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Systematic Review

The Role of Blockchain in Improving the Processes and Workflows in Construction Projects

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Abstract: Construction is prone to disputes similar to other business dealings. Construction delays are the most common causes of disputes in construction projects. Most of the time, construction projects are delayed not only because of a lack of funding, but also because of disputes between the contractor and the client. Blockchain Technologies (BCT) have the potential to make the construction industry more efficient, inexpensive, or completely automated. In this paper, an extensive literature review is conducted to locate authoritative sources about the most common applications of blockchain technology in the construction industry. The study aims to identify the potential, benefits, challenges, and uses of blockchain in the construction industry. Furthermore, this paper explores the roles of BCTs in improving and enhancing the workflow efficiency of construction projects. In addition, this paper identifies the major causes of disputes and delays in the construction industry. These causes were used as the baseline for identifying the most relevant solutions provided by blockchain technologies to develop a matching model to find applicable solutions from the literature cases to resolve the identified causes of disputes and delays. The research findings indicated that the common cases of BCT including administrative purposes, smart contracts for transactions, permanent transaction records, and permanent ownership records contribute to solving the causes of disputes and delays in construction projects. The findings of this paper recommend that both public and private stakeholders in the construction sector adopt blockchain technologies and blockchain-based Building Information Models (BIMs) to improve construction workflows and processes.

Keywords: blockchain; constriction industry; project delays; use cases

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1. Introduction

Construction is a critical component of human development and occupies a significant portion of global spending. According to the McKinsey Global Institute, construction-related spending has reached 13% of global GDP, making the real estate, infrastructure, and industrial sectors the world's largest industries [1]. Thus, any improvements in construction management would be amplified by the facts.

Construction industries are facing several challenges such as poor project documentation and construction delays [2]. Project documents are poorly prepared with inaccurate specifications, and owners have different expectations for what constitutes a successful project. Contractors fail to deliver if they are not qualified or if the contract is too vague. These bad practices may lead to inefficient work processes, including rework and re-planning, contractor disappointment and owner dissatisfaction, unproductive workers that are engaged in activities that do not lead projects forward, and unproductive project managers that are engaged in appeasing stakeholders. In addition, construction delays are the most common causes of disputes globally [3]. All parties want to receive the money as soon as possible and are frequently unwilling to compromise. Most construction projects

are delayed not only because of a lack of funding, but also because of disputes between the contractor and the client. Some contractors argue that if the dispute is not resolved, no construction will be completed [3].

Examining projects in a conservative industry such as construction reveals a lack of innovation and a need for an improvement in quality, efficiency, accessibility, and sustainability. More specifically, aspects such as record keeping, arbitration, dispute resolution, contractual workflows, resources tracking, delivery confirmation, and post-delivery services can be plagued by different problems that impact the outcome or progress of the project [4]. Poor documentation and construction delays have resulted in inefficient collaborations between parties involved in construction projects. Due to its decentralized nature, blockchain technology promotes information sharing and empowers all parties involved in the construction industry.

Blockchain technology has been realized as a pillar of the Industry 4.0 revolution and is considered as a disruptive innovation in a variety of industries and businesses, including construction [5]. Industry 4.0 has realized a paradigm shift in production from input-intensive to knowledge-intensive manufacturing. Increasing the emphasis on information technology and the digitization of business operating models, a framework emphasizing innovation, growth, and sustainability has emerged [6]. The technology of Industry 4.0 plays a crucial role in manufacturing industries and their long-term viability due to enhanced technologies, improved communication technology, a decreased lead time, an improved work environment, and product quality [6,7].

Therefore, BCT adoption can be an effective solution for the better management of construction projects by providing transparent data, and a clear communication of requirements and expectations through smart contracts that clearly define the terms agreed upon by the involved parties. BCT has the potential to enhance the management and funding of public and private projects. For example, BCT could improve bidding processes, contract management processes, project management processes, risk assessment processes, and insurance processes [8]. It could also dramatically reduce the time and costs involved in transferring funds for international projects from days to seconds [9]. BCT disrupts many industries as transactions become more efficient, inexpensive, or completely automated [10]. The most promising implementations of blockchain are those that can improve construction processes and workflows by removing a number of existing barriers or inefficiencies. To improve the construction process without the need for costly intermediaries, blockchain technologies can be integrated in project processes [11]. Moreover, blockchain technologies decentralize information by empowering all parties involved in the process which improves transparency.

Blockchain technologies are considered to be mainstream, especially in a conservative sector such as the construction industry, which has been known to be slow in adopting technological advances, especially in relation to the improvement of its processes and workflows. However, there have been several applications that have demonstrated outstanding results in overcoming some issues in the construction industry. The Australian National Blockchain Roadmap Steering Committee estimated that the global market for blockchain construction projects is expected to be worth around USD 200 billion by 2025 [12]. The market for Blockchain in construction is estimated to grow from USD 7.92 million in 2016 to USD 164.5 million by 2021, at a compound annual growth rate of 70%. The key factors driving this growth are the use of blockchain-based contracts, an increased transparency and traceability through smart contracts, and an improved flow of information [13].

This study aims to explore how construction projects could benefit from implementing blockchain technologies to improve the efficiency of their processes and workflows, as well as to identify the potential, limitations, and challenges in the construction industry. This is valid for tracking materials, installations, audits, deliveries, and payments. It also has the potential to build a trusted and consensus-based reputation ledger for contractors and subcontractors by relying on their service records [14]. In addition, delays and disputes negatively impact the quality and cost of construction projects. For instance, Noman

et al. [15] revealed that 662 projects worth SAR 40 billion (USD 12 billion) were delayed significantly. On the other hand, according to the consulting firm Arcadis's "2020 Global Construction Disputes Report", the average value of construction disputes in the Middle East has averaged USD 62 million compared to USD 30.7 million globally. Moreover, disputes have been reported to extend over 17 months on average in the Middle East, compared to 15 months globally [6].

Despite the diverse impact of blockchain technologies in resolving the construction industry's challenges, few papers have addressed blockchain in the construction industry [16–18]. Moreover, no studies have focused on the role of blockchain in improving the processes and workflows within construction projects. Specifically, no studies have addressed the ways in which the causes of disputes and delays of construction projects can be resolved. Moreover, the available studies of delays and disputes have ignored the possibility of using modern solutions to improve the situation and to minimize the impact of delays and disputes. Consequently, this paper aims to identify the areas of the construction industry in which blockchain has been demonstrated to be useful, as well as explore the most common cases for implementing blockchain technologies in the construction industry. It also identifies the challenges and benefits of blockchain in the construction industry in order to improve construction processes and workflows. Furthermore, it proposes practical solutions from the literature to resolve the identified causes of disputes and delays.

2. Blockchain Technology Overview

Blockchain is a type of database technology that consists of a distributed ledger, a consensus protocol, and cyptography. Blockchain can use a decentralized peer-to-peer network to track and store the past and present status of tangible goods or intangible occurrences. Data are saved in a series of blocks that are linked in a chain. Cryptographic protocols forbid any changes to the data stored in a block without the cooperation or collaboration of the majority of participants [19]. Moreover, it uses a decentralized peer-to-peer network to create a distributed ledger. The users of this network can interact with or transact a variety of information, such as building data, agreements, or ownership records. All interactions on the network are verified by its participants and are then chronologically stored on a certain block on the blockchain. The newly minted block, which contains a certain number of new records, is then propagated to all instances of the ledger across all computers connected to the network. Due to its decentralized nature, blockchain is not prone to manipulation or control by a centralized component because the ledger is duplicated across all computers running it and is used to verify its integrity [20]. Figure 1 illustrates the blockchain operation in terms of sequential steps. To ensure reliability, anyone with access to the blockchain can view the data and track its history on the network [21]. A global advisory firm to the construction industry estimated that only 5% of building construction data are preserved on handover to the first owner [22].

In the construction sector, there is a lack of transparency and trust in working relationships. As a result, there has been a lack of cooperation among project stakeholders, as well as difficulties in exchanging information. This motivates the use of blockchain technology to tackle these issues. Blockchain technology's decentralized feature promotes high transparency and trust and has piqued the interest of numerous industrial sectors, including the construction industry. In a decentralized system, each participant is allowed to access data in an open system with no need for third-party authorization or verification. The validity of the transactions is ensured through consensus and public validation [23]. Furthermore, blockchain technology plays a major role in future worldwide networks leading to a maximization of the movement of information between stakeholders [24]. A consensus mechanism is one of the fundamentals of blockchain used to verify transactions. As a result, all participants must agree for a transaction to be accepted as valid, which means that before any transaction can take place, it must be verified by everyone on the network and encrypted with their private key to ensure that their identity is kept anonymous. Then, a transaction can take place securely and transparently because it is visible

to all parties involved in verifying it a few seconds after this validation process has been completed, once again through consensus from all parties involved in the verification [25].

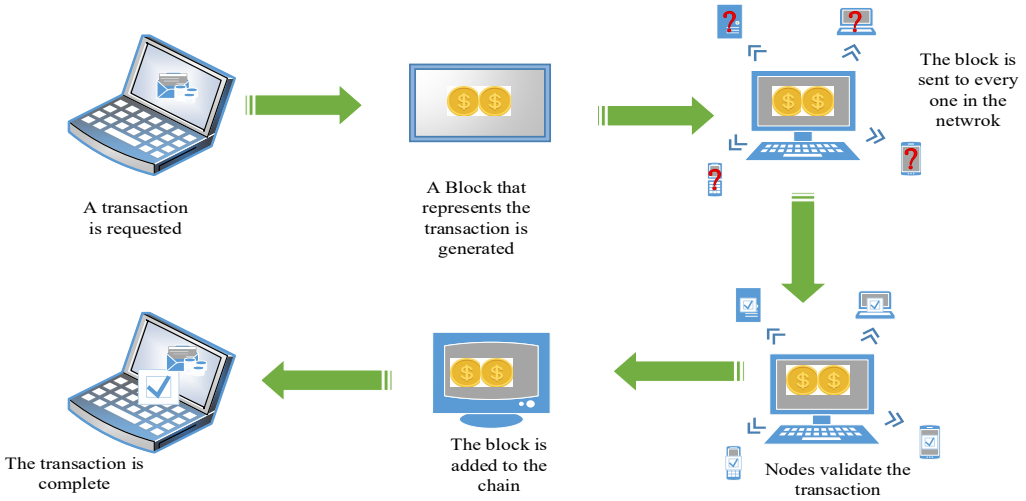


Figure 1. A diagram summarizing how blockchain works.

Moreover, immutability is achieved in blockchain technology by making all transactions on the blockchain unchangeable and providing a record for each transaction that cannot be altered. The irreversible blocks generated by the blockchain can be used to settle financial transactions. When cryptographic hashes are chained together to create data files, they cause immutability in the data. Because no one can go back and edit or change any of the existing records, this can be useful for ensuring good quality assurance [26].

Furthermore, smart contract technology could provide a more reliable way to keep track of contracts through a decentralized network. The idea is to create an electronic and self-executing digital agreement between two or more parties. The smart contract could be a process by which construction contracts could be formed and monitored [27]. To execute a smart contract, it has to be triggered to deliver the intended outcome. However, if smart contracts are adopted in construction projects, they must interact with real-world objects and building components. This is where blockchain oracles could perform a major role in overcoming the hurdle of interacting with the non-digital world [28]. The smart contract needs to know if prefabricated components of a building have arrived on location or if the required amount of metal beams are brought in. The oracle can feed such information via the RFID or IoT technologies. Therefore, blockchain oracles would provide the necessary data to trigger the smart contract when the original terms of the contract are met. Oracles enable developers to conclude powerful smart contracts that open the blockchain ecosystem to the centralized world and invite it to participate [29]. However, relying on a centralized source of data as an input or trigger for decentralized smart contracts nullifies the purpose of utilizing blockchain technology and represents what is known as "the Blockchain Oracle Problem" [30,31].

Several attempts have been made to present a solution to this problem by employing decentralized oracles. A decentralized oracle consists of group or network of independent oracles that feed off chain data into a blockchain where they are firstly aggregated to yield a single source of truth.

3. Methodology

In this paper, the systematic mapping process adopted by Petersen et al. [32] and the guidelines on systematic literature reviews by Kitchenham and Charters [33] were utilized to achieve the objectives of this research. The goal of the mapping study was to synthesize the quantitative and qualitative research. The reason for choosing this mapping system was to allow for an exploration into the research in the construction industry from different

perspectives and to allow for a better understanding of how blockchain technology affects the construction industry. The primary focus of this study is on peer-reviewed and high-quality papers published in scientific databases. However, due to a scarcity of material found in the blockchain field in the construction area, a search of the grey literature was also conducted to ensure that the list was comprehensive. The grey papers were used to identify the challenges of blockchain in the construction industry. Remarkably, we found that a significant proportion of the important information was available in the grey literature. Figure 2 illustrates the systematic mapping flow used in this study to prepare the literature review. The mapping flow will be explained in details in the following subsections.

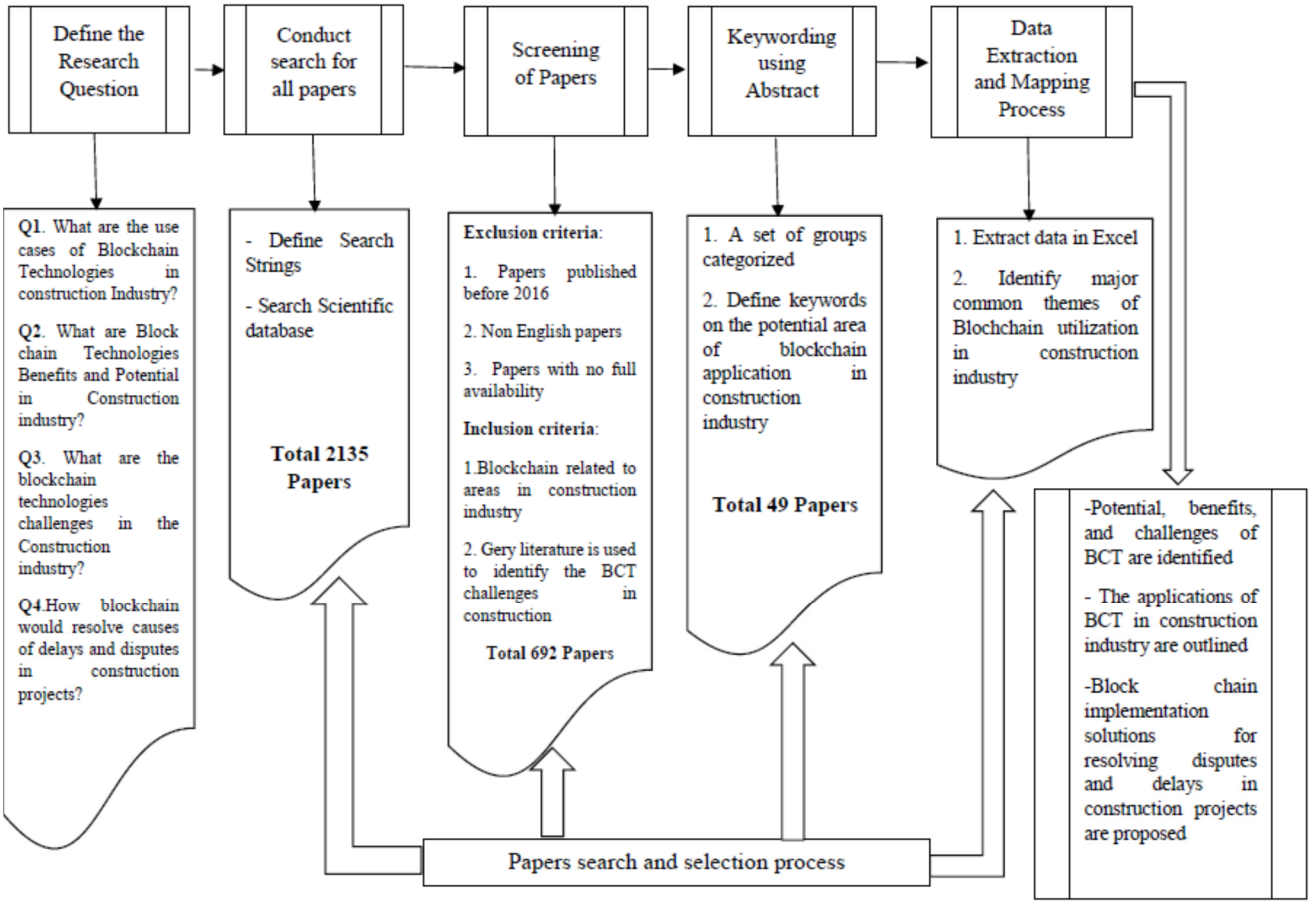


Figure 2. Systematic mapping flow.

3.1. Research Questions Definition

The first step in conducting a systematic review is to identify research questions. In this paper, four research questions were identified in accordance with our goal of determining the state-of-the-art methods in the study and BCT applications in the construction industry.

3.1.1. What Are the Cases of Blockchain Technology in the Construction Industry?

The first question in this paper aimed to identify the areas of the construction industry where blockchain has been demonstrated to be useful, as well as the most common cases related to the implementation of blockchain technologies in the construction industry. By analyzing related papers from scientific databases, we had the ability to determine the issues in the construction industry that could be solved using blockchain, and so we had the ability to identify the issues that could be best tackled using other methodologies. This will assist practitioners and researchers in their focus on the most promising blockchain applications in the construction industry.

3.1.2. What Are the Benefits and Potentials of Blockchain Technologies in the Construction Industry?

This question seeks to realize the benefits and potentials of using blockchain technology in construction projects. By reviewing the papers that discussed the various applications of blockchain technologies to improve construction processes and workflows, it was possible to identify the benefits and potentials of blockchain in the construction industry.

3.1.3. What Are the Challenges of Using Blockchain Technologies in the Construction Industry?

This question seeks to comprehend the difficulties of blockchain-based construction applications during implementation. Several studies from the literature were examined for the purpose of identifying these challenges.

3.1.4. How Would Blockchain Resolve the Causes of Delays and Disputes in Construction Projects?

This research question seeks to better understand the role of blockchain technology in resolving some of the main construction issues, which are construction delays and disputes. For this purpose, several studies from the literature were investigated to identify the causes of the delays and disputes. Then, the solutions based on blockchain technology were then identified.

3.2. Conducting the Research

The second step of the systematic mapping study process was to conduct the research. The reviewed papers were selected by searching scientific databases using keywords or a search string. A wide-ranging search was conducted across multiple online general and scientific databases including Google Scholar, Elsevier's Scopus, ProQuest, and Web of Science. Initially, a systematic literature search for relevant articles and papers without a time limit was conducted which resulted in a total of 2135 articles from all selected databases. To further improve the screening of the results, a number of exclusions were defined such as:

- Limiting the search time frame between 2016 and 2020 to have a consistent a range of results across all databases;
- Non-English papers and articles;
- Material without full access;
- Material which did not focus on management or engineering aspects such as programming, theoretical, etc.

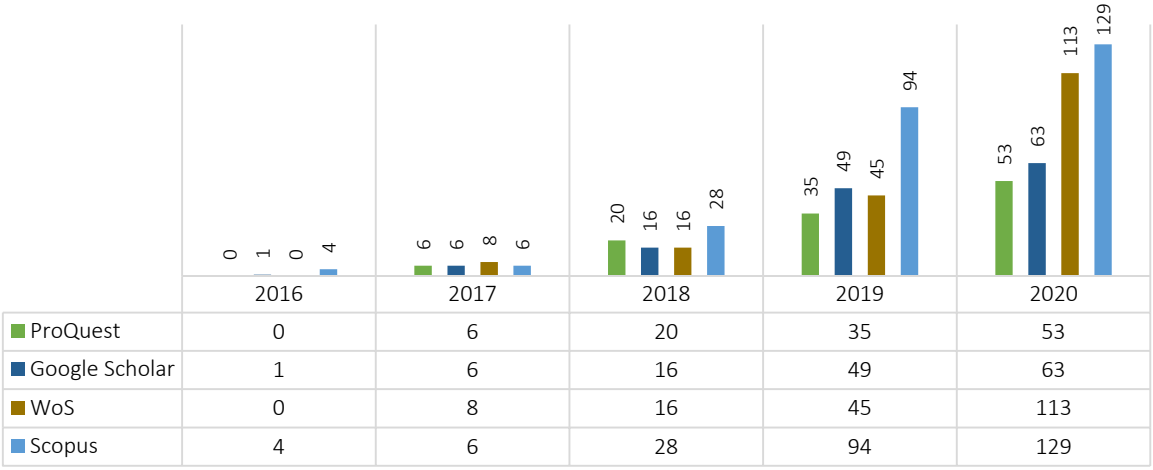
In addition, the grey literature was investigated to identify the challenges of blockchain in the construction industry.

3.3. Screening of Relevant Papers

The third step was to screen the papers for relevance after retrieving them from the databases. In this paper, a total of 2135 papers were collected from the scientific databases. Many of these papers were eliminated after the first screening based on the titles of the papers, leaving 692 papers for further screening. The papers that were omitted were not related to construction or did not satisfy one of the exclusion criteria; however, in some papers, the construction industry may have been stated in the abstracts as one of the non-financial blockchain applications.

In addition, duplicated papers were eliminated by merging all the papers in Mendeley. Figure 3 shows the analysis of the publications over the years in each of the searched databases. The analysis revealed that there has been an increase in the application of blockchain technology over time, which reflects the growing interest in blockchain technology in the construction industry. As shown in Figure 3, the publications trended dramatically across all databases, reflecting the current sentiment toward blockchain in the

construction industry. This demonstrates that blockchain in the construction industry is a relatively new area of research.



	2016	2017	2018	2019	2020
ProQuest	0	6	20	35	53
Google Scholar	1	6	16	49	63
WoS	0	8	16	45	113
Scopus	4	6	28	94	129

Figure 3. Publication analysis by year in the four databases.

Figure 4 depicts the types of papers reviewed. As shown in Figure 4, four main types of publications were included in this research: journals (86%), trade journals (2%), books (3%), and other forms (8%).

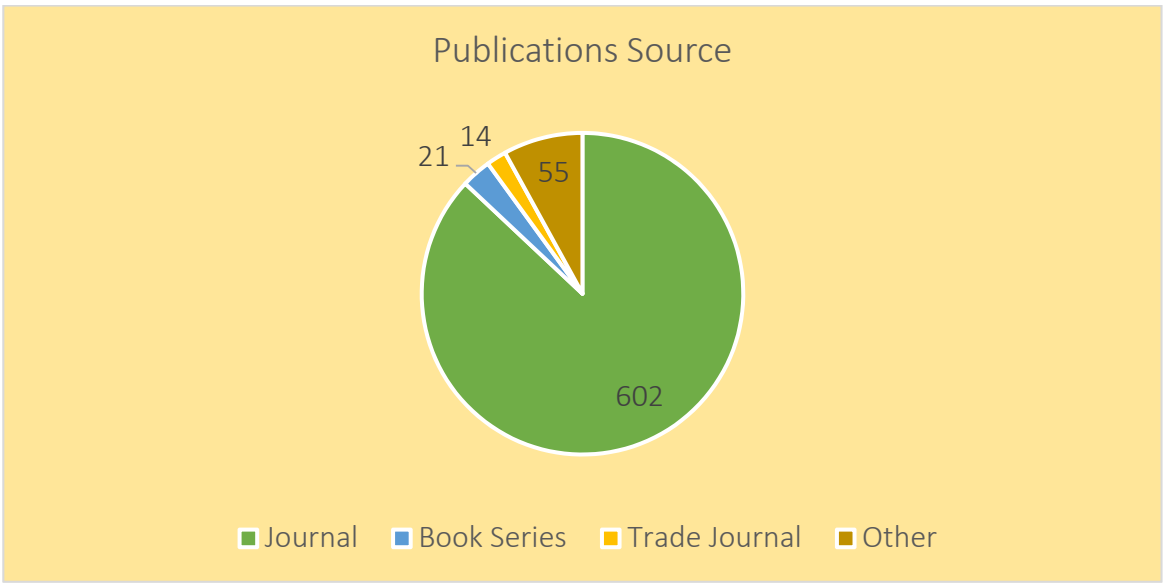


Figure 4. Publication sources of the matching 692 publications from database searches.

Furthermore, the geographical distribution of the reviewed papers from various countries is depicted in Figure 5. The geographical distribution of the chosen papers demonstrates that blockchain technology in the construction industry has gained the attention of researchers all over the world. The analysis was performed based on the disclosed country of the author. If not disclosed, the publication location was used instead. In the case of multiple authors, the location of the first author or the principal author was considered. It is clear that the United States dominates other countries in relation to the authorship and publication of blockchain and smart contracts in the construction industry. The United States' publications represent 24% of the total, followed by China which scored 17% as per the analysis globally. South Korea and India were close to each other in the

ranking, with 10% and 9% of the papers, respectively. These statistics show that blockchain is receiving a lot of attention in construction projects over the world.

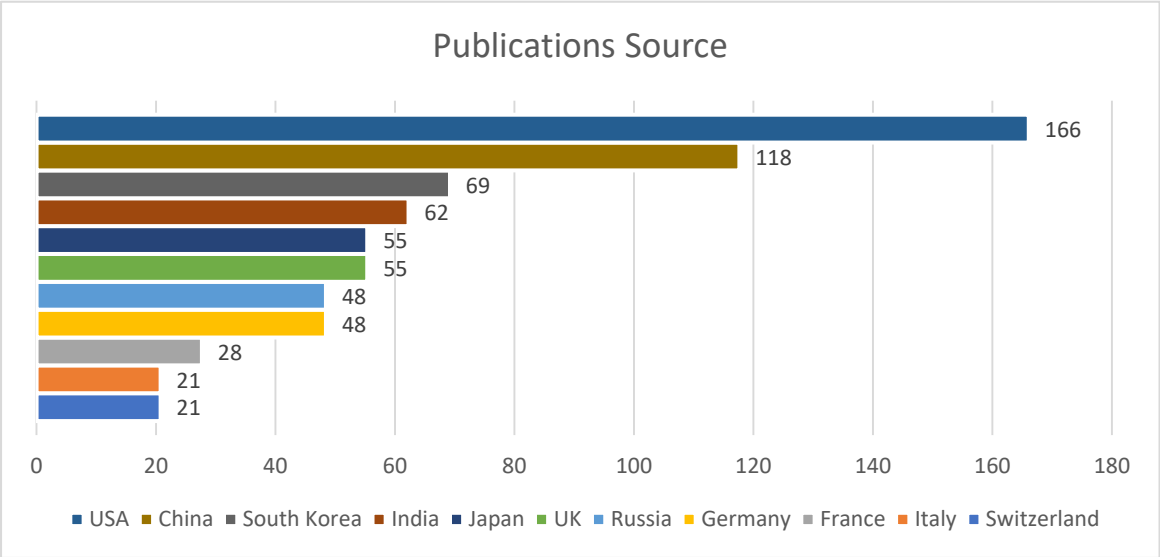


Figure 5. Publication Distribution by Country.

3.4. Keywording Strategy

Considering the aforementioned exclusion criteria, the following string was used to narrow the results: ("blockchain" AND "construction" AND "management") OR ("blockchain" AND "construction" AND "projects") OR ("blockchain" AND "construction" AND "industry") OR ("smart" AND "contracts" AND "construction" AND "projects") OR ("smart" AND "contracts" AND "construction" AND "industry") OR ("blockchain" AND "construction" AND "sector") OR ("blockchain" AND "construction" AND "benefits") OR ("blockchain" AND "construction" AND "BIM") OR ("smart" AND "contracts" AND " BIM") OR ("blockchain" AND "construction" AND "Disputes and delays") OR ("blockchain" AND "construction" AND "Potentials").

3.5. Data Extraction and Mapping Process

The number of selected papers was reduced to 49 by fine-tuning the search with keywords to focus on results emphasizing:

- Real-life BCT applications and challenges in construction management;
- The improvement of BIM implementation using blockchain technologies;
- The enhancement of construction management processes and workflows to prevent disputes and workflows;
- A common theme and utilization with other studies and research in the literature.

4. Results and Discussion

In this section, the results of the research questions are presented. First, the applications of blockchain in the construction industry are identified. Then, the benefits of blockchain technology are summarized, followed by the challenges of blockchain in the construction sector. Finally, ways of resolving the causes of construction delays using blockchain are discussed based on the literature review.

4.1. The Most Common Use Cases of BCT in the Construction Industry

Reviewing the available literature revealed use cases that included real-time record-keeping, and real-time property titles with smart property for all purposes. Table 1 summarizes the identified blockchain applications based on the proportion of selected papers.

In other words, not all the reviewed papers addressed the blockchain applications in the construction industry. The main applications of blockchain in the construction industry are:

Administrative purposes: Blockchain will serve as the backbone for the administrative and paperwork aspects of construction projects. For example, ownership deeds for land lots can be documented in blockchain to guarantee an immutable record [34]. Moreover, all data through the supply chain can be registered, tracked, and monitored in detail including specifications, manufacture details, engineering diagrams, etc. [35].

Use of smart contracts for transactions: The construction industry is an area of business that is replete with disputes. The majority of these disputes are related to payments, which can often involve complex and lengthy discussions about the validity of payments that can be attributed to segmentation. The segmentation of the parties within project is primarily due to the inability to find a single individual who can take full responsibility for the coordination and execution of the project. Smart contracts are simple, self-executing contracts between parties which are written in software code using blockchain technology and contain the rules to execute a contract. Smart contracts can be considered as a mechanism that could potentially eliminate the need for attorneys and other intermediaries. These contracts are produced by software that is programmed to meet specific criteria and rules based on conventional contractual clauses. Because of the way these contracts are programmed, they operate on the if-then principle, which means that for each command where predefined conditions are met, certain actions will automatically take place without the need for human intervention [36].

Smart contract technology could provide a more reliable way to keep track of contracts through a decentralized network. The idea is to create an electronic, self-executing digital agreement between two or more parties. The smart contract can be a process for forming and monitoring construction contracts [27].

Smart contracts are computer programs that facilitate, verify, and enforce the negotiation or performance of a contract (or any other legal document) without the need for those involved to trust each other or depend on an intermediary. The benefits of smart contracts include the elimination of one party being in a position to take advantage of another. They also eliminate the risks involved in terms of using traditional contracts as these do not have to be hammered out and agreed upon every time that one has a transaction with someone. Smart contracts can be implemented with the blockchain protocol which ensures that they cannot be tampered with, adding additional benefits [37]. A smart contract will create an agreement between one or more parties. The contract is programmed with specific conditions that must be fulfilled before the obligations under the contract are considered complete. All of this happens on the blockchain which makes it more secure. Smart contracts can also trigger transactions to release payments once certain contingencies have been met, such as delivering goods or services without the need for any human intervention or traditional money wiring required for other transactions to take place [18].

Permeant transaction records: Information in the blockchain is safe because it is decentralized. This means that if someone changes information in one place, the change would be visible in all places where that information exists. It is also impossible to delete or rewrite history without leaving a trail of evidence [38].

Permeant ownership records: Blockchain also provides complete transparency because it will have an immutable record of all transactions stored on it. Records cannot be lost or altered and can be traced if needed by back to their originator so that they can provide evidence about them when they are needed most [39].

From Table 1, it is clear that most of the papers cited multiple use cases among the identified common four cases. However, a statistical analysis of the involved papers revealed that most of the papers considered the usage of blockchain technologies for permeant record-keeping, followed by smart contracts for transactions, permanent ownership records, and then finally administrative purposes.

Table 1. Summary of the researched papers on blockchain technologies (BCTs) cases in the construction industry.

Refrence	Use Case			
	Administrative Purposes	**Use of Smart Contracts for Transactions**	**Permanent Transaction Records**	**Permanent Ownership Records**
[40]		√		
[41]				√
[42]			√	
[43]		√	√	√
[24]			√	
[44]			√	√
[44]	√	√	√	√
[36]	√	√	√	
[37]		√	√	√
[39]	√	√	√	√
[11]		√	√	√
[38]		√	√	√
[27]	√	√	√	√
[45]		√	√	
[18]		√	√	√
[46]		√	√	
[9]		√		
[47]		√	√	√
[48]			√	
[49]	√	√	√	√
[50]	√	√	√	√
[51]	√	√	√	√
Total	7	17	19	14

4.2. The Benefits and Potentials of Blockchain Technologies in the Construction Industry

Reviewing the literature revealed some of the global use cases of the distributed ledger for the construction industry, presenting the potentials, challenges, and barriers for adoption, the status of blockchain projects and trends, and the role of blockchain in the construction sector.

Hargaden et al. [27] argued that blockchain technology can be used in the construction industry to streamline processes and increase efficiency by proposing a conceptual idea for implementing blockchain technologies within the construction industry. Hunhevicz and Hall [49] encouraged exploration of the utilization of BCT in construction by establishing a correlation between the use of distributed ledger technology (DLT) in construction and the fundamental properties of DLT. The study identified solid use cases where BCT will serve as the backbone of eliminating some of the shortcomings in construction management.

Yanga et al. [51] attempted to apply different actual BCT architectures (Hyperledger Fabric and Ethereum) over two real-world business use cases with a proposed framework to guide future adoption efforts. Both BCTs showed out-of-the-box implementation capability and applicability in construction management. The authors proposed a process design where all stakeholders in a given construction project may utilize a single BCT platform to interact and draw up contractual agreements, supply chain requests, and receipts, architecture designs, clients approvals, planner surveys, and contractors. Turka

and Klinc [44] concluded that blockchain would resolve some of the issues plaguing the adoption of BIM in the construction industry such as confidentiality, traceability, record-keeping, change tracking, and data ownership. Prakash and Ambekar [50] supported the fact that blockchain has the potential to help the construction industry to enhance procurement processes and reduce complexity. In addition, in smart contracts, the efficiency of both business and administrative processes can be elevated through automation to yield perpetual compliance with contractual terms.

4.3. The Challenges of Blockchain Technologies in the Construction Industry

The blockchain has evolved over the last decade. Many technical obstacles such as chain structure, storage, data management, and consensus processes still exist. The body of literature reviewed was used to compile a comprehensive list of the challenges associated with blockchain implementation in the construction industry. Based on the literature, the non-construction challenges mentioned are also applicable to the construction industry; conversely, specific examples to provide context were not available. Furthermore, to ensure that the list was as comprehensive as possible, the grey literature (e.g., news articles, online articles, agency reports, industry reports,) was reviewed. Table 2 demonstrates the challenges of the implementation of blockchain technology based on the reviewed papers that addressed these challenges.

Table 2. Blockchain implementation challenges in the construction industry.

Challenge	Construction Context and Description	Reference
Technological state of the industry	Prior to implementation, there is a fundamental requirement for a certain level of technology to existing within an industry. The industry is still not adequately digitalized to fully benefit from blockchain technology	[52]
Skills	Given the nascence of the technology, there are a significant number of people who are inadequately trained in blockchain. For successful implementation, the industry requires new talent.	[53,54]
Resistance to change	Changes in processes at all levels of the organization are required for implementation. Because the industry has been resistant to change in the past, it is possible that blockchain will not reap all of its potential benefits.	[52,55]
Readiness for adoption	To achieve full adoption, all participants must share information and collaborate. Information sharing, trust, and collaboration are the most critical issues in the construction industry.	[41,56]
Power	The blockchain consensus mechanism uses a lot of computational resources and energy, which results in a low throughput and long delays.	[57]
Malicious attacks	Blockchain is vulnerable to various types of attacks. Theft of data/currency puts construction projects and other projects at risk.	[58]
Legal	There are not enough legal precedents or regulations in place. Construction has a difficult time enforcing regulations because it relies heavily on legally binding contracts to operate.	[59,60]
Interoperability	When various applications need to communicate, data transfer might be difficult. This is already viewed as a major issue for BIM in the construction industry.	[36]
Coding of smart contracts	Human error and poorly written contracts have the potential to be disastrous. All construction projects rely on well-written contracts that spell out all of the parties' responsibilities.	[61]
Connectivity and bandwidth	For system stability and continuous internet connectivity, sufficient server capacity is required. Lack of connectivity could cause parts of the supply chain delivery system to fail.	[53,62]

Blockchain challenges need to be addressed in terms of protocol enhancements. The goal is to figure out how to build smart contracts that will enhance system performance. For

example, instance consensus algorithms which are nodes selected from a small number of trusted endpoints; an adaptive consensus technique to improve the likelihood of high accuracy; a consensus algorithm to reduce network transmissions based on security assertion; a consensus protocol using reliable components; and a consensus algorithm combining PoW and PBFT [63–65]. As a result, researchers are working to develop better protocols that can save more energy, reduce costs, and protect against adversarial power [66]. In addition, data storage has grown so large that maintaining backups at each node is impractical [66]. The problem can be partially solved by lightweight verification nodes, but more effective industrial solutions must be researched and designed. Moreover, the existing blockchains' faults and flaws can be addressed via multichain and sidechain technology. Furthermore, cross-chain technology can achieve interoperability and can lead to enhanced mutual confidence in the face of a variety of blockchain platforms [67]. Regulations and laws related to blockchain activities can be established and improved with extensive knowledge of the blockchain's future. Numerous countries are implementing blockchain technology and enhancing governing measures actively, including privacy concerns, deletion rights and reliability issues, internet real name and anonymization issues, and jurisdiction, decentralization, and legal application issues. Blockchain-enabled smart contracts and distributed verifiable databases have the ability to alter legal and technical limitations, as well as to create new government models. Laws such as equality and justice, however, can benefit from technology solutions by increasing their efficiency and certainty [68]. Furthermore, blockchain trust and security tools combine well with privacy protection, allowing for excellent data visibility and authorization management. Cryptocurrency is used in a safe and fair transaction procedure to increase anonymity, as well as to defend against threats such as anti-DoS and Sybil attacks. A smart contract encrypts data and ensures availability and scalability using distributed hashing methods. The blockchain fixes the issue of guiding sensitive and personal data without the involvement of a third party, as well as calculations and analyses using the actual data without releasing it [69–71].

4.4. The Use of Blockchain Technology to Resolve the Causes of Delays and Disputes in Construction Projects

To better understand how blockchain would resolve the delays in construction projects, the causes of the delays were identified first from the literature. Albogamy et al. [72] identified 63 causes of delays and disputes in construction projects in Saudi Arabia. The researchers carried out the surveys across five Saudi cities to represent the major construction spots. Another study conducted by Assaf and Al-Hejji [73] was carried out in Saudi Arabia and the top contributors to delays were, amongst other things from the owners' perspective, inadequate management practices, poor communication among stakeholders, and delayed payments. The researcher stated the most common reasons behind the relays and disputes in Saudi Arabia based on a questionnaire response from 57 contractors, consultants, and owners. Furthermore, other causes were identified based on the previous papers, as shown in Table 3.

Based on the previous revered articles that were repeatedly cited, it was possible to gain a clear understanding of the main causes of the delays and disputes in construction projects. The analysis of the collected reasons for the delays and disputes plaguing the construction projects revealed the frequency of each cause throughout the investigated literature, as shown in Table 4.

It has been observed that many of the causes of delays and disputes can be addressed by employing blockchain technologies throughout the construction industry which poses the potential for tremendous cost savings.

To better illustrate the relationship between the major reasons behind delays and disputes in the construction projects and blockchain technologies with relevant use cases, the snakey diagram was developed, as shown in Figure 6. The diagram represents how each of the previously identified issues in Table 4 can be resolved based on the analysis retrieved from the literature review.

Table 3. Major reasons of disputes and delays.

No.	Causes of Disputes and Delays	Source
1	Delayed payments	[72]
2	Delay in approval of shop drawings	
3	Delays in the sub-contractor's work	
4	Design changes by the owner	
5	Non-utilization of professional construction contractual management	
6	Short contract duration	[73]
7	Owner delaying progress payments	
8	Contractor failure to finance	
9	Errors in design documents	
10	Lag in material delivery times	
11	Delayed issuance of municipality permits	
12	Unqualified contractors due to low prices bidding	[74]
13	Inadequate communication among construction project stakeholders	
14	Poor construction site management	
15	Payment delays	
16	Work repetition due to change requests, poor materials, or design mistakes	
17	Delayed delivery of design drawings	[4]
18	Delayed in contractors' progress	
19	Delayed payments	
20	Owners' change requests	
21	Design errors	
22	Delayed payments	[75]
23	Delayed permits issuance	
24	Design changes	
25	Delayed payments	[76]
26	Suspension of work to allow change request	
27	Delayed client approvals	
28	Poor contractors experience and qualification	
29	Material availability	
30	Unrealistic time frame	
31	Problems due to subcontractor performance	[77]
32	Contractor cash flow problems	
33	Delay in obtaining approval from public authorities	

Table 4. Frequency and percentage of occurrence of each cause.

Cause	Frequency	Percentage
Delayed payments	6	21%
Unqualified workers	4	14%
Poor communication	4	14%
Rework	4	14%
Delayed permits	3	11%
Documentation errors	2	7%
Late material delivery	2	7%
Contract duration	1	4%
Financial issues	1	4%
Poor site management	1	4%

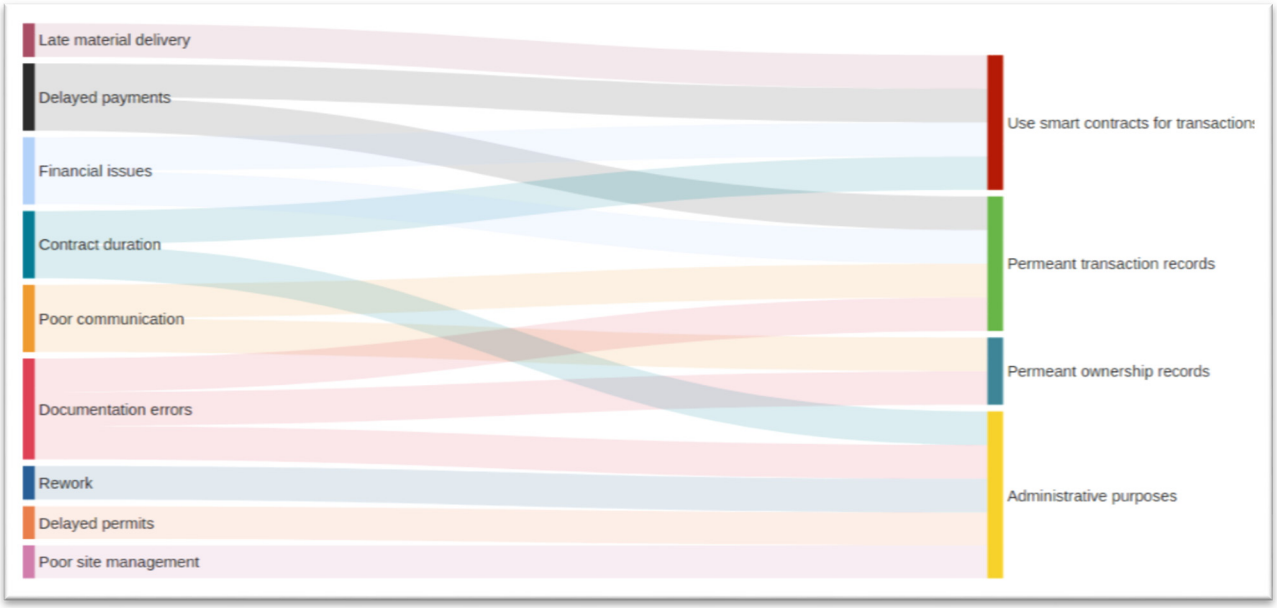


Figure 6. Snakey diagram illustrating the relationship between BCT use cases and major delays and disputes reasons.

4.5. The Benefits of Blockchain in Improving the Processes and Workflows of Construction Projects

This section describes how blockchain technologies can help in resolving the top five construction project disputes and delays as shown in Table 5.

- *Delayed Payments*

The blockchain is a system that functions as a digital ledger for the recording and documenting of transactions. Through the use of blocks, it creates a shared system from which users can view transactions occurring within it, which allows for a faster and easier transfer of assets between two parties without the use of any third-party intermediaries or central authorities. The advantage of this technology over traditional systems is that in addition to speeding up transactions, it also increases security from cybercriminals by making any attempted theft more complicated. The decentralized nature of this technology makes data manipulation more difficult. Another advantage is that recent advancements have reduced the cost of blockchain transactions compared to traditional methods, which may charge fees for each transaction. A company, Skuchain, has offered a new product called Commerce Cloud which ties up the processes of procurement, contracts, and financing arrangements. It also enables direct enterprise control of payments and inventory

mentorship. This solution would assist in the creation of an automated process based on smart contract contractual agreements that would ensure that once a construction milestone is achieved or material delivery is confirmed, a payment is processed [78]. Another construction-focused startup, Bariq, has developed a product called BriqCash that allows contractors to automate their entire accounts payable (AP) workflow from procurement to payments [19].

Table 5. Matched BCT use cases with identified causes of disputes and delays.

Causes	Administrative Purposes	Use of Smart Contracts for Transactions	Permanent Transaction Records	Permanent Ownership Records
Delayed payments		√	√	
Unqualified workers				
Poor communication			√	√
Rework	√			
Delayed permits	√			
Documentation errors	√		√	√
Late material delivery		√		
Contract duration	√	√		
Financial issues		√	√	
Poor site management	√			

- *Rework, Poor Communication, and Documentation errors*

To mitigate rework issues, Building Information Models (BIMs) have been utilized to assist construction stakeholders to detect conflicts and problems in projects beforehand. Moreover, BIMs avoid having poor quality materials ahead of time. Integrating blockchain into BIM will boost its capabilities in elevating rework issues, as BCT can assist in ensuring that designs are well documented and distributed among all stakeholders and changes are made only after consensus is reached accordingly. Moreover, all change orders can be traced and documented in immutable records [24]. BCT would provide a permanent record of documents with cryptographic validation. Blockchain technology could be useful in positively impacting archives by making them more accessible to those who need them in the future [79].

Brickschain is a company that provides a platform for recording, updating, and publicizing projects in blockchain where building information management systems are integrated into the supply chain and workflows of a building. The system records every step of the process, so there is no confusion about how the construction is progressing.

- *Delayed permits*

This issue has been improved in the last few years through the introduction of new platforms. For example, some platforms were developed in cooperation with the various agencies in support of government services. These include the electronic services that help submit electronic applications to extract the most commonly used licenses and the information services that help the beneficiaries to make relevant decisions in a way that contributes to improving the level of satisfaction. In addition, permits from other government agencies are still lacking in digital services. To overcome this issue, blockchain technology is integrated with IBM. IBM is planning to create a blockchain-based solution, then it will integrate the technology into government services [80].

- *Unqualified Workers*

The literature review did not reveal relevant examples or real-world applications where blockchain assisted in elevating the quality of workers' productivity beyond preserving the credentials [81]. However, Tapscott and Vargas [14] proposed a very interesting

idea of utilizing blockchain technology to create a "reputation ledger" where contracts and subcontractors' deliverables will be tracked in an immutable record which enables the project owners to access reliable contractors and subcontractors for their projects.

The main findings of this paper are shown in Table 6. It shows that blockchain has many uses in the construction industry which improve the efficiency of the processes and workflows in construction. Furthermore, the results explain how the benefits of blockchain can be harnessed to improve construction management, remove the shortcomings and complexity, improve procurement processes, and improve communications among all stakeholders. In addition, the findings revealed that blockchain implementation can resolve many causes of the delays and disputes throughout the construction industry, which has the potential to save enormous amounts of money.

Table 6. The main findings of this study.

Question	Answers
What are the most common use cases of BCT in the construction industry?	Administrative purposes. Use of smart contracts for transactions. Permanent transaction records. Permanent ownership records.
What are the benefits and potential of blockchain technologies in the construction industry?	Streamline processes and increase efficiency by proposing a conceptual idea for implementing blockchain technologies within the construction industry. Eliminate some of the construction management shortcomings by establishing a correlation between the use of Distributed Ledger Technology in construction and the fundamental properties of Distributed Ledger Technology. Improve communication between all stakeholders. Resolve some of the issues plaguing the adoption of BIM in the construction industry. Enhance procurement processes and reduce their complexity. Elevate the efficiency of both business and administrative processes through automation to yield perpetual compliance with contractual terms.
What are the challenges of blockchain technologies in the construction industry?	Technological state of the industry. Skills. Resistance to change. Readiness for adoption. Power. Malicious attacks. Coding of smart contracts. Interoperability. Legal. Connectivity and bandwidth.
How would blockchain technology resolve the causes of delays and disputes in construction projects?	Create a shared system from which users can view transactions occurring within it. This allows for the faster and easier transfer of assets among parties without the use of any third-party intermediaries or central authorities. Enable direct enterprise control of payments and inventory mentorship. Ensure that designs are well documented and distributed among all stakeholders and changes are made only after consensus is reached. Trace all change orders and document them in immutable records. Submit electronic applications to extract the most commonly used licenses and the information services that help the beneficiaries to make relevant decisions in a way that contributes to improving the level of satisfaction. Create a "reputation ledger" where contracts and subcontractors' deliverables will be tracked in an immutable record.

- *Study Limitations*

Although blockchain is the biggest buzzword in the industry, there are many opportunities for this emerging technology to be used in construction projects, which typically entails the coordination and the transfer of ownership of assets. The use of blockchain would improve coordination and also reduce disputes due to a shared client–contractor database. However, while opportunities exist to use blockchain applications in construction, there are few limitations that must be addressed first. The first limitation is lack of personnel expertise on how to implement blockchain into an organization's existing processes. The second limitation is the limited research on the benefits of blockchain for specific stakeholders. In addition, some search keywords such as "blockchain" and "construction" could have very overreaching results. Moreover, the scattered and very conservative nature of the construction industry made it difficult to obtain firsthand data to build a meaningful sample of contractors and project managers' feedback.

5. Conclusion and Recommendations

This study conducted a systematic literature review of previous papers with the aim to identify the potential, challenges, and use cases of blockchain in the construction industry and to explore the benefits of implementing BCTs to enhance the workflow efficiency in construction projects. The study also identified the major causes of disputes and delays in the construction industry. The identified causes of disputes and delays were used as a baseline for evaluating the most relevant solutions provided by blockchain technologies with the purpose to find applicable solutions from the literature and real-world cases to resolve the identified causes.

The study identified five practical solutions provided by blockchain technologies to resolve the causes of disputes and delays in the construction projects including the administrative purposes, smart contracts for transactions, permanent transaction records, and permanent ownership records.

Moreover, the study revealed that blockchain technology holds the potential to transform construction projects into more transparent and efficient enterprises by reducing or even eliminating information asymmetries between various stakeholders on a project's team. This technology could help reduce risk and improve project performance while decreasing the time it takes to complete projects by automating certain activities that are currently being handled manually or by subcontractors. However, the lack of experience to implement blockchain and the limited research on whether there can actually be benefits for specific stakeholders are limitations that may hinder the advancement of blockchain in organizations. Moreover, the construction industry has been known to be slow in adopting blockchain technological advances, especially in improving its processes and workflows. In light of the conducted research study, it is recommended that:

1. Blockchain technologies are to be considered by concerned parties by collaboration among both public and private sectors to develop a standardized platform to provide a trusted and a commonly accessible platform to enhance the loosely regulated construction sector by utilizing its immutable records and smart contracts features.
2. Building Information Models (BIM) are to be adopted and encouraged to provide an interactive environment where all stakeholders can work together with architects, engineers, contractors, and other professionals on every aspect of the project. This shall be supplemented and integrated with blockchain technologies to document all aspects of the project and track the required material as per agreed upon specifications and designs.

Future research may focus on analyzing the capability of blockchain technologies in real life construction industries and developing simulation models to understand the theoretical and working aspects of blockchain technologies. Inputs from multi-disciplinary parties such as construction stakeholders, blockchain experts, and researches are required to advance the adoption of blockchain technology and to efficiently and successfully integrate blockchain technology with construction decentralized applications.

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