performance related to quality issues may be an area worth exploring; From the performance point of view, the technical level of the blockchain has not yet reached a certain height, the number of transactions that can be processed per second on the blockchain is limited, and with the continuous advancement of construction projects, a large amount of transaction data will be generated in the supply chain, which will produce a series of performance problems; From the perspective of supply chain efficiency, it will be of great significance to study the role of blockchain technology on the rate increase of supply chain processes. In addition, the development of blockchain technology cannot form a good interaction with the laws and regulations and management methods related to construction projects, and there is a lack of blockchain-based governance frameworks and mechanisms in the construction industry, which will affect the operability of the technology in the construction supply chain. As the scalability and scalability of blockchain are further revealed, the supply chain integration value chain based on multiple blockchains is also a possible future research area.

Blockchain as an emerging technology has been shown to benefit supply chain operations in other industries, such as food consumer markets, healthcare, and finance. The application of blockchain technology in the CSC is an emerging area of research and development in the construction industry. The application prospects of blockchain technology can be uncovered through key issues in the CSC. To further adapt to blockchain technology, the most important step is to identify the key issues facing the CSC and identify the main influencing factors for solving the problem, reflecting on how blockchain technology can potentially combine with these factors. However, a comprehensive review of blockchain-based solutions to key problems is conducted. However, at this stage, there is a lack of relevant research to provide theoretical guidance, determine the causal relationship between the key problems faced by the CSC and the potential solutions of the application of blockchain technology, and establish a basis for effective management of blockchain implementation.

REFERENCES

Abedi, M., Rawai, N. M., Fathi, M. S., & Mirasa, A. K. (2014). Cloud computing as a construction collaboration tool for precast supply chain management. *Jurnal Teknologi*, *70*(7). doi:10.11113/jt.v70.3569

Abeyratne, S. A., & Monfared, R. P.Saveen A. Abeyratne. (2016). Blockchain ready manufacturing supply chain using distributed ledger. *International Journal of Research in Engineering*, *5*(9), 1–10. doi:10.15623/ijret.2016.0509001

Aghimien, D., Aigbavboa, C. O., Oke, A. E., Edwards, D., Thwala, W. D., & Roberts, C. J. (2021). Dynamic capabilities for digitalisation in the AECO sector–a scientometric review. *Engineering, Construction, and Architectural Management*. doi:10.1108/ECAM-12-2020-1012

Ahmed, V., Tezel, A., Aziz, Z., & Sibley, M. (2017). *The future of big data in facilities management: opportunities and challenges*. Facilities., doi:10.1108/F-06-2016-0064

Akan, M. Ö. A., Dhavale, D. G., & Sarkis, J. (2017). Greenhouse gas emissions in the construction industry: An analysis and evaluation of a concrete supply chain. *Journal of Cleaner Production*, *167*, 1195–1207. doi:10.1016/j.jclepro.2017.07.225

Al Barghuthi, N. B., Ncube, C., & Said, H. (2019). State of art of the effectiveness in adopting blockchain technology-UAE survey study. *2019 Sixth HCT Information Technology Trends (ITT)*, 54-59. 10.1109/ITT48889.2019.9075108

Al-Saeed, Y., Edwards, D. J., & Scaysbrook, S. (2020). Automating construction manufacturing procedures using BIM digital objects (BDOs): Case study of knowledge transfer partnership project in UK. *Construction Innovation*, *20*(3), 345–377. Advance online publication. doi:10.1108/CI-12-2019-0141

Azmi, N. A., Sweis, G., Sweis, R., & Sammour, F. (2022). Exploring Blockchain-enabled smart contracts technology implementation within ready-mixed concrete plants industry in Saudi Arabia. *International Journal of Construction Management*, 1-9. 10.1080/15623599.2022.2059914

Badzar, A. (2016). *Blockchain for securing sustainable transport contracts and supply chain transparency-An explorative study of blockchain technology in logistics*.

Bakhtiarizadeh, E., Shahzad, W. M., Poshdar, M., Khalfan, M., & Rotimi, J. O. B. (2021). Blockchain and information integration: Applications in New Zealand's prefabrication supply chain. *Buildings*, *11*(12), 608. doi:10.3390/buildings11120608

Balasubramanian, S., & Shukla, V. (2018). Environmental supply chain management in the construction sector: Theoretical underpinnings. *International Journal of Logistics Research Applications*, *21*(5), 502–528. doi:10.1080/13675567.2018.1452902

Barbosa, F., Woetzel, J., & Mischke, J. (2017). Reinventing construction: A route of higher productivity. In Bashir, I. Mastering blockchain. Packt Publishing Ltd.

Betti, Q., Khoury, R., Hallé, S., & Montreuil, B. (2019). Improving hyperconnected logistics with blockchains and smart contracts. *IT Professional*, *21*(4), 25–32. doi:10.1109/MITP.2019.2912135

Bhattacharyya, S. S., Maitra, D., & Deb, S. L. (2021). Study of adoption and absorption of emerging technologies for smart supply chain management: A dynamic capabilities perspective. *International Journal of Applied*, *11*(2), 14–54. doi:10.4018/IJAL.2021070102

Bryman, A. (2016). *Social research methods*. Oxford university press.

Butkovic, L. L., Kauric, A. G., & Mikulic, J. (2016). *Supply chain management in the construction industry-a literature review.* Paper presented at the International OFEL Conference on Governance, Management and Entrepreneurship. IEEE.

Chamberlain, D. A., Edwards, D., Lai, J., & Thwala, W. D. (2019). *Mega event management of formula one grand prix: an analysis of literature*. Facilities., doi:10.1108/F-07-2018-0085

Cheng, J. C., Law, K. H., Bjornsson, H., Jones, A., & Sriram, R. (2010). A service oriented framework for construction supply chain integration. *Automation in Construction*, *19*(2), 245–260. doi:10.1016/j.autcon.2009.10.003

Cheng, M., Liu, G., Xu, Y., & Chi, M. (2021). When blockchain meets the AEC industry: Present status, benefits, challenges, and future research opportunities. *Buildings*, *11*(8), 340. doi:10.3390/buildings11080340

Corbet, S., Lucey, B., & Yarovaya, L. (2018). Datestamping the bitcoin and ethereum bubbles. [In.]. *Finance Research Letters*, *26*, 81–88. doi:10.1016/j.frl.2017.12.006

Dallasega, P., & Rauch, E. (2017). Sustainable construction supply chains through synchronized production planning and control in engineer-to-order enterprises. %. *J Sustainability*, *9*(10), 1888. doi:10.3390/su9101888

Du, Q., Huang, Y., Xu, Y., Bai, L., Bao, T., & Wang, H. (2019). Benefit allocation in the construction supply chain considering carbon emissions. *Polish Journal of Environmental Studies*, *28*(5), 3697–3709. doi:10.15244/pjoes/94995

Duan, J., Zhang, C., Gong, Y., Brown, S., & Li, Z. (2020). A content-analysis based literature review in blockchain adoption within food supply chain. *International Journal of Environmental Research and Public Health*, *17*(5), 1784. doi:10.3390/ijerph17051784 PMID:32182951

Dubey, R., Gunasekaran, A., Bryde, D. J., Dwivedi, Y. K., & Papadopoulos, T. (2020). Blockchain technology for enhancing swift-trust, collaboration and resilience within a humanitarian supply chain setting. *International Journal of Production Research*, *58*(11), 3381–3398. doi:10.1080/00207543.2020.1722860

Edwards, D. J., Akhtar, J., Rillie, I., Chileshe, N., Lai, J. H., Roberts, C. J., & Ejohwomu, O. (2021). Systematic analysis of driverless technologies. *Journal of Engineering, Design Technology*. 10.1108/JEDT-02-2021-0101

Fearne, A., & Fowler, N. (2006). Efficiency versus effectiveness in construction supply chains: The dangers of "lean" thinking in isolation. *Supply Chain Management*, *11*(4), 283–287. doi:10.1108/13598540610671725

Fischer, M., Ashcraft, H. W., Reed, D., & Khanzode, A. (2017). *Integrating project delivery*. John Wiley & Sons. doi:10.1002/9781119049272

Gaur, A., & Vazquez-Brust, D. A. (2019). Sustainable development goals: Corporate social responsibility? A critical analysis of interactions in the construction industry supply chains using externalities theory. In *Sustainable Development Goals and Sustainable Supply Chains in the Post-global Economy* (pp. 133–157). Springer. doi:10.1007/978-3-030-15066-2_8

Guo, J., Yu, H., & Gen, M. (2020). Research on green closed-loop supply chain with the consideration of double subsidy in e-commerce environment. *Computers & Industrial Engineering*, *149*, 106779. doi:10.1016/j.cie.2020.106779

Gurgun, A. P., Genc, M. I., Koc, K., & Arditi, D. (2022). Exploring the Barriers against Using Cryptocurrencies in Managing Construction Supply Chain Processes. *Buildings*, *12*(3), 357. doi:10.3390/buildings12030357

Hamledari, H., & Fischer, M. (2021). The application of blockchain-based crypto assets for integrating the physical and financial supply chains in the construction & engineering industry. *Automation in Construction*, *127*, 103711. doi:10.1016/j.autcon.2021.103711

Hao, C., Du, Q., Huang, Y., Shao, L., & Yan, Y. (2019). Evolutionary game analysis on knowledge-sharing behavior in the construction supply chain. *Sustainability*, *11*(19), 5319. doi:10.3390/su11195319

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), 03121005. doi:10.1061/(ASCE)CO.1943-7862.0002142

Isatto, E. L., Azambuja, M., & Formoso, C. T. (2015). The role of commitments in the management of construction make-to-order supply chains. *Journal of Management Engineering*, *31*(4), 04014053. doi:10.1061/(ASCE)ME.1943-5479.0000253

Jiang, W., Lu, W., & Xu, Q. (2019). Profit distribution model for construction supply chain with cap-and-trade policy. *Sustainability*, *11*(4), 1215. doi:10.3390/su11041215

Karlsson, I., Rootzén, J., & Johnsson, F. (2020). Reaching net-zero carbon emissions in construction supply chains–Analysis of a Swedish road construction project. *Renewable & Sustainable Energy Reviews*, *120*, 109651. doi:10.1016/j.rser.2019.109651

Kim, M. G., Woo, C., Rho, J. J., & Chung, Y. (2016). Environmental capabilities of suppliers for green supply chain management in construction projects: A case study in Korea. *Sustainability*, *8*(1), 82. doi:10.3390/su8010082

Kshetri, N. (2018). 1 Blockchain's roles in meeting key supply chain management objectives. *International Journal of Information Management*, *39*, 80–89. doi:10.1016/j.ijinfomgt.2017.12.005

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

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

Li, C. Z., Xue, F., Li, X., Hong, J., & Shen, G. Q. (2018). An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction. *Automation in Construction*, *89*, 146–161. doi:10.1016/j.autcon.2018.01.001

Li, J., Greenwood, D., & Kassem, M. (2019). Blockchain in the construction sector: A socio-technical systems framework for the construction industry. In *Advances in informatics and computing in civil and construction engineering* (pp. 51–57). Springer. doi:10.1007/978-3-030-00220-6_7

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

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), 04021195. doi:10.1061/(ASCE)CO.1943-7862.0002229

London, K., & Singh, V. (2013). Integrated construction supply chain design and delivery solutions. *Architectural engineering design management, 9*(3), 135-157. 10.1080/17452007.2012.684451

Long, H., Liu, H., Li, X., Chen, L., & Health, P. (2020). An evolutionary game theory study for construction and demolition waste recycling considering green development performance under the Chinese government's reward–penalty mechanism. *International Journal of Environmental of Research*, *17*(17), 6303. doi:10.3390/ijerph17176303 PMID:32872529

Longo, F., Nicoletti, L., Padovano, A., d'Atri, G., & Forte, M. (2019). Blockchain-enabled supply chain: An experimental study. *Computers & Industrial Engineering*, *136*, 57–69. doi:10.1016/j.cie.2019.07.026

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*, 103816. doi:10.1016/j.autcon.2021.103816

Meng, X. (2020). Proactive management in the context of construction supply chains. *Production Planning and Control*, *31*(7), 527–539. doi:10.1080/09537287.2019.1657977

Mensi, W., Al-Yahyaee, K. H., & Kang, S. H. (2019). Structural breaks and double long memory of cryptocurrency prices: A comparative analysis from Bitcoin and Ethereum. *Finance Research Letters*, *29*, 222–230. doi:10.1016/j.frl.2018.07.011

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. *Decentralized Business Review*, *21260*. Advance online publication. doi:10.2139/ssrn.3977007

Nazir, F. A., Edwards, D. J., Shelbourn, M., Martek, I., Thwala, W. D. D., & El-Gohary, H. (2020). Comparison of modular and traditional UK housing construction: A bibliometric analysis. *Journal of Engineering, Design Technology*. 10.1108/JEDT-05-2020-0193

Oh, J., & Shong, I. (2017). *A case study on business model innovations using Blockchain: focusing on financial institutions*. Asia Pacific Journal of Innovation Entrepreneurship., doi:10.1108/APJIE-12-2017-038

Pala, M., Edum-Fotwe, F., Ruikar, K., Peters, C., & Doughty, N. (2016). Implementing commercial information exchange: A construction supply chain case study. *Construction Management and Economics*, *34*(12), 898–918. doi:10.1080/01446193.2016.1211718

Perianes-Rodriguez, A., Waltman, L., & Van Eck, N. J. (2016). Constructing bibliometric networks: A comparison between full and fractional counting. *Journal of Informetrics*, *10*(4), 1178–1195. doi:10.1016/j.joi.2016.10.006

Plevris, V., Lagaros, N. D., & Zeytinci, A. Blockchain in Civil Engineering, Architecture and Construction Industry: State of the Art, Evolution, Challenges and Opportunities. *Frontiers in Built Environment*, *49*. 10.3389/fbuil.2022.840303

Qian, X. A., & Papadonikolaki, E. (2020). Shifting trust in construction supply chains through blockchain technology. *Engineering, Construction, and Architectural Management*, *28*(2), 584–602. doi:10.1108/ECAM-12-2019-0676

Roberts, C. J., Pärn, E. A., Edwards, D. J., & Aigbavboa, C. (2018). Digitalising asset management: concomitant benefits and persistent challenges. *International Journal of Building Pathology Adaptation*. 10.1108/IJBPA-09-2017-0036

Rodrigo, M., Perera, S., Senaratne, S., & Jin, X. (2021). Systematic development of a data model for the blockchain-based embodied carbon (BEC) estimator for construction. *Engineering, Construction, and Architectural Management*. doi:10.1108/ECAM-02-2021-0130

Rodrigo, M. N. N., Perera, S., Senaratne, S., & Jin, X. (2020). Potential application of blockchain technology for embodied carbon estimating in construction supply chains. *Buildings*, *10*(8), 140. doi:10.3390/buildings10080140

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, *57*(7), 2117–2135. doi:10.1080/00207543.2018.1533261

Sadeghi, A.-R., Wachsmann, C., & Waidner, M. (2015). *Security and privacy challenges in industrial internet of things.* Paper presented at the 2015 52nd ACM/EDAC/IEEE Design Automation Conference (DAC). ACM. doi:10.1145/2744769.2747942

Saini, M., Arif, M., & Kulonda, D. J. (2019). Challenges to transferring and sharing of tacit knowledge within a construction supply chain. *Construction Innovation*, *19*(1), 15–33. doi:10.1108/CI-03-2018-0015

Samaniego, M., Jamsrandorj, U., & Deters, R. (2016). *Blockchain as a Service for IoT.* Paper presented at the 2016 IEEE international conference on internet of things (iThings) and IEEE green computing and communications (GreenCom) and IEEE cyber, physical and social computing (CPSCom) and IEEE smart data (SmartData). IEEE. doi:10.1109/iThings-GreenCom-CPSCom-SmartData.2016.102

Saunders, M., Lewis, P., & Thornhill, A. (2019). Research Methods for Business Students Eight Edition. *Qualitative Market Research*.

Scott, D. J., Broyd, T., & Ma, L. (2021). Exploratory literature review of blockchain in the construction industry. *Automation in Construction*, *132*, 103914. doi:10.1016/j.autcon.2021.103914

Scully, P., & Höbig, M. (2019). *Exploring the impact of blockchain on digitized Supply Chain flows: A literature review.* Paper presented at the 2019 Sixth International Conference on Software Defined Systems (SDS). IEEE. doi:10.1109/SDS.2019.8768573

Smith, J., Edwards, D. J., Martek, I., Chileshe, N., Hayhow, S., & Roberts, C. J. (2021). The antecedents of construction project change: An analysis of design and build procurement application. *Journal of Engineering, Design Technology*. 10.1108/JEDT-12-2020-0507

Spellacy, J., Edwards, D. J., Roberts, C. J., Hayhow, S., & Shelbourn, M. (2020). An investigation into the role of the quantity surveyor in the value management workshop process. *Journal of Engineering, Design Technology*. 10.1108/JEDT-07-2020-0289

Taggart, M., Koskela, L., & Rooke, J. (2014). The role of the supply chain in the elimination and reduction of construction rework and defects: An action research approach. *Construction Management and Economics*, *32*(7-8), 829–842. doi:10.1080/01446193.2014.904965

Tezel, A., Papadonikolaki, E., Yitmen, I., & Hilletofth, P. (2020). Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions. *Frontiers of Engineering Management*, *7*(4), 547–563. doi:10.1007/s42524-020-0110-8

Tian, F. (2016). *An agri-food supply chain traceability system for China based on RFID & blockchain technology.* Paper presented at the 2016 13th international conference on service systems and service management (ICSSSM). IEEE.

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

Van Eck, N. J., & Waltman, L. (2020). *VOSviewer Manual: Manual for VOSviewer version 1.6. 15*. Centre for Science Technology Studies of Leiden University.

Wang, M., Wang, C. C., Sepasgozar, S., & Zlatanova, S. (2020). A systematic review of digital technology adoption in off-site construction: Current status and future direction towards industry 4.0. *Buildings*, *10*(11), 204. doi:10.3390/buildings10110204

Wang, Z., Wang, T., Hu, H., Gong, J., Ren, X., & Xiao, Q. (2020). Blockchain-based framework for improving supply chain traceability and information sharing in precast construction. *Automation in Construction*, *111*, 103063. doi:10.1016/j.autcon.2019.103063

Watanabe, H., Fujimura, S., Nakadaira, A., Miyazaki, Y., Akutsu, A., & Kishigami, J. J. (2015). *Blockchain contract: A complete consensus using blockchain.* Paper presented at the 2015 IEEE 4th global conference on consumer electronics (GCCE). IEEE. doi:10.1109/GCCE.2015.7398721

Xiong, F., Xiao, R., Ren, W., Zheng, R., & Jiang, J. (2019). A key protection scheme based on secret sharing for blockchain-based construction supply chain system. *IEEE Access : Practical Innovations, Open Solutions*, *7*, 126773–126786. doi:10.1109/ACCESS.2019.2937917

Xu, G., Li, M., Chen, C.-H., & Wei, Y. (2018). Cloud asset-enabled integrated IoT platform for lean prefabricated construction. *Automation in Construction*, *93*, 123–134. doi:10.1016/j.autcon.2018.05.012

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*, 104101. doi: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*, 103270. doi:10.1016/j.autcon.2020.103270

Yin, S., Li, B., & Xing, Z. (2019). The governance mechanism of the building material industry (BMI) in transformation to green BMI: The perspective of green building. *The Science of the Total Environment*, *677*, 19–33. doi:10.1016/j.scitotenv.2019.04.317 PMID:31051380

Yoo, S. (2017). *Blockchain based financial case analysis and its implications*. Asia Pacific Journal of Innovation Entrepreneurship., doi:10.1108/APJIE-12-2017-036

Yoon, J. H., Pishdad-Bozorgi, P., & management. (2022). State-of-the-art review of blockchain-enabled construction supply chain. *Journal of construction engineering, 148*(2), 03121008. 10.1061/(ASCE)CO.1943-7862.0002235

Zhai, Y., Chen, K., Zhou, J. X., Cao, J., Lyu, Z., Jin, X., Shen, G. Q. P., Lu, W., & Huang, G. Q. (2019). An Internet of Things-enabled BIM platform for modular integrated construction: A case study in Hong Kong. *Advanced Engineering Informatics*, *42*, 100997. doi:10.1016/j.aei.2019.100997

Zhang, X., Sun, P., Xu, J., Wang, X., Yu, J., Zhao, Z., & Dong, Y. (2020). Blockchain-based safety management system for the grain supply chain. *IEEE Access : Practical Innovations, Open Solutions*, *8*, 36398–36410. doi:10.1109/ACCESS.2020.2975415

Zhong, R. Y., Peng, Y., Xue, F., Fang, J., Zou, W., Luo, H., Thomas Ng, S., Lu, W., Shen, G. Q. P., & Huang, G. Q. (2017). Prefabricated construction enabled by the Internet-of-Things. *Automation in Construction*, *76*, 59–70. doi:10.1016/j.autcon.2017.01.006

Zhu, J., Fang, M., Shi, Q., Wang, P., & Li, Q. (2018). Contractor cooperation mechanism and evolution of the green supply chain in mega projects. *Sustainability*, *10*(11), 4306. doi:10.3390/su10114306