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Systematic Review

Smart Contracts in the Construction Industry: A Systematic Review

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Abstract: On-time delivery of documentation and contracts has been recognized as a crucial requirement for the successful delivery of projects. However, the construction industry still depends on time-consuming traditional contract processes, which negatively affect the overall productivity of projects in the industry. The use of Smart Contracts (SCs) is highlighted as a suitable novel technology to expedite the contract processes and establish a reliable payment environment in the construction industry. Whilst there has been an increase in the debate about the use of SCs in construction in recent years, their use in practice still seems to be in its infancy. As such, the topic will benefit from a thorough review of benefits, drivers, barriers and strategies that can enhance the implementation of SCs in construction. This article presents the key findings from a Systematic Literature Review (SLR) on SCs in the construction industry, critically assessing existing studies on the topic. The study initially involved 171 research papers for the SLR process, and out of that 49 research papers were filtered for further analysis after reading their abstracts. A total of 30 papers were finally filtered after the full-text reading for the SLR. Descriptive and content analysis were used to analyse the full-text findings. The study graphically mapped the bibliographic materials by using the Visualization of Similarities (VoS) Viewer software. As per the findings, the topic has mostly been researched in Asia and the Pacific as a region and China as a country. It was noted that there were more empirical articles than theoretical studies related to SCs, evidencing the industry relevance of the issue. A total of 55% of the articles reviewed have been published in journals with a Q1 ranking. All the articles were written by multiple authors, with 30% of the journal articles having international co-authors and benefitting from the collaboration between authors. Key advantages identified in the literature go beyond contract and payment provisions and include aspects such as logistic handling, decentralized applications, business process management, automated payments, etc. Key drivers for adoption are supply chain pressure, competitive pressure, top management support, simple layout, reduction in risks of clients, clarity in responsibility and risk allocation, whereas the key barriers include insecurity, limited observability, incompatibility, inactive government collaboration and limited storage capacity. Key strategies to enhance the application of SC in construction include integrating theorems proving symbolic execution, using the selective transparency method and lock fund system, testing the integration of SCs with other systems at the initial stage, incorporating semi-automated consensus mechanisms for payments, constructing a mechanism to actively engage with government bodies, etc.

Keywords: smart contracts; construction industry; systematic literature review; bibliographic; automation

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1. Introduction

Globally, the construction industry is expected to spend $15.2 trillion by 2030 [1]. According to the Construction Output Census 2022 report, the annual rate of construction industry output price increases was around 7% in the year through March 2022, and this was the strongest annual rate since 2014 [2]. Although the construction industry is among the prominent industries in any country, it is still plagued by various issues. The three

main constraints of time, cost and quality are often considered the most important factors in a project's success or failure, and these metrics are, therefore, consciously managed throughout the project duration [3]. However, various issues (e.g., disputes, delays, overruns, etc.) related to these factors are common occurrences in construction projects. The contract process involved in construction is highlighted as a root factor for such issues in construction [4]. The construction industry mostly relies on traditional contracts and information-intensive payment applications, which are time-consuming to create and essentially depend on a human workflow [5]. Hence, project stakeholders suffer from delays or non-payments, making construction projects credit-heavy and financially challenging [6]. These payment issues are substantially contributing to various problems related to suppliers and subcontractors [7]. Further, a study conducted in 2017 by the McKinsey Institute recognized difficulties making traditional contracts as one of the seven major barriers to the progress of construction projects [8].

Construction projects typically involve a supply chain consisting of hundreds of organizations, especially when used to deliver major construction projects and generate a vast amount of project information. With the advent of novel digital technologies, new opportunities have emerged for managing this vast amount of project information and solving various issues in the construction industry [5]. Today's construction industry has access to digital technologies such as digitalized data, robotics technology, building information modelling, deep learning, machine learning, etc. Smart Contracts (SCs) is one such digital technology that has demonstrated a novel approach to addressing the inefficiencies in the payment system [9]. SC can be recognised as the algorithmic description of a contractual transaction protocol that is written in a programming language that is relevant to a specific domain and that is automatically executed according to the information provided by its parties [10]. SCs can be beneficial to the stakeholders in a construction project, including clients, contractors, consultants, subcontractors, suppliers and many more [11]. SCs can result in time- and cost-saving and facilitate a smooth contract process [12,13]. Especially, Verified Market Research reported that the global SCs market size was valued at around $145 million in 2020, and it is projected to reach approximately $770 million by 2028, recording a compound annual growth rate of 25% from 2021 to 2028 [14].

This paper presents a Systematic Literature Review (SLR) of SCs in the construction industry. Despite the revolution of digital technologies and their profound involvement in the construction industry, such an extensive SLR purely related to SCs does not exist yet in the literature. This research addresses this knowledge gap by presenting the results of an SLR of the literature related to SCs in the construction industry published from January 2005 to August 2021. This SLR contributes by improving our understanding of the current status of SCs in the construction industry and making the available evidence accessible to decision-makers. This research aimed to assess the demographic information in published studies on SCs in construction and review their content in terms of drivers, barriers and strategies to facilitate the implementation of SCs. The article first introduces SCs and their operation before discussing the method followed in undertaking the systematic literature review. A bibliographic analysis of trends observed in published articles is then presented. Finally, a summative analysis of drivers, barriers and strategies for implementation as reported in the published literature is presented.

2. Background

2.1. Issues in the Construction Industry

Despite the major contribution of the construction industry to the national economy in any country, it is well known that the industry has long been plagued with late or non-payments [5,7]. Severe issues affecting the construction industry are delays in payments and other payment-related disputes among the parties in construction projects [15]. These issues result in cost and time overruns and difficulties in cash flows, as well as business bankruptcy [16]. Further, exceeding payment deadlines, lack of payment assurance, refusals and rejections to paying as the major contributing factors to contractual disputes in

construction [17]. On the other hand, the construction industry has been traditionally slow in innovations and digital improvements [18]. Moreover, limitations in knowledge and understanding of various technologies among stakeholders in the construction industry might influence most of the issues. Apart from that, many studies highlighted that there is a poor implication of modernization-related technologies in the construction industry when compared with other industries, such as logistics, automotive, hospitality and mechanical engineering [19,20].

Even though contracts and payment processes involve automation techniques and digitalized data, most contractual applications still depend on ineffective and inefficient manual or human operator-based work processes that are time-consuming to design or prepare, review, approve and finally execute [5]. To mitigate these identified issues and enhance total productivity, the construction industry needs to adhere to digitalized mechanisms and novel technologies that are effective and efficient in cost, quality and time to implement and operate. Smart contracts are identified as one such technology that can deliver significant benefits to the industry.

2.2. Smart Contracts

SCs have contributed to various industries, such as healthcare [21], banking [22], hospitality, etc. Compared to other industries, the construction industry deals with failures related to payments and disputes in contracts on a recurrent basis [5]. The involvement of SCs is considered a potential initiative that could help the construction industry to mitigate such issues. For instance, they offer the ability to automate payments to be released on a set date without delay, thus removing the potential for late payment. The industry has long desired to establish a reliable payment environment to mitigate issues in the construction process, and therefore, any positive contribution from novel technologies is a welcome addition [15]. The construction industry, however, is seen as an industry that is resistant to adopting novel technology [23].

Accordingly, SCs have been recognized as a promising technology to expedite time-consuming contract processes. Szabo first introduced the concept of SCs in his study conducted in 1994, which explains the SC as a transaction protocol that executes the terms and conditions of a contract [24]. A SC can be described as a computerized transaction protocol that replicates binding contracts through codes [24]. Further, SC is one of the essential elements of blockchain technology, which uses computer protocols to facilitate beds of automatic implementation of pre-defined and pre-agreed legal conditions based on decentralized network coding [25,26]. However, there is no generally accepted definition of SCs. Even though terms such as digital contracts and intelligent contracts are used to refer to the SCs, all of these terms seem to share similar ideologies. SCs are used as an alternative to traditional contracts, also known as paper contracts, that result in negotiation among construction parties, and which are created to represent parties' obligations in relation to a specific work [27]. Moreover, SCs are established by coding traditional paper contracts in a digital or computer environment. Because of the digital and code-based nature of SCs, the requirement for the physical presence of parties is excluded from drafting the contract clauses, and the virtual presence of parties is only expected. Due to this virtual interaction, a digital signature is replaced with a wet signature to approve and sign the contract clauses [15]. Contract overhead costs and other transaction costs are significantly decreased because of the absence of intermediaries [28]. Accordingly, a SC guarantees the trustful chain of interaction and payments between project parties [15]. Moreover, expenses regarding notaries and administrations are also mitigated. It also helps to minimize time and cost overruns [15]. Apart from that, the reduction of mistakes, improved transparency and trust-building, and better predictability in cash flows can be recognised as benefits of SCs when compared with traditional bank-related payment methods. A cryptocurrency is a peer-to-peer digital currency system that is used to exchange currency units through a computer network and the transaction fees for cryptocurrencies such as Ethereum are between 0 to 4 dollars, which are lower than bank transaction costs.

2.3. Operation of Smart Contracts

In SCs, clauses and instructions required for the operation of a contract can be coded into a computer programme and can be programmed to be actioned automatically when the coded contractual conditions are fulfilled [10]. Therefore, SCs are known as a self-enforcement type of contract [10]. SCs allow a digital transaction—for example, the payment amount—to be embedded in the system and then automatically transferred to the contract parties [28]. Moreover, payment security is also ensured in this process by blocking the amount to be paid, and no single person can access the blocked money [15]. The blocked amount is only released to relevant parties if the coded terms and conditions are satisfied. Therefore, SCs are decisive because of the presence of a binary logic, which dictates the input and output are the same, and the functions of contract conditions rely on coded scopes [15].

Additionally, Cardeira introduced a payment platform that depends on SCs and implements multiple participants in a project to facilitate the payment process by using coded programs [29]. In this web payment system, once the instructions are fulfilled, the amount is released automatically, and therefore, the contractor is unable to withdraw the payment unless the subcontractors are paid. Since SCs are decentralized, third parties involved in a project, such as banks, can be minimised in the payment process. In detail, project parties can code contract clauses—such as the amount, the due date of payment, etc.—in the procurement stage of the project, and this payment amount and due date need to be embedded in an SC. Moreover, none of the project parties can access this amount until the due date of the payment. Then the supplier can notify the receiver through the SC as the equipment or material is ordered away, and the receiver can notify the supplier when the ordered goods are delivered. By considering the self-implemented feature of SCs, both parties verify the coded clauses, and then the payment is released to the exporter's cryptocurrency account [15]. Li, Kassem, Ciribini and Bolpagni investigated an approach to integrate SCs with digital ledger technology, BIM, and IoT [30]. In addition, Jin studied the integration of BIM and SCs and identified the working principles by analysing various use cases. These studies emphasised the technical aspects of SCs [31].

Contracts are legal agreements and inevitably involve legal and contractual implications. If a SC is to replicate binding contractual arrangements, it will essentially be subjected to the same jurisdictional legal provisions as a regular contract. Considering the legal nature of SCs, the rapid development of information and communication technologies of SCs has highlighted the concerns related to legal regulations. For instance, in the United States, a "contract" is considered an agreement that is legally binding and enforceable in a court of law. In order to assess the enforceability, state courts normally assess whether common law requirements such as offer, acceptance and consideration are satisfied. The state versions of the Uniform Electronic Transaction Act (UETA) have been amended to incorporate aspects of blockchain and smart contracts [32]. This suggests that jurisdictions, especially in developed countries, are on-board with the implementation of smart contracts. Despite initiatives to make the process more collaborative, construction as an industry still remains an adversarial one, and disputes between parties to a contract are a common occurrence. The objective and streamlined decision-making involved in a smart contract could offer the potential to minimise such contractual disputes between parties. However, if a dispute crystallises, it may inevitably end up in Alternative Dispute resolution (ADR) or ultimately in courts. The right to ADR and legal appeal is guaranteed in standard form contracts used in construction, e.g., JCT and NEC contracts in the UK. Whether SCs could incorporate more collaborative dispute resolution methods, whether they will be subjected to the same legal rights of appeal or whether they will be able to circumvent such provisions will have a significant impact on the operation of SCs. However, some of the ADR provisions, such as adjudication as used in the UK, seem to offer greater potential to be included within SCs due to the more defined process involved. The adjudication provisions used in the UK for construction involve a strict timeline and decision-making process [33]. Therefore, whilst the implementation of SCs will raise important legal implications, it is

probable that well-defined legal rules and regulations can be linked with smart contracts to enhance enforceability.

3. Research Method

The SLR method was utilized in this study to recognize and report on previous research findings in a methodical manner. The VoS Viewer tool was used to visually display the network findings of SLR. SLR is recognized as a rigorous and transparent method, especially for supporting future studies and decision-making [34]. This method builds theories and other relevant concepts by consolidating knowledge after evaluating several studies in a knowledge domain, establishing new knowledge and documenting the state of the art [35].

This research sought to obtain a better understanding of the current research on SCs in the construction industry. Moreover, this study provides new knowledge on the research scope by revealing research patterns that are essential for guiding future research. The study followed the steps of SLR as defined by Kitchenham et al. [36]. Kitchenham et al. developed this procedure as a rigorous and auditable method to conduct SLR [36]. Various studies have followed Kitchenham's procedure to strengthen their research method [37,38]. Initially, five steps were followed to conduct the SLR and then synthesize the collected data and finally report the findings. Formulating research objectives, identifying the search process and inclusion and exclusion criteria, conducting data collection, performing quality assessment and conducting the descriptive analysis were considered when conducting the SLR [36]. Especially, all of the names of the authors were checked for data normalization and standardization to ensure the duplication results.

3.1. Formulation of Research Objectives

In the first step of the SLR process, the research objectives were formulated. The three research objectives (RO) addressed in this study are:

Research Objectives

RO1: Explore the evolution of research on SCs in the construction industry.

RO2: Evaluate the implications and benefits of SCs in the construction industry.

RO3: Analyse the drivers and barriers to adopting SCs in construction and strategies to overcome the identified barriers.

To fulfil these objectives, previous studies were examined where the use of SCs in the construction industry was discussed. To address RO1, previous studies were collected, analysed and reported in tabular formats and figures generated through the VoS viewer software. To address RO2 and RO3, a content analysis was conducted regarding the collected data.

3.2. Identification of the Search Process and the Inclusion and Exclusion Criteria

A manual search regarding articles to be included in the study was conducted as the search process. For this research, the data collection sample consisted of peer-reviewed journal papers related to SCs in the construction industry that was published in the last 16 years from 2005 to 2021, a period where SCs in the construction industry research domain has visibly matured. Scopus was selected as the scientific database for this study due to considering its recognition as one of the largest academic online databases and considering the access to indexed articles it provides [39–41]. Therefore, the sample consisted of peer-reviewed journal articles published in the Scopus database. Books, book chapters and conference papers were excluded from the study. However, this exclusion can be recognized as a common exclusion in SLR [42]. The SLR focused on journal articles explicitly devoted to SCs in the construction industry and the built environment. The sampling was conducted according to the following procedures:

- Define a search string according to the focus of the study and search for articles accordingly. The keywords were mainly categorized into two groups. The first group was

"smart contract" OR "intelligent contract" OR "digital contract". "Construction" OR "building" OR "built environment" OR "civil engineering" was included in the second group. The search string according to the keywords yielded 476 results in Scopus.

- The articles were then refined according to the filters, namely, source type as Journal. Accordingly, 171 articles were found in Scopus. Out of that, only one article was not published in the 2005–2021 category, and it was published in 1996.
- The 171 resultant articles were then screened by reading the article titles and abstracts. To ensure the high quality of the study, only peer-reviewed articles were included. Exclusion criteria of whether the articles were published in English, whether they were peer-reviewed, and whether they focused on an industry other than construction or the built environment were applied at this stage. Figure 1 presents the process of the SLR.

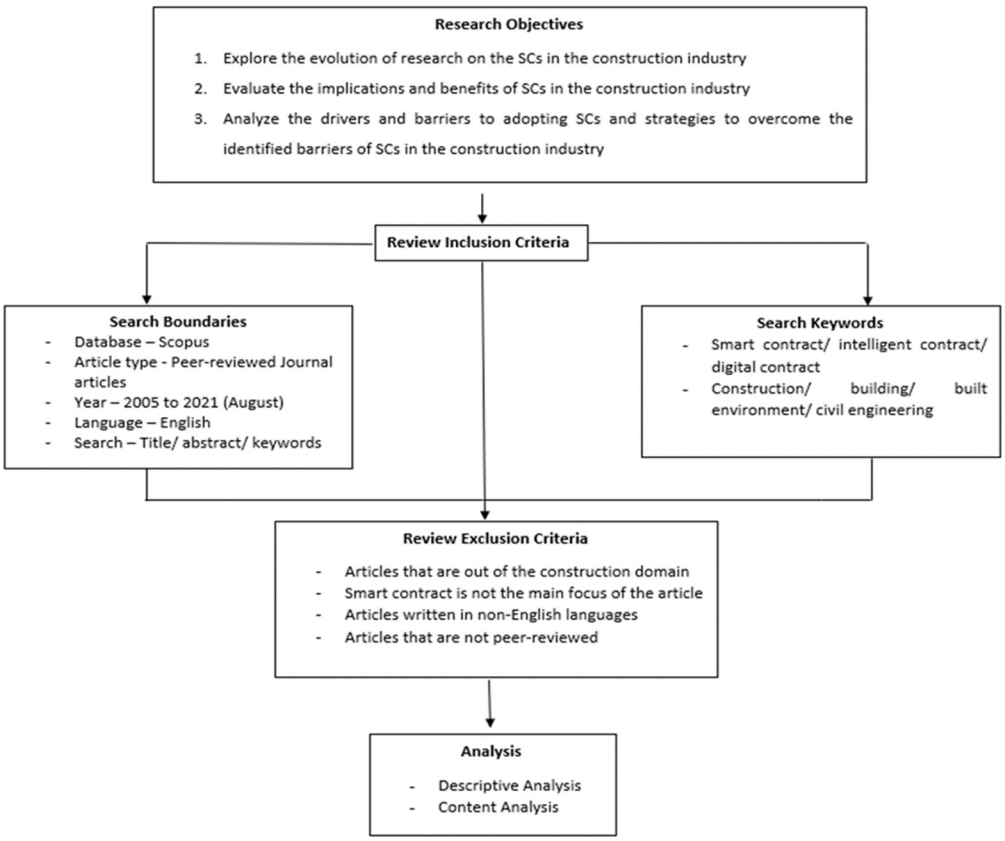

Figure 1. The process of SLR.

3.3. Performance Quality Assessment

A quality assessment was conducted for the reviewed articles by following Kitchenham et al.'s quality assessment steps. Followed steps in this process were:

1. Does the study define the research aim?
2. Does the study describe the research methodology?
3. Does the study describe the data collection method?
4. Does the study discuss the research findings?
5. Does the study discuss the limitations of the study?
6. Does the study discuss future research focus?

Collected articles were evaluated according to these quality criteria, the study's reliability and validity. Table 1 presents the summary of the quality assessment.

Table 1. Quality assessment of SLR.

No.	Quality Assessment Question	Percentage of Qualified Articles through the Assessment Question
01.	Does the study define the research aim?	100%
02.	Does the study describe the research methodology?	100%
03.	Does the study describe the data collection method?	100%
04.	Does the study discuss the research findings?	100%
05.	Does the study discuss the limitations of the study?	55%
06.	Does the study discuss future research focus?	93%

4. Data Analysis and Discussion

This study initially involved 171 research papers for the SLR process and out of that, 49 research papers were filtered after the abstract reading. Among the filtered research papers, 30 papers were selected after the full-text reading and 19 research papers were excluded due to the reasons shown in Table 2.

Table 2. Reasons for excluded papers in the SLR.

Reason for Exclusion	No. of Papers Excluded
Out of the defined time frame (2005–2021)	1
Unavailability of full text	1
Written in a non-English language	3
No critical focus on smart contracts in the construction industry	14

Only one article was published in 1996 that was out of the defined time frame of 2005–2021. Even though the abstract and first page of this article were available, the rest of the study could not be reviewed due to access restrictions, and therefore it was excluded. Three research papers were written in the Chinese language, which was a non-English language, and therefore, those three papers had to be removed from the study. The rest of the 14 research papers were not critically focused on SCs in the construction industry, even though the studies briefly addressed some aspects of SCs in the construction industry. These 14 articles were mainly focused on energy management, supply chain, security, architecture and the financial sector. The remaining 30 research papers were then objectively reviewed and relevant data were extracted and presented in the analysis.

4.1. Evolution of Smart Contracts in the Construction Industry

Descriptive analysis together with bibliometric network visualization through the VoS viewer software was conducted to fulfil RO1 by referring to the following information.

- Publication Year
- Geographic Origin
- Keywords
- Type of Article
- Journal Quality
- Author contribution

Based on the above information, the descriptive analysis was conducted as below.

4.1.1. Publication Year

All the papers in the sample literature on SCs in the construction industry were published in the last four years of the selected period, namely, 2018, 2019, 2020 and 2021. This indicates that although the SC concept was introduced in 1994, peer-reviewed journal articles solely focusing on SCs in construction have only started to emerge in 2018. Recent digital innovations and technical maturity, and slow adoption of new technologies generally

in the construction industry, can be recognized as the reasons for this. Figure 2 illustrates how the analyzed literature is spread in terms of publication year.

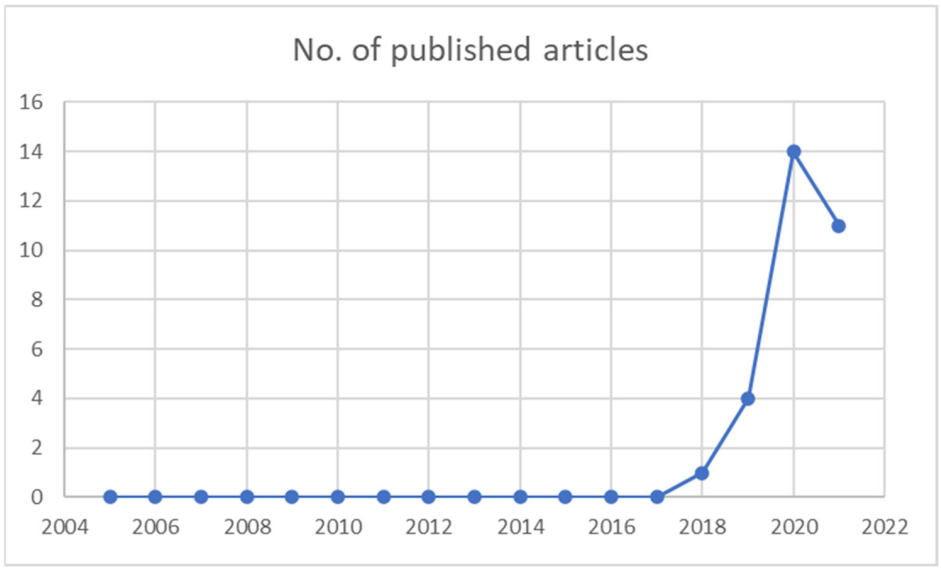

Figure 2. Articles distribution based on the publication year.

After 2018, steady growth can be seen in the research on SCs in the construction industry. The highest number of articles were published in 2020 and 2021, and it is 47% and 37%, respectively. The reason for this distribution may be due to the increased popularity of smart contracting procedures led by technological developments and capabilities in recent years. The inclusion of the most recent articles in the review makes the review topical and current.

4.1.2. Geographical Regions of Origin

Bibliographic coupling of countries publishing in SCs related to the construction industry was considered to identify the knowledge distribution among different nations. The empirical setting of the referred literature sample analysed was typically around the globe; however, Asia & Pacific, Europe, the Middle East and North America can be recognized as the respective regions. Figure 3 displays article distribution among different countries and the country network of publication.

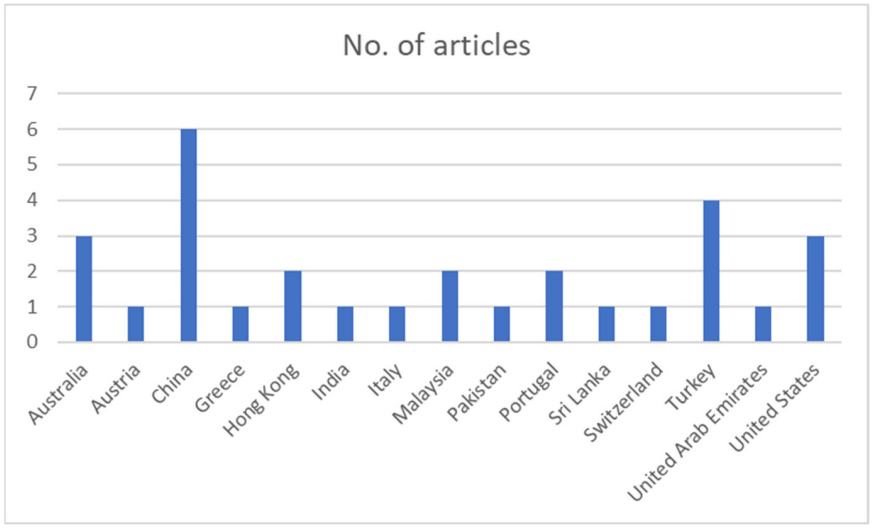

Figure 3. Article distribution among different countries.

According to Figure 3, SCs in the construction industry have been mostly studied in China, with six publications. Turkey was found as the country with the second highest number of publications. Both Australia and the United States were recognized as the countries with the third highest number of published articles related to SCs in the construction industry. Accordingly, the overall number of papers illustrates a country's impact on a particular field of study [43]. Therefore, it can be concluded that the aforementioned countries have the most impact on the SCs in the construction industry. By considering the publication distribution according to the region, the Asia & Pacific region contributed more than half of the articles, demonstrating the enthusiasm of the Asia & Pacific researchers towards SCs in the construction industry as shown in Figure 4.

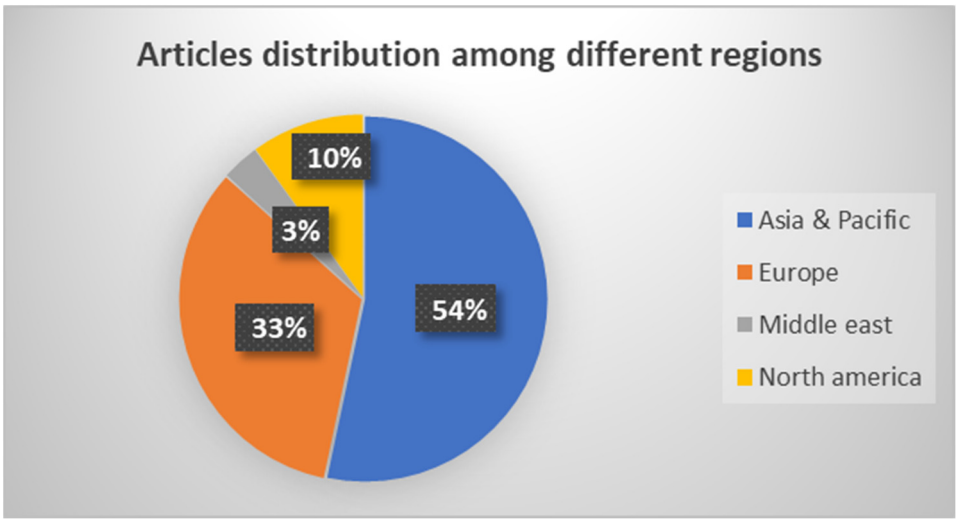

Figure 4. Articles distribution among different regions.

In addition, European countries have produced a considerable number of articles, followed by North America. As per the comparison of the articles in terms of the region, it can be deduced that within the last fifteen years, SCs in the construction industry were a more popular research area in the Asia & Pacific region as opposed to Europe, North America or the Middle East regions, which represent wealthy regions with better research infrastructure. It is no surprise that SC research has been undertaken in countries with a track record of technology use, and developing countries are less well-represented in the sample.

4.1.3. Article Type

The frequency distribution of the articles, whether they are empirical or theoretical, is presented in Figure 5. Empirical articles are those in which authors present their own study by collecting data via interviews, surveys, questionnaires, observation and various other methods to fulfil the research aim. On the other hand, theoretical articles use existing knowledge to make an important theoretical contribution to a research area.

As per Figure 5, 63% of empirical articles contributed to the field of SCs, while only 37% of theoretical articles are available to support the field. This suggests that researchers tend more towards empirical studies to explore novel findings on SCs in different regions. The technology and the practical nature of the concepts are the reasons for these empirical-based studies. For example, Das, Luo and Cheng developed a SCs-based model for securing interim payments in construction projects [44]. However, it can be proposed to improve the theoretical research on SCs in the construction industry to expand the theory-based knowledge in the area.

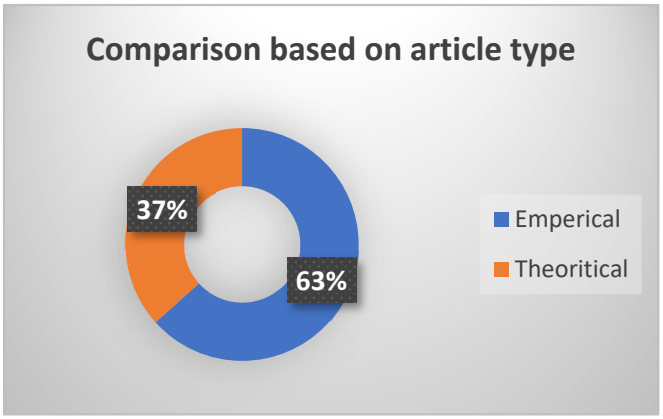

Figure 5. Comparison based on article type.

4.1.4. Journal Quality

The quality of the journal articles was assessed using the ranking of the journal as a proxy. A quartile (Q) in Scopus is a group of scientific journals which is determined by bibliometric indicators that reflect the level of citation. The quartile number shows the ranking of the journal and the demand for the specific journal by the particular research community. Each journal is categorized into four quartiles, namely Q1, Q2, Q3 and Q4. The top 25% of the journals in the list belong to the Q1 group. Q2 is occupied by the journals in the 25–50% group. Q3 represents the journals in the 50–70% group, and Q4 is occupied by the journals that are in the 75–100% group. The most prestigious journals within the relevant research area are in the Q1 group. Accordingly, Figure 6 denotes the quality of articles according to the quartile of their respective journals.

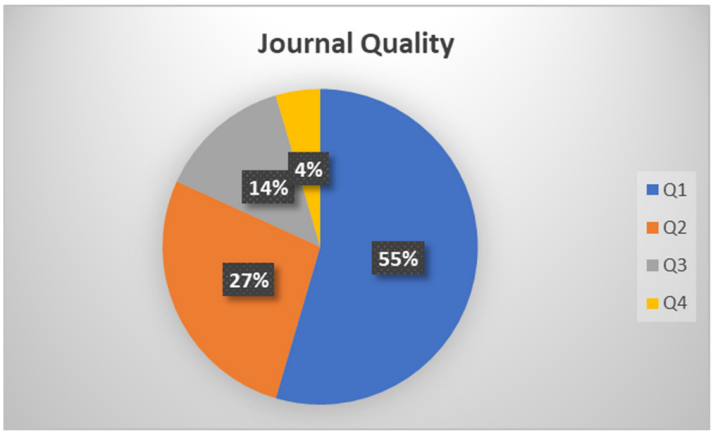

Figure 6. Quality of journals.

As per Figure 6, more than half of the articles (55%) are from the journals ranked in Q1, which are considered higher quality. Furthermore, 27% and 14% of the articles are from the Q2- and Q3-ranked journals, respectively. The lowest percentage of articles are from the Q4-ranked journals. According to the analysis, most of the articles were published in the Q1 and Q2 journals. This adds to the validity and credibility of the findings presented in these articles.Table 3 depicts the list of journals identified through the study. The journal *Automation in Construction* contains the highest number of articles in this study. In addition to that, this journal has been recorded as the most cited journal in another systematic review related to BIM in the construction industry [45].

Table 3. List of Journals that contributed to the SCs in the construction industry.

Name of the Journal	No. of Articles
Advanced Engineering Informatics	1
ASM Science Journal	1
Automation in Construction	7
Buildings	1
Civil Engineering Journal (Iran)	1
Computer Networks	1
Computers, Materials and Continua	1
Construction Management and Economics	1
Defence Science Journal	1
Engineering, Construction and Architectural Management	1
Electronics (Switzerland)	1
IEEE Access	1
IEEE Internet of Things Journal	1
Informatics	1
Information Systems and e-Business Management	1
International Journal of Construction Management	1
International Journal of Safety and Security Engineering	1
Journal of Building Engineering	1
Journal of Construction Engineering, Management & Innovation	1
Journal of Legal Affairs and Dispute Resolution in Engineering and Construction	1
Journal of Facilities Management	1
Journal of Industrial Information Integration	1
Patterns	1
Proceedings of Institution of Civil Engineers: Management, Procurement and Law	1

4.1.5. Author Contribution

The importance of a research paper depends on the quality of the research work. Whilst the number of authors is not an indicator of quality, it does indicate collaborative research work. As per the SLR, all the papers in this study had multiple authors. Figure 7 indicates the number of authors for the research papers in the SLR.

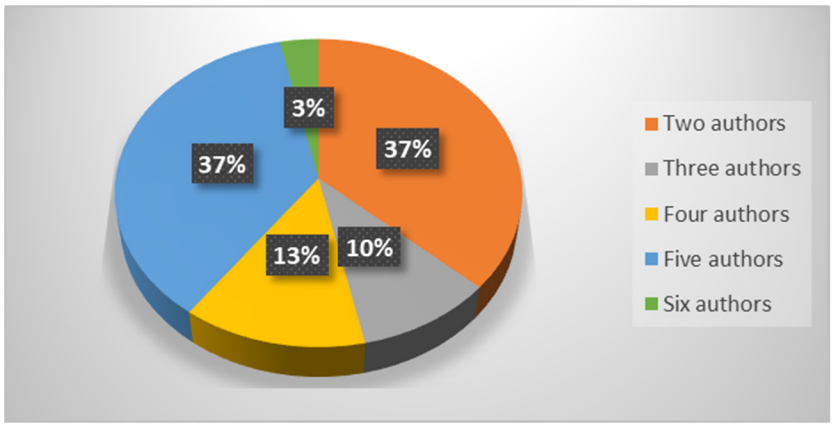

Figure 7. Number of author contributions for articles.

Throughout the 2005–2021 time period, many authors published their work related to SCs in the construction industry. Nanayakkara S., Perera S., Seneratne S, Weinand R., and Rodrigo M.N.N. were identified as the most productive authors who contributed to the SCs in the construction industry with the highest number of publications. The number of citations received by an author is involved in quantifying their influence on a certain research discipline [46]. Table 4 displays the top ten authors with the most citations. The

number of citations reflects the amount of research that has been undertaken on the topic and suggests whether the topic is yet to attract significant research attention. However, it is also noteworthy that these are mostly recent publications and, therefore, they have yet to result in a higher number of citations.

Table 4. Authors with the highest number of citations.

	Name of the Author	No. of Citations
1–3	Nanayakkara S., Perera S, Senaratne S	105
4–5	Weinand R., Rodrigo M.N.N	97
6–10	Gong J., Hu H., Ren X., Wang T., Wang Z.	91

International author involvement was also analysed by considering the country of the authors' institutions. Figure 8 displays the involvement of international authors in research papers. Accordingly, only 30% of the research articles were produced by international authors and the other 70% of the research articles were written by authors from the same country. This suggests that there is scope for further collaboration between researchers based in different countries to advance the topic.

Figure 8. Involvement of International Authors.

4.1.6. Keywords Analysis

Keywords are important research tools as they recognize and indicate the essential areas of the research topic [47]. To identify the most cited keywords that appear on the title page of a published journal article related to SCs in the construction industry and the interconnection between the keywords, Figure 9 depicts the most common keywords selected by the authors in the 2005 to 2021 period.

The keyword "smart contract" appears in the first place with 25 author keyword occurrences in total. In addition, the keyword "blockchain" was ranked second with 20 author keyword occurrences. This indicates that even though this study selected papers that have the highest focus on SCs, "blockchain" displays a strong interrelation with SCs in

the construction industry. Apart from that, "construction industry" was identified as the third most frequent author keyword occurrence, demonstrating that authors have included the context of their research (construction industry) as a keyword, and also demonstrating that the articles selected for this review are relevant to the industry.

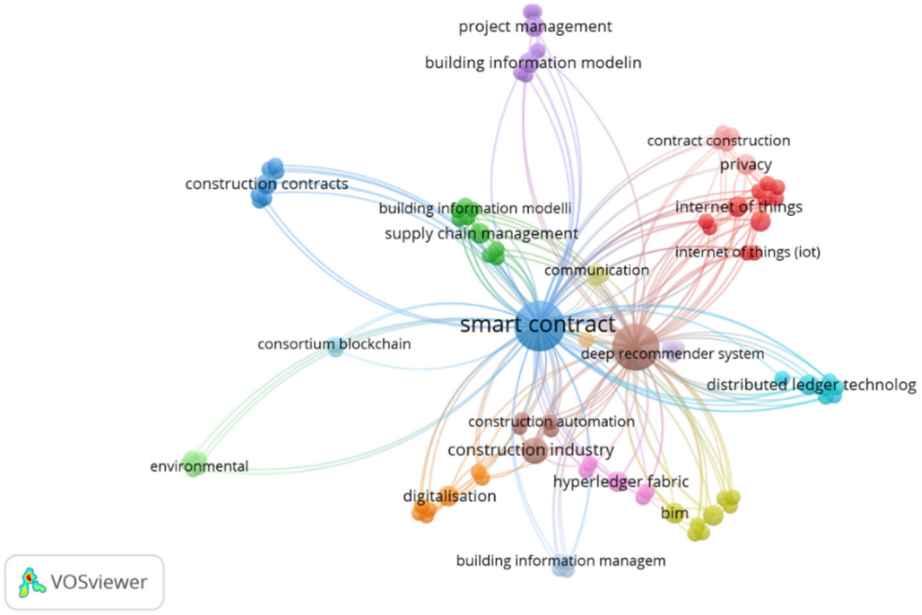

Figure 9. Co-occurrence of keywords.

4.2. Implications and Benefits of Smart Contracts in the Construction Industry

It is noteworthy that the benefits and implications identified in the literature go beyond the payment- and contractual-related benefits discussed earlier in this paper. The literature points to various other applications and benefits that can be derived from the application of SCs in construction, as indicated below.

4.2.1. Automated Payments

SCs consist of protocols that are automated and enforceable [48]. SCs can be used to procure expensive items for an international construction project. As with cryptocurrencies, permissionless or permission-given public blockchains are needed that allow parties to access the blockchain network, such as Bitcoin, Ether and XRP [49]. The current status of a SC will only change when the defined requirements are fulfilled. For example, a buyer cannot order items if he/she does not have the required funds to execute the process [49].

4.2.2. Cash Flow Management

Delayed payments and other cash-flow-related issues are the most common issues in most construction projects [50]. When compared with other industries, the construction industry consists of a chained payment culture and default settlement durations [51]. Apart from that, partial payments and non-payments are common in the construction industry. These issues lead to additional costs and cause a high contract price. The majority of small- and medium-scale enterprises are unable to bear these costs without having a proper payment and cash flow [52]. Due to these issues, many large construction organizations such as Strongbuild, Dawnus, Cooper & Oxley, Interserve and Carillion have moved into administration. Therefore, it is critically important to manage cash flows in construction projects. As a solution to these issues, SC-enabled blockchains with automated payment applications are highlighted at present [50].

4.2.3. Logistic Handling

OriginChain is a blockchain created for tracing products between suppliers and retailers in supply chain management [50]. When a supplier or retailer requires traceability of the process, the two parties can sign a legal agreement that ultimately creates a SC. Due to the limited storage capacity in blockchain, OriginChain stores two different types of data on-chain as aspects of SC: (1) the hash of traceability photographs or certificates and (2) the traceability details required by the traceability regulation. Accordingly, a SC can be utilized between any two parties in a construction supply chain: between the client and the main contractor, the main contractor and subcontractors, sub-contractors and suppliers, and among other contractual parties along the chain [53].

4.2.4. Temperature Monitoring

Wang et al. illustrated the use of SC in temperature monitoring [54]. When the overall temperature level of the construction site is higher than the specified level, the client pays a special allowance to the contractor. Li et al. developed a simulation tool that presents the operation of automating the installation of external thermal insulators [30]. This system is simulated with a coded contract agreement which analyses the process and pays accordingly.

4.2.5. Trustworthy Business Practices

Presently, clients have concerns about purchasing materials directly from suppliers due to trust issues [50]. This results in additional costs due to the involvement of third parties, such as banks and other financial institutions. However, SCs enable payment applications with automation to create high enforceability of the contracts while enhancing trust in the transactions. With a SC, the client can directly buy materials from the supplier by making an initial payment at the ordering stage. Once the materials are delivered to the construction site, the client can release the full payment to the supplier through an automated process [50].

4.2.6. Maintenance Requests

Planned and preventive maintenance play key roles in occupant satisfaction and safety concerns. SC can easily manage maintenance requests, procurement processes and ordering and delivery of products and payments. With a SC, all relevant parties become aware of the status of maintenance requests from the start to the completion of work. These mechanisms enhance the transparency of the process and present the details of the maintenance work [55].

4.2.7. Water Trading

Water trading facilities allow users to buy and sell water resources. Water trading is a highly concerning factor for ongoing construction projects. The majority of water trading activities are governed by government agencies, and they have their own rules and procedures that commonly create trust and transparency issues [56]. SCs and cryptocurrencies can solve these issues while eliminating intermediaries and enabling a transparent platform. One of the US-based water treatment technology providers, OriginClear, is developing a blueprint with the aim of creating transparency and an efficient water treatment process with the involvement of SCs [57].

4.2.8. Transaction Automation

Digital ledger technology can fully automate transactions between external stakeholders with the support of SCs. SC can support creating automatic triggering payments in the construction industry. Automatic triggering is helpful because delays in monetary transactions always create conflicts and disputes [58]. When there is an update regarding the status of the ledger, it causes predefined contractual actions. Moreover, SCs enable automated information sharing while ensuring consistent reporting on construction projects [58].

4.2.9. Decentralized Automation Organizations

Fully automated business organizations, such as decentralized automated organizations, can run on digital ledger technology without any human interactions with the support of SCs. Government rules and regulations and other organizational policies are coded in SCs and incentive mechanisms are worked through a crypto-economic design [58].

4.2.10. Decentralized Applications

SCs consist of code protocols that perform certain logic based on the state of the ledger. Since these SCs operate on digital ledger technology, the codes in the system are immutable unless programmed to be updateable. Therefore, these SCs can be used to create autonomous work processes, such as currencies, securities, utilities, etc. [44]. Many SCs can be used to create decentralized applications or decentralized autonomous business organizations.

4.2.11. Business Process Management

Delayed payments and contract issues have been troubling the applications of the construction process and this has resulted in various disputes and other project failures [7,59]. Since contractual clauses can be coded into SCs and are self-executing, SCs can be involved with cryptocurrencies to create contracts for safeguarding numerous stakeholders in the project from the liquidation of payment withheld and delayed payment [29,59,60]. Luo, Das, Wang, & Cheng introduced a framework for the integration of SCs for automated construction payments [44]. With this system, stakeholders can guarantee the availability of required funds, eliminate payment issues, reduce contract administration time and, especially, create trust behavior, such as human trust and coding trust.

4.3. Drivers and Barriers of Adopting SCs and Strategies to Overcome the Identified Barriers of SCs in the Construction Industry

An extensive list of drivers and barriers related to SCs in the construction industry was recognized from the body of literature reviewed and is presented in Table 5. In Table 5, each driver and barrier has been mapped across four aspects (Technical, Policy, Process and Social) by considering the supported similar literature [61] and its suitability to the SCs in the construction industry.

Table 5. Drivers and barriers to adopting SCs in the construction industry under four dimensions.

Drivers for Adopting SCs in the Construction Industry	Technical	Policy	Process	Social
Supply chain pressure			✓	✓
Competitive pressure				✓
Simple layout to read	✓	✓	✓	
Reduction in risks of clients			✓	✓
The clarity in responsibility and risk allocation			✓	✓
Ease to comprehend from various stakeholders				✓
Reduction in conflict, claim and dispute			✓	✓
Smoother processes in client/contractor relationship				✓
Better stakeholder communication				✓
Reduction in risks of contractors				✓
Improvement in the quality of the procurement process			✓	
Reduction in risks of suppliers				✓
Expediting procurement processes			✓	
Reduction in risks of subcontractors				✓
Adaptability to construction contracts				✓
Smoother functioning in the relationships with suppliers				✓
Smoother processes in contractor/subcontractor relationship				✓
Client's orientation to adopt smart contracts				✓
Cost reduction in the procurement process			✓	
Contractor's orientation to adopt smart contracts				✓

Table 5. *Cont.*

Barriers for adopting SC in the construction industry	Technical	Policy	Process	Social
Insecurities of SCs	✓	✓	✓	✓
Limited observability				✓
Incompatibilities of SCs	✓		✓	
Inactive government collaboration		✓		✓
Limited storage capacity	✓			
Lack of confidentiality			✓	✓
Limited interoperability	✓		✓	
Limited data reliability	✓			
Lack of driving force	✓	✓	✓	✓
Lack of dispute resolution mechanism		✓		
Regulation changes		✓		
Works not accounted for in planning		✓	✓	
Difficulties in defining unforeseen conditions			✓	
Too many variables, complications and calculations'	✓		✓	
Decrease trust and communication due to rigidness	✓	✓	✓	✓
Decrease interaction between parties involved				✓
Cultural resistance				✓
Managers' attitudes towards full control of payment				✓
Frequently occurring vulnerabilities				✓
Incomplete design paradigms	✓			
Inefficient analysis tools	✓			
Low processing rate and complexity	✓			
Lack of privacy	✓			✓
Lack of technological capabilities	✓			
Irrevocable nature of smart contracts	✓		✓	

The following paragraphs provide a detailed discussion of the identified drivers and barriers for adopting SCs in the construction industry.

4.3.1. Drivers for Adopting SCs in the Construction Industry

Badi, Ochieng, Nasaj, and Papadaki conducted a study to identify significant factors that drive the adoption of SCs in the construction industry (CI) in the United Kingdom [53]. This study was based on linear regression analysis and the findings show that environmental factors, such as supply chain pressure and competitive pressure, are the significant determinants for SC adoption in the UK construction industry. The first determinant is the supply chain pressure, and it is consistent with other research that underlines the significant role of supply chain parties in the effective implementation of technological innovation [62,63]. Competitive organizations in the CI may exert conformance pressure on stakeholders to adopt new technologies. In this case, SCs act as a key determinant of transactional technology between supply chain actors. Moreover, SC can add value to supply chains by handling the structural and relational complexity among supply chain aspects through supporting enhanced transparency, efficiency, trust and traceability among supply chain actors [64].

The second determinant is competitive pressure, and it is identified as a key facilitator of technological adoption in construction. In fiercely competitive environments, such as the construction industry, SCs are adopted to facilitate the requirements of clients [53]. Especially, SCs offer an edge that strengthens the competitive position of small firms against rival firms in the construction industry. According to Badi et al., the third most determinant factor for SC adoption is top management support [53]. Top management in CI acts as the main body of support in the integration of SCs for their projects. Further, top management raises awareness of the benefits of SCs and shows the potential changes that can be adopted with SCs. Moreover, they can support eliminating internal forces resisting change, communicate the concept of SC to employees and cultivate positive change for SCs [53].

Koc and Gurgun explored eighteen drivers in their study and ranked them using the fuzzy technique with similarity-to-ideal-solution (TOPSIS) [65]. The findings revealed that a simple layout to read; reduction in risks to clients; clarity in responsibility and risk allocation; ease in comprehending various stakeholders; and conflict, claim and dispute reduction are the top five drivers for implementing SCs in CI. The authors expressed an expectance of becoming "simple to read" as the top driver. As the SC is based on code, it can be argued that it is a barrier too because of the occurrence of coding errors and wrong interpretations of contractual clauses while coding SCs. Moreover, the study clearly explained that SCs can be easy to read as compared to long and complex traditional contracts. Smoother processes in the client/contractor relationship, better stakeholder communication, reduction in risks to contractors, improvement in the quality of the procurement process and reduction in risks to suppliers were listed as the 6th, 7th, 8th, 9th and 10th drivers in the ranking, respectively. Further, expediting procurement processes, reduction in risks to subcontractors, adaptability to construction contracts, smoother functioning in relationships with suppliers, smoother processes in the contractor/subcontractor relationship, the client's orientation toward adopting smart contracts, cost reduction in the procurement process, and the contractor's orientation toward adopting smart contracts were ranked as the next drivers in the list. The findings also revealed a special concern that, other than the advantages of SCs, the reasons to seek adoption were mainly the deficiencies of traditional contract documents.

4.3.2. Barriers to Adopting SCs and Strategies to Overcome the Identified Barriers Insecurity

Security is a vital requirement in the context of SCs. SCs are worked with codes that are stored in the blockchain system, which allows users to start the operation at any time with any participating node. These SCs are usually working as autonomous agents because they provide their accounts and addresses on the networks. Even though it is difficult to modify records stored on a distributed ledger, it is possible to have some misconduct and problems. Some of the notable examples of SC vulnerabilities are the hack of Mt. Gox with $450 million losses and the $60 million in losses related to decentralized autonomous organizations. Brotsis et al. explained that most of the vulnerabilities in SCs apply to Solidity [66]. Solidity is a high-level, object-oriented programming language that is supported by Ethereum. The authors mentioned that this was due to mismatches between programmers' intuition and language semantics. Further, the absence of a single source of documentation is also the main reason for insecurities in SCs [66].

Researchers have developed several techniques and tools to overcome these severe consequences that occur due to the insecurities of SCs. To improve the security of SCs, theorem proving, symbolic execution, model checking and abstract interpretation can be integrated [66]. Theorem proving is one of the most ordinary ways to develop SCs. Theorem proving is a mathematically modelled system for which verification is done by a theorem prover software [66]. Model checking is an automated system for formal verification that applies to systems that can be expressed by a finite-state model. Same as the theorem proving technique, model checking also involves software for verifications, called model checking software, such as NuSMV. Symbolic execution tests data generation and provides proof regarding the quality of a developed system while acting as a testing technique for programs. Symbolic execution can be recognized as the most prominent technique for vulnerability detection in SCs. Abstract interpretation estimates the programme's semantics, and it is one of the basic static analysis techniques. Apart from that, Hamledari and Fischer proposed some strategies to overcome the security barrier [5]. To ensure the security of payment, lock funds systems can be integrated. In this system, funds in the SC account are locked for 30 days and reduce the trades' involvement in the insolvency of clients. In addition, the selective transparency method, which exposes sensitive information to key contract parties only, can be used to secure SCs.

- Limited Observability

Observability can be recognized as a barrier to SC adoption. Limited publicity and a smaller number of available use cases trigger the observability factor as a barrier (Badi et al., 2021). According to the descriptive statistical analysis conducted by Badi et al. in 2021, 35% of respondents agree that there is an absence of publicity about the advantages of SCs, and also nearly 75% of respondents are not aware of whether other companies involving SCs have had a positive impact using such contracts or not [53]. This clearly communicates the inability of practitioners in CI to recognize the positive impact of SCs, which acts as a barrier to the wider adoption of SC in the industry.

- Incompatibility with Standards and Laws

The incompatibility of SCs with other existing contractual systems can be recognized as a barrier [53]. According to the study, only 33% of respondents stated that SCs are compatible with other systems, while the rest of the participants highlighted how SCs need to be improved with proper compatibility. Moreover, the European Parliament report of 2017 also expressed concern regarding the compatibility of SCs and identified the inevitable variations, especially with long-duration pre-coded SCs [67]. The report also suggested that organizations need to bear some high initial costs to overcome this barrier and to make a smooth integration process. However, the integration of some of the legal/contractual provisions included within the tried and tested standard form contracts, such as the NEC and JCT contracts, may help SCs to be streamlined with jurisdictional requirements as well as client requirements.

- Inactive Government Collaboration

Badi et al. mentioned that the role of government in supporting the development of SCs is observed to be unclear [53]. A considerable number of respondents in this study were unable to provide a definitive view of the involvement of the UK government in SC adoption. Among the respondents, 52% remained neutral on whether rules and regulations regarding SCs are transparent, while 49% neither agreed nor disagreed that construction projects are legally protected through SCs. Not only that, around 39% of respondents were unable to determine whether government rules and regulations are fostering the adoption of SCs or otherwise. The authors suggest that government involvement in SC development needs to be increased and solid work needs to be done to strengthen the legal aspects of SCs.

Further, Li et al. mentioned that SCs always struggle with barriers, such as limitations regarding storage capacity, confidentiality, interoperability and data reliability [61]. Gurgun, & Koc conducted a study in 2021 by using fuzzy AHP analysis to identify the barriers associated with SC adoption [68]. The study categorized risks into five categories, namely managerial, planning, contractual, relational and cultural. According to the results, lack of driving force, lack of dispute resolution mechanism, regulation change, works not accounted for in planning, difficulties in defining unforeseen conditions, "too many variables, complications, and calculations", decrease trust and communication due to rigidness, decrease interaction between parties involved, cultural resistance and managers' attitudes towards full control of payment were ranked as the top barriers in each main category. Apart from that, Mason and Escott highlighted the requirement of an additional driving force to mitigate the resistance to change in the construction industry [20]. Furthermore, for better improvement of SCs, a considerable amount of initial cost needs to be invested for SCs in CI [69]. Other types of issues related to changing conditions resulting from a lack of information during the planning stage—namely site conditions, weather conditions, etc.—could lead to underperformance of SCs in CI [70].

Hu et al. recognized five barriers of SCs in their studies: frequently occurring vulnerabilities, incomplete design paradigms, inefficient analysis tools, low processing rate and limited complexity, and lack of privacy [71]. The study highlighted various industries that are experiencing threats and risks related to SCs due to their poor security and privacy practices. According to the interviewees in the study, incomplete design paradigms of SCs impact the identification of significant risks in the system. However, since the SC concept is

still in the developing stage, paradigms may also change rapidly and are far from adequate. In addition, several paradigms in the present might be found to be impractical, inefficient or vulnerable in the near future. When considering the inefficient analysis tools, the authors stated that most of the tools are inefficient, and they need extra effort to perform in the relevant language correctly. The trade-off between high accuracy and full coverage was also recognized as a barrier in current practice. Moreover, the low processing rate of SCs acts as a cause for delays in current transactions. Even though off-chain networks and other systems are practiced to ensure the privacy of SCs, they rely on additional cryptographic processes that are still in the developing stage. Therefore, lack of privacy can be identified as a common barrier that is still present. Hamledari and Fischer proposed the integration with building automation models (BIM) as a solution for transparency issues in SCs [5]. The study has introduced a framework for using 5D BIM for automated billing and bill of quantities in the project while enhancing the transparency of SCs. Sillaber et al. highlighted the auditing of SCs with testing and validation as one of the suitable methods to eliminate the poor quality issues in SCs and to enhance transparency [72]. According to the above findings, Table 6 presents the barriers to SCs and the relevant strategies to overcome the identified barriers.

Table 6. Barriers and Strategies to Overcome the Identified Barriers of Adopting SCs in the Construction Industry.

Barrier	Strategy	Source
Insecurities of SCs	– Create single key documentation. – Integration of theorem proving symbolic execution, model checking and abstract interpretation. – Selective transparency method and lock fund system.	[5,66]
Limited observability	– Publish successful cases related to the involvement of SCs. – Enhance the private sector involvement to conduct seminars, forums and other knowledge-sharing methods.	[53]
Incompatibilities of SCs	– Invest high initial cost to test the integration of SCs with other systems at the initial stage of the project.	[53]
Inactive government collaboration	– Build up a mechanism to actively engage with the government regarding SCs adoption. – Promote successful SCs aid projects and make them aware of the overall benefits.	[53]
Limited storage capacity	– Keep in mind the theoretical and practical storage limitations of different types of SCs from the initial stage.	[61]
Lack of confidentiality	– Keep sensitive information only visible and available to key parties and provide access through a secret password key. – Involve semi-automated consensus mechanisms for payments.	[5]
Limited interoperability	– Use of a developed framework that is using 5D BIM in the context of automated billing, extracting BOQs. – Validate the introduced systems or processes for better interoperability.	[5]
Limited data reliability	– Maintain a full set of documentation even after the SC is no longer used. – Check and validate the information in the SC by involving separate parties.	[72]

Table 6. *Cont.*

Barrier	Strategy	Source
Lack of driving force	– Consider SCs as a top required criteria when awarding the project. – Project owners need to be acted as the driving force by considering relevant selection criteria at the tendering stage.	
Lack of dispute resolution mechanism	– Define conflicting criteria in a quantitative manner. – Involve human intervention mechanisms for complex disagreements.	
Regulation changes	– Include external sources and other documents related to encoded rules and regulations. – Avoid complex legal expressions while coding. – Introduce procedures related to regulation changes during the initial drafting stage.	
Works not accounted for in planning	– Develop semi-automated modules within the SC which need to include new work. – Get necessary approvals from relevant parties.	
Difficulties in defining unforeseen conditions	– Engage semi-automated algorithms which reduce unforeseen conditions.	[68]
Too many variables, complications and calculations	– Maintain codes, calculations and variables of different projects separately.	
Decrease trust and communication due to rigidness	– Implement human intervention when communication is essential, namely dispute resolution mechanisms.	
Decrease interaction between parties involved	– Involve human intervention with a dyadic nature.	
Cultural resistance	– Implement SCs with demonstrating their drivers and benefits in an industry-led innovative platform.	
Managers' attitudes towards full control of payment	– Consider payment-related issues in advance. – Use SCs as a controlling mechanism for milestones of the intended payments or projects.	
Frequently occurring vulnerabilities	– Testing each and every code in the SC. – Involve security analysis tools to check the bugs and other vulnerabilities.	[69]
Incomplete design paradigms	– Test and validate design paradigms that can be found in the literature.	[71]
Inefficient analysis tools	– Maintain immutable distributed ledger in the SC to act as an intelligent contract enforcement mechanism.	[73]
Low processing rate and complexity	– Involve a dedicated watchdog, which is a software that tracks SCs operation and alerts in emergency and problematic situations. – Simplify the conditions in traditional contracts to suit the programming requirements in SC.	[72]
Lack of privacy	– Do not allow sensitive data and information publicly available. – Involve on-chain encryption mechanism for relevant cases.	[58]
Lack of technological capabilities	– Adapt industrial policies, address legal hurdles and develop new business models	[74]
Irrevocable nature of smart contracts	– Careful monitoring during runtime in the development phase. – Actively maintain the feedback loops with backend parties, SC developers and customers and discuss necessary improvements.	[72]

5. Conclusions

It is no secret that the construction industry is often associated with problems such as late payments and other finance-related issues. There is substantial scope to involve current and emerging technological solutions to address some of such age-old problems prevalent in the construction industry. Digitalizing the built environment is therefore recognized as a key priority for the industry. As part of the digitalization agenda, attention is now being paid to traditional contracts. Research findings have evidenced that SCs are now advocated as the next wave in digitalizing traditional contracts into code-based digital contracts. This study contributes to the literature by providing a state-of-the-art SLR on SCs in the construction industry. SLR was conducted to identify the evolution of SCs in the construction industry by evaluating bibliographical information from the journal articles, implications and benefits of SCs, drivers and barriers to SC adoption in the construction industry, and strategies to overcome the identified barriers. The review makes a niche contribution to knowledge by contextualizing current research on SCs in construction under one roof.

This research has identified the evolution of research, implications, benefits, drivers, barriers, and strategies to overcome the identified barriers to SCs in the construction industry through a SLR. According to the key findings, the highest number of articles were published in 2020, and when considering the distribution of the articles among different countries, SCs in the construction industry have been studied mostly in China as a country and Asia & Pacific as a region. Especially, more than half of the articles were reported in journals ranked as Q1, which is considered higher quality. Further, Nanayakkara S., Perera S., Seneratne S, Weinand R. and Rodrigo M.N.N. were identified as the most productive authors, who have contributed to research on SCs in the construction industry with the highest number of publications. On the other hand, keywords are important research tools as they recognize and indicate the essential areas of the research topic. Accordingly, the keywords "smart contract" and "blockchain" were in first and second place, respectively. In addition, various implications and benefits that can be derived from the application of SCs in construction were recognized. Automated payments, cash flow management, logistic handling, temperature monitoring, trustworthy business practices, maintenance requests, water trading, transaction automation, decentralised automation organisations, decentralised applications and business process management were highlighted as implications and benefits of SCs in the construction industry. Further, 20 drivers and 25 barriers were identified and categorized into four aspects, namely technical, policy, process and social. Moreover, strategies to overcome each identified barrier were highlighted in this research.

Nonetheless, there were a few limitations of this review. Non-peer-reviewed articles were excluded from the analysis. This, however, has ensured that only articles considered of higher quality were included in the review. Sources such as websites, blogs, social network posts, etc., which are considered grey literature, were excluded in this SLR. Yet, it is noted that such sources are commonly referenced by industry practitioners, and valuable information related to SCs in the construction industry is shared through such grey literature. Such sources, however, may not be evidence-based and lack credibility for inclusion in a review of scientific articles. Given the selection criteria adopted, there is a possibility of the exclusion of articles that contain information related to SCs in the construction industry, but that do not explicitly mention this in their titles, abstracts or keywords. Moreover, future research work is recommended to explore the potential impacts of the strategies identified to increase the adoption of SCs in the construction industry.

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References

1. Oxford Economics. Future of Construction: A Global Forecast for Construction to 2030. Available online: https://resources.oxfordeconomics.com/hubfs/Future%20of%20Construction_Full%20Report_FINAL.pdf (accessed on 22 May 2022).
2. Construction output in Great Britain—Office for National Statistics. Available online: https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/bulletins/constructionoutputingreatbritain/march2022newordersandconstructionoutputpriceindicesjanuarytomarch2022 (accessed on 22 May 2022).
3. Eke, G.; Elgy, J.; Wedawatta, G. Establishing a Link between Contractor Selection Strategy and Project Outcomes: Simulation. *Study J. Constr. Eng. Manag.* **2019**, *145*, 04019062. [CrossRef]
4. Atkinson, R.J.; Tennakoon, M.; Wedawatta, G. Use of new models of construction procurement to enhance collaboration in construction projects: The UK construction industry perspective. *J. Financ. Manag. Prop. Constr.* **2022**, *39*, 36–54. [CrossRef]
5. Hamledari, H.; Fischer, M. The application of blockchain-based crypto assets for integrating the physical and financial supply chains in the construction & engineering industry. *Autom. Constr.* **2021**, *127*, 103711.
6. Rostami, A.; Oduoza, C.F. Key risks in construction projects in Italy: Contractors' perspective. *Eng. Constr. Arch. Manag.* **2017**, *24*, 451–462. [CrossRef]
7. Bolton, S.; Wedawatta, G.; Wanigarathna, N.; Malalgoda, C. Late payment to subcontractors in the construction industry. *J. Leg. Aff. Disput. Resolut. Eng. Constr.* **2022**, *14*, 04522018. [CrossRef]
8. McKinsey Global Institute. Reinventing Construction: A Route to Higher Productivity. Available online: https://www.mckinsey.com/~{}/media/mckinsey/business%20functions/operations/our%20insights/reinventing%20construction%20through%20a%20productivity%20revolution/mgi-reinventing-construction-executive-summary.pdf (accessed on 25 May 2022).
9. Nanayakkara, S.; Perera, S.; Senaratne, S.; Weerasuriya, G.T.; Bandara, H.M.N.D. Blockchain and Smart Contracts: A Solution for Payment Issues in Construction Supply Chains. *Informatics* **2021**, *8*, 36. [CrossRef]
10. Hu, K.; Zhu, J.; Ding, Y.; Bai, X.; Huang, J. Smart Contract Engineering. *Electronics* **2020**, *9*, 2042. [CrossRef]
11. Faraji, A. Smart contract based conceptual model for optimizing risk distribution in construction industry. In Proceedings of the 3rd International Conference on Applied Researches in Structual Engineering and Construction Management, Chicago, IL, USA, 26–27 June 2019; pp. 26–27.
12. Assaf, S.A.; Al-Hejji, S. Causes of delay in large construction projects. *Int. J. Proj. Manag.* **2006**, *24*, 349–357. [CrossRef]
13. Durdyev, S.; Hosseini, M.R. Causes of delays on construction projects: A comprehensive list. *Int. J. Manag. Proj. Bus.* **2019**, *13*, 20–46. [CrossRef]
14. Smart Contracts Market Size Worth $ 770.52 Million, Globally, by 2028 at 24.55% CAGR: Verified Market Research®. Available online: https://www.globenewswire.com/news-release/2021/12/01/2344251/0/en/Smart-Contracts-Market-size-worth-770-52-Million-Globally-by-2028-at-24-55-CAGR-Verified-Market-Research.html#:~{}:text=According%20to%20Verified%20Market%20Research,24.55%25%20from%202021%20to%202028 (accessed on 25 May 2022).
15. Ahmadisheykhsarmast, S.; Sonmez, R. Smart contracts in construction industry. In Proceedings of the 5th International Project & Construction Management Conference, Kyrenia, Cyprus, 16–18 November 2018; pp. 767–774.
16. Tran, H.; Carmichael, D.G. Contractor's Financial Estimation based on Owner Payment Histories. *Organ. Technol. Manag. Constr. Int. J.* **2012**, *4*, 481–489. [CrossRef]
17. Collins, B. Inquiry into Construction Industry Insolvency in NSW. Available online: https://www.smallbusiness.nsw.gov.au/sites/default/files/2019-07/OSBC-Summary-Document-Inquiry-into-Construction-Industry-Insolvency_Asset25642.pdf (accessed on 26 May 2022).
18. Agarwal, R.; Chandrasekaran, S.; Sridhar, M. Imagining construction's digital future. McKinsey & Company. Available online: https://www.mckinsey.com/capabilities/operations/our-insights/imagining-constructions-digital-future (accessed on 28 May 2022).
19. Hossain, M.A.; Nadeem, A. Towards digitizing the construction industry: State of the art of construction 4.0. In Proceedings of the 10th International Structural Engineering and Construction Conference, ISEC, Chicago, IL, USA, 20–25 May 2019; Volume 10.
20. Mason, J.; Escott, H. Smart contracts in construction: Views and perceptions of stakeholders. In Proceedings of the FIG Conference, Istanbul, Turkey, 8–11 May 2018.
21. Ekblaw, A.; Azaria, A.; Halamka, J.D.; Lippman, A.A. Case Study for Blockchain in Healthcare: "MedRec" prototype for electronic health records and medical research data. In Proceedings of the IEEE Open & Big Data Conference, Chengdu, China, 13 August 2016; Volume 13, p. 13.
22. Guo, Y.; Liang, C. Blockchain application and outlook in the banking industry. *Financ. Innov.* **2016**, *2*, 24. [CrossRef]
23. Arslan, G.; Tuncan, M.; Birgonul, M.T.; Dikmen, I. E-bidding proposal preparation system for construction projects. *Build. Environ.* **2006**, *41*, 1406–1413. [CrossRef]
24. Szabo, N. The Idea of Smart Contracts. Nick Szabo's Papers and Concise Tutorials. Available online: https://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/idea.html (accessed on 27 May 2022).

25. Cuccuru, P. Beyond bitcoin: An early overview on smart contracts. *Int. J. Law Inf. Technol.* **2017**, *25*, 179–195. [CrossRef]
26. Turk, Z.; Klinc, R. Potentials of blockchain technology for construction management. *Procedia Eng.* **2017**, *196*, 638–645. [CrossRef]
27. Naughter, T. Smart Contracts Vs. Traditional Contracts. Available online: https://www.contractworks.com/blog/smart-contracts-vs.-traditional-contracts (accessed on 4 July 2018).
28. Crosby, M.; Nachiappan, P.P.; Verma, S.; Kalyanamaran, V. Blockchain technology: Beyond bitcoin. *Appl. Innov. Rev.* **2016**, *2*, 6–19.
29. Cardeira, H. The advantages of using a web payments platform in the construction industry based on smart contracts and cryptocurrencies. In Proceedings of the 5th international Project and Construction Management Conference (IPCMC2018), Girne, North Cyprus, 16–18 November 2018.
30. Li, J.; Kassem, M.; Ciribini, A.; Bolpagni, M.A. Proposed Approach Integrating DLT, BIM, IoT and Smart Contracts: Demonstration Using a Simulated Installation Task. In Proceedings of the International Conference on Smart Infrastructure and Construction (ICSIC), Cambridge, UK, 8–10 July 2019.
31. Jin, Y. Blockchain Smart Contract Technology in Urban Energy Management System. *Distrib. Gener. Altern. Energy J.* **2021**, *36*, 43–56. [CrossRef]
32. Martino, P. Regulation of Blockchain Technology: An Overview. In *Blockchain and Banking*; Palgrave Pivot: Cham, Switzerland, 2021; pp. 71–98.
33. Housing Grants, Construction and Regeneration Act 1996. C.53. Available online: https://www.legislation.gov.uk/ukpga/1996/53/part/II/crossheading/adjudication (accessed on 5 May 2022).
34. Munn, Z.; Peters, M.D.J.; Stern, C.; Tufanaru, C.; McArthur, A.; Aromataris, E. Systematic Review or Scoping Review? Guidance for Authors When Choosing between a Systematic or Scoping Review Approach. *BMC Med. Res. Methodol.* **2018**, *18*, 143. [CrossRef]
35. Gough, D.; Oliver, S.; Thomas, J. *An Introduction to Systematic Reviews*; Sage: Thousand Oaks, CA, USA, 2017.
36. Kitchenham, B.; Brereton, O.P.; Budgen, D.; Turner, M.; Bailey, J.; Linkman, S. Systematic literature reviews in software engineering–a systematic literature review. *Inf. Softw. Technol.* **2009**, *51*, 7–15. [CrossRef]
37. Khan, M.M.; Ibrahim, R.; Ghani, I. Cross domain recommender systems: A systematic literature review. *ACM Comput. Surv. (CSUR)* **2017**, *50*, 1–34. [CrossRef]
38. Naeem, A.; Farooq, M.S.; Khelifi, A.; Abid, A. Malignant Melanoma Classification Using Deep Learning: Datasets, Performance Measurements, Challenges and Opportunities. *IEEE Access* **2020**, *8*, 110575–110597. [CrossRef]
39. Ghaleb, H.; Alhajlah, H.H.; Bin Abdullah, A.A.; Kassem, M.A.; Al-Sharafi, M.A. A Scientometric Analysis and Systematic Literature Review for Construction Project Complexity. *Buildings* **2022**, *12*, 482. [CrossRef]
40. Jaya, I.; Alaloul, W.S.; Musarat, M.A. Role of inflation in construction: A systematic review. In Proceedings of the International Conference on Civil, Offshore and Environmental Engineering, Kuching, Malaysia, 13–15 June 2021; pp. 701–708.
41. Khallaf, R.; Khallaf, M. Classification and analysis of deep learning applications in construction: A systematic literature review. *Autom. Constr.* **2021**, *129*, 103760. [CrossRef]
42. Papadonikolaki, E.; Krystallis, I.; Morgan, B. Digital transformation in construction-Systematic literature review of evolving concepts. In Proceedings of the Engineering Project Organization Conference (EPOC), Vail, CO, USA, 22–25 June 2020.
43. Yang, H.; Liu, L.; Yang, W.; Liu, H.; Ahmad, W.; Ahmad, A.; Aslam, F.; Joyklad, P. A comprehensive overview of geopolymer composites: A bibliometric analysis and literature review. *Case Stud. Constr. Mater.* **2022**, *16*, e00830. [CrossRef]
44. Luo, H.; Das, M.; Wang, J.; Cheng, J. Construction payment automation through smart contract-based blockchain framework. In Proceedings of the International Symposium on Automation and Robotics in Construction, Banff, AB, Canada, 21–24 May 2019; Volume 36, pp. 1254–1260.
45. Tezel, A.; Taggart, M.; Koskela, L.; Tzortzopoulos, P.; Hanahoe, J.; Kelly, M. Lean construction and BIM in small and medium-sized enterprises (SMEs) in construction: A systematic literature review. *Can. J. Civ. Eng.* **2020**, *47*, 186–201. [CrossRef]
46. Yu, F.; Hayes, B.E. Applying data analytics and visualization to assessing the research impact of the Cancer Cell Biology (CCB) Program at the University of North Carolina at Chapel Hill. *J. Escience Librariansh.* **2018**, *7*, 4. [CrossRef]
47. Su, H.-N.; Lee, P.-C. Mapping knowledge structure by keyword co-occurrence: A first look at journal papers in Technology Foresight. *Scientometrics* **2010**, *85*, 65–79. [CrossRef]
48. Nawari, N.O.; Ravindran, S. Blockchain and the built environment: Potentials and limitations. *J. Build. Eng.* **2019**, *25*, 100832. [CrossRef]
49. Houben, R.; Snyers, A. Cryptocurrencies and Blockchain: Legal Context and Implications for Financial Crime, Money Laundering and Tax Evasion. 2018. Available online: https://www.europarl.europa.eu/cmsdata/150761/TAX3%20Study%20on%20cryptocurrencies%20and%20blockchain.pdf (accessed on 10 May 2022).
50. Perera, S.; Nanayakkara, S.; Rodrigo, M.; Senaratne, S.; Weinand, R. Blockchain technology: Is it hype or real in the construction industry? *J. Ind. Inf. Integr.* **2020**, *17*, 100125. [CrossRef]
51. Ramachandra, T.; Rotimi, J.O. The Nature of Payment Problems in the New Zealand Construction Industry. *Constr. Econ. Build.* **2011**, *11*, 22–33. [CrossRef]
52. Penzes, B.; KirNup, A.; Gage, C.; Dravai, T.; Colmer, M. Blockchain technology in the construction industry: Digital transformation for high productivity. Available online: https://myice.ice.org.uk/ICEDevelopmentWebPortal/media/Documents/News/Blog/Blockchain-technology-in-Construction-2018-12-17.pdf (accessed on 5 May 2022).

53. Badi, S.; Ochieng, E.; Nasaj, M.; Papadaki, M. Technological, organisational and environmental determinants of smart contracts adoption: UK construction sector viewpoint. *Constr. Manag. Econ.* **2020**, *39*, 36–54. [CrossRef]
54. Wang, Y.; Han, J.H.; Beynon-Davies, P. Understanding blockchain technology for future supply chains: A systematic literature review and research agenda. *Supply Chain. Manag.* **2019**, *24*, 62–84. [CrossRef]
55. Nanayakkara, S.; Perera, S.; Bandara, D.; Weerasuriya, G.T.; Ayoub, J. Blockchain technology and its potential for the construction industry. In Proceedings of the AUBEA Conference, Noosa, QLD, Australia, 6–8 November 2019; pp. 662–672.
56. Nguyen, B.; Buscher, V.; Cavendish, W.; Gerber, D.; Leung, S.; Krzyzaniak, A.; Robinson, R.; Burgess, J.; Proctor, M.; O'Grady, K.; et al. Blockchain and the Built Environment. Available online: https://www.arup.com/-/media/arup/files/publications/b/blockchain-and-the-built-environment.pdf (accessed on 17 May 2022).
57. Pee, S.J.; Nans, J.H.; Jans, J.W. A simple blockchain-based peer-to-peer water trading system leveraging smart contracts. In Proceedings of the International Conference on Internet Computing (ICOMP), Las Vegas, NV, USA, 12–15 July 2010; pp. 63–68.
58. Hunhevicz, J.J.; Hall, D.M. Do you need a blockchain in construction? Use case categories and decision framework for DLT design options. *Adv. Eng. Inform.* **2020**, *45*, 101094. [CrossRef]
59. Wang, J.; Wu, P.; Wang, X.; Shou, W. The outlook of blockchain technology for construction engineering management. *Front. Eng. Manag.* **2017**, *4*, 67–75. [CrossRef]
60. Hargaden, V.; Papakostas, N.; Newell, A.; Khavia, A.; Scanlon, A. The role of blockchain technologies in construction engineering project management. In Proceedings of the IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), Valbonne Sophia-Antipolis, France, 17–19 June 2019; pp. 1–6.
61. Li, J.; Greenwood, D.; Kassem, M. Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Autom. Constr.* **2019**, *102*, 288–307. [CrossRef]
62. Soosay, C.A.; Hyland, P.W.; Ferrer, M. Supply chain collaboration: Capabilities for continuous innovation. *Supply Chain. Manag. Int. J.* **2008**, *13*, 160–169. [CrossRef]
63. Laforet, S. A framework of organisational innovation and outcomes in SMEs. *Int. J. Entrep. Behav. Res.* **2011**, *17*, 380–408. [CrossRef]
64. Law, A. Smart Contracts and Their Application in Supply Chain Management. Ph.D. Thesis, MIT, Cambridge, MA, USA, 2017.
65. Koc, K.; Gurgun, A.P.; Yildiz Technical University. Drivers for construction stakeholders to adopt smart contracts. *J. Constr. Eng. Manag. Innov.* **2020**, *3*, 101–112. [CrossRef]
66. Brotsis, S.; Limniotis, K.; Bendiab, G.; Kolokotronis, N.; Shiaeles, S. On the suitability of blockchain platforms for IoT applications: Architectures, security, privacy, and performance. *Comput. Netw.* **2021**, *191*, 108005. [CrossRef]
67. Lauslahti, K.; Mattila, J.; Seppala, T. Smart contracts—How will blockchain technology affect contractual practices? *ETLA Rep.* **2017**, *68*, 1–32. [CrossRef]
68. Gurgun, A.P.; Koc, K. Administrative risks challenging the adoption of smart contracts in construction projects. *Eng. Constr. Arch. Manag.* **2021**, *29*, 989–1015. [CrossRef]
69. Yang, R.; Wakefield, R.; Lyu, S.; Jayasuriya, S.; Han, F.; Yi, X.; Yang, X.; Amarasinghe, G.; Chen, S. Public and private blockchain in construction business process and information integration. *Autom. Constr.* **2020**, *118*, 103276. [CrossRef]
70. Mitropoulos, P.; Howell, G. Model for understanding, preventing, and resolving project disputes. *J. Constr. Eng. Manag.* **2001**, *127*, 223–231. [CrossRef]
71. Hu, B.; Zhang, Z.; Liu, J.; Liu, Y.; Yin, J.; Lu, R.; Lin, X. A comprehensive survey on smart contract construction and execution: Paradigms, tools, and systems. *Patterns* **2021**, *2*, 100179. [CrossRef]
72. Sillaber, C.; Waltl, B.; Treiblmaier, H.; Gallersdörfer, U.; Felderer, M. Laying the foundation for smart contract development: An integrated engineering process model. *Inf. Syst. e-Bus. Manag.* **2021**, *19*, 863–882. [CrossRef]
73. Kiu, M.S.; Chia, F.C.; Wong, P.F. Exploring the potentials of blockchain application in construction industry: A systematic review. *Int. J. Constr. Manag.* **2020**, *22*, 1–10. [CrossRef]
74. Tezel, A.; Papadonikolaki, E.; Yitmen, I.; Hilletofth, P. Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions. *Front. Eng. Manag.* **2020**, *7*, 547–563. [CrossRef]