BLOCKCHAIN-DRIVEN SMART CONTRACTS: AN OVERVIEW OF APPLICATION AREAS AND GAP IDENTIFICATION IN CONSTRUCTION MANAGEMENT LITERATURE

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ABSTRACT

The dynamics in industry 4.0 have continued to transform construction contract execution. Blockchain and smart contract technologies represent the future of construction contracts delivery in the built environment, although, they are still in the infancy in the construction sector. While studies on the potentials of Blockchain-based smart contracts in construction have continued to increase as evident in the extant literature, there is yet to be a consensus on the most crucial application areas in construction. This emerging technology requires more attention; therefore, this study presents the result of a critical review of blockchain-enabled smart contracts studies in construction. Forty documents were obtained from the Scopus and Web of Science databases, and they formed the basis for the review and analysis. The top application areas of smart contract technology were identified and discussed. Furthermore, the application areas that require to be explored are refurbishment contracts, consultancy contracts, long-term PPP projects, circular economy, and waste management. The adoption of blockchain-based smart contracts in these areas will improve sustainable construction targets and enhance the diffusion of blockchain-enabled smart contracts among key built environment experts.

Keywords: Blockchain; construction contract; critical review; Smart contract; Construction projects.

1.0 INTRODUCTION

The advancement in industry 4.0 is driving a major change in the ways construction projects are delivered and stakeholders' relationship management. Inefficiencies and productivity problems in the construction industry are linked to many stakeholders in construction, centralised systems of management, and paper-based, conventional construction systems, have been identified as contributors to the drawback the industry is experiencing. The lack of trust and transparency among stakeholders, predominance of claims and disputes and lack of satisfaction of clients (Li et al., 2019), further worsen the poor productivity and performance efficiency situation of the construction sector. Digitalization is key to the successes recorded in the operational efficiency and productivity of the aerospace and automotive industries (Ye et al., 2022). Blockchain technology (BT) and smart contracts (SC) are industry 4.0 technologies that offer the wide potential to the numerous problems limiting the construction industry's efficiency and productivity.

Extant studies have shown the potential of smart contracts in the management of construction contracts, which automate processes and enforce compliance with contractual provisions and conditions when the pre-defined conditions are met (Wahab et al., 2022). The problems of enforceability, deviance monitoring and tracking, execution and compliance issues, and irregular behaviours, that are associated with the traditional paper-based contracts are avoided with the adoption of smart contracts, leading to better productivity, cost and time savings, and reduction in disputes (McKinsey, 2017; Dakhli et al. 2019). A smart contract, however, cannot function without being embedded in blockchain technology (BT). BT provides a decentralised, distributed ledger of transactions (blocks) that are immutable, secured and can be tracked across a peer-to-peer network. These attributes of the BT are inherited by the SC when it is embedded in BT. Therefore, Blockchain-enabled smart contracts provide immutability, security and traceability of data exchanged spontaneously amongst stakeholders without an intermediary or centralised authority (Bousquin, 2020).
Even though the adoption of BT and SC is limited in construction, there exist some review studies on various potential areas of application of blockchain technology and smart contacts

in the built environment. Scott et al. (2021) identified 7 areas of application of blockchain in construction, but their study was limited to data obtained from the Scopus database. Yoon and Pishdad-Bozorgi (2022) through a review, found that blockchain can improve construction supply chain performance using only data from the Web of Science (WoS) database. Others used multiple data basses but included non-rated, non-index, non-academics/non-peer review sources. for example, Mahmudnia et al. (2022) review the impact of Blockchain technology characteristic on construction dispute resolution and management, Wu et al. (2022) focused on the challenges and future opportunities of blockchain applications in the construction whole life. Li and Kassem (2021) reported that DLT and smart contact can be applied in eight areas in the construction industry. Perera et al. (2020) found that blockchain is not a hype as its credible potential in construction industry. These studies considered grey literature (e.g., Webpage, blog post, conferences, reports, etc) which may not have gone through the rigorous peer review like Journal articles, and this could impact the quality of the findings. To overcome the domain focus, single database and documents choices of these studies, the present study utilised only peer-reviewed rated, index Journal articles from the Scopus and WoS databases. Furthermore, there is the likelihood that there exist other potential areas of usage of Blockchain-enabled smart contracts that have not been explored in extant literature. This study, through a systematic review, explores smart contracts studies to identify the application areas based on previous studies and to identify the gap in the literature and proposed directions for future research. This is vital as blockchain-enabled smart contract represents the technology that will drive the future agenda of construction contracts as it has been found to be in consonance with contracting system of the industry.

2.0 RESEARCH METHODOLOGY

This study adopted a systematic review of blockchain-enabled smart contract studies in construction, to understand the current status and map out future research direction. The systematic review method provides more organised and exploratory outcomes than the conventional review approach (Green and Higgins, 2005). This study was guided by Charles et al., (2021) 4-sequence search approaches of articles (i)identification, (ii)screening, (iii)eligibility evaluation, and (iv)inclusion and analysis. Furthermore, "preferred reporting items for systematic reviews and meta-analyses (PRISMA)" was also leveraged in this study.

Identification of document; 601 articles were initially retrieved from the Scopus and Web of Science (WoS) databases (Scopus=369; WoS=232). These databases are the world's leading databases that offer reliable sources of scientific data to researchers undertaking review-based studies (Zheng et al., 2016; Xu et al., 2021). The search took place on August 10, and was updated on October 18, 2022, using the search stings "(*TITLE-ABS-KEY ("smart contract" OR "Smart contracts" OR "Intelligent Contract" OR "Automated Contract" OR "Automated Contract Conditions") AND TITLE-ABS-KEY ("Construction Project" OR "Building Projects" OR "Construction")*)".

Screening of documents: the 601 documents were further screened by refining the search to research articles published in the English language, focused on construction management, engineering, and built environment.151 documents were retained after this exercise. Research articles provide detailed scientific knowledge on any subject of interest because of the rigorous review processes they undergo (Jin et al., 2018). Smart contract adoption in the Architecture, engineering, and construction (AEC) sector is still in its infancy. Hence, no year limit was set during to search in order not to lose vital documents. A skim of the titles, abstracts, and keywords, led to the elimination of 81 studies on a smart contract that did not focus on the construction industry. 17 duplicates were also removed leaving 53 documents.

Documents inclusion /exclusion criteria: to ensure articles used for the analysis are of high quality; documents from the Scopus database are required to be from rated sources (e.g, Q1 - Quartile 1 ranked journals). While documents from the WOS database are expected to be from SCI- or SCI-E-ranked journals (Source citation index/ Source citation index expanded). These criteria must be met by a document under the two databases. The approach was guided by the studies such as (Elghaish et al., 2021). 40 articles scaled through this stage and were downloaded for critical evaluation, and the results presented in subsequent sections arise from them.

3.0 ANALYSIS AND FINDINGS

3.1 Distribution of publications by year

the analysis shows that the retained documents covered publications between 2020 and 2022. It is evident that smart contract studies are growing progressively, as evident in the breakdown which shows that in 2020, a total of 9 (22.50%) of the articles were published, it grew by another 5% in 2021 to 11 (27.5%), and a sharp jump 20 (50%) was observed in 2022. The trend is expected to continue into the year, as interest in a smart contract in contract administration and management among practitioners and academics continues to increase.

3.2 Publication by sources of articles

The 40 assessed articles came from 12 sources (figure 1). “Automation in Construction” has the highest number 26(65.0%) of the articles, followed by “Buildings” 3(7.50%) articles and “Journal of Construction Engineering and Management” 2(5.0%) articles. “Automation in Construction” is the world’s leading source of scientific knowledge on technological adoption and innovations in the construction sector. This corroborates the findings of previous construction technologies and innovations review studies (e.g. Aghimien et al., 2020; Darko et al., 2020).

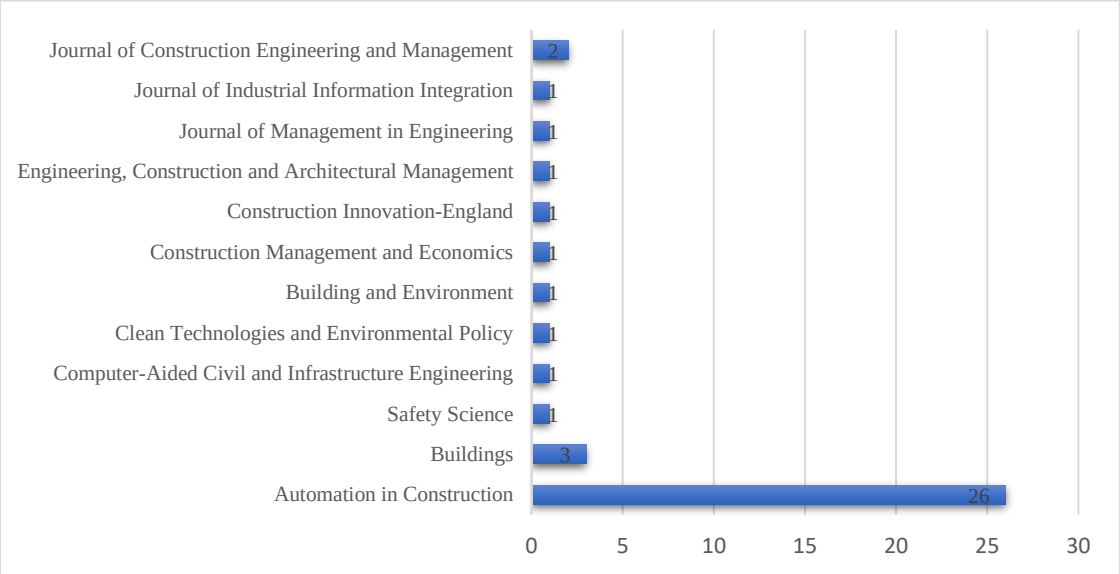

Figure 1: Distribution of Smart contract application areas in construction

3.3 Distribution of publications by country/Continents

In terms of publication by country, China has the highest number with 10 (25.0%) documents, this is closely followed by Australia with 9 (22.50%) documents, then, the United States has 5 (12.50%) and turkey has 4(10.0%) Publications. The United Kingdom and Hong Kong have 3(7.50%) publications each. The continental distribution shows that 18(45%) of studies originated from Asia, followed by Oceania with 10 (25%), then Europe and North America have 5 (22.55) articles each. However, no article emanated from South America while the African continent has 2(5.0%) (Table 1). This is a clarion call on the academics and researchers in these areas to collaborate and fund research in smart contract adoption in their built environment. Furthermore, the governments, and other stakeholders in Africa and South American need to intensify actions in propagating the message of automating construction contract conditions and reducing the over-reliance on the traditional manual construction contract conditions that is prevalent among projects stakeholder in the continents.

Table 1 Publications by country/geographical regions

Countries	Countries	Continents	No of publication	Per cent
Egypt	2	Africa	2	5.00
China	10	Asia	18	45.00
Hong Kong	3			
Turkey	4			
United Arab Emirates	1			
United Kingdom	3	Europe	5	12.50
Netherlands	1			
Italy	1			
United State	5	North America	5	12.50
		South America	0	0.00
Australia	9	Oceania	10	25.00
New Zealand	1			

3.4 Smart contract Application in construction

The focus of Smart contract studies based on the review is categorised into eight (figure 2). Based on the number of publications per category, the potential of smart contracts in resolving payment issues categorised as "**Payment and financial administration**" is ranked 1st. Ten studies focused on the potential of smart contracts in resolving payment-related issues in construction contracts. This is the most researched area in construction management literature. This indicates how critical payment is in ensuring the smooth working relationship of project parties, going concerns of construction organisations and the successful delivery of

construction projects. The blockchain-led smart contract has been advocated as a panacea for payment delays and non-payment problems in the sector (Bolton et al., 2022). This is evident in the studies of Hamledari and Fischer, 2021; Ahmadisheykhsarmast and Sonmez, 2020; Sonmez et al., 2022).

The second is "**information and data management**" and it is covered in six documents. The complex networks of activities, interactions, and many stakeholders, have made construction projects to be information and data-laden. A lot of reports are generated throughout the life of a project. A major problem is the use of numerous errors, omissions, and lack of clarity (Liu et al., 2019). The centralised nature of the traditional contractual system makes tracking these problems, compliance issues and controlling activities to be expensive as a result of a lot of intermediaries (Adel et al., 2022). The smart contract provides information traceability and offers a decentralised, secured, and reliable platform for effective data and information management in construction. The interest in this area of application has grown as evident in studies (Qian and Papadonikolaki, 2020).

Supply chain management is the 3rd category with five publications. Supply chain management (SCM) is founded on the integration of various critical stakeholders to ensure the success of a project. SCM ensure the smooth execution of project activities, especially, in ensuring the balance of the relationship between the suppliers of construction management, subcontractors and the main contractors and other stakeholders. Information sharing and data coordination across distances in the paper-based contractual system, breeds doubts, trust, and transparency challenges. Tracing of deviances in products and services compliance, quality assurance verification and process control checking present some problems. Blockchain-enabled Smart contracts have the potentials to automatically check compliances in a decentralised way through the provision of transparent and trusted data, and immutable records across the entire supply chain. The application of Smart contracts (SC) in construction supply chain management has attracted one of the highest interest among construction management researchers and industry practitioners (Lu et al., 2021).

Disputes resolution and management: It is impracticable to eliminate disputes in construction, but they can be greatly minimised. This is due to the complex nature and the high number of stakeholders involved in the construction operating environment. A lot of time and finances have been wasted on claims and disputes over the last decades (Lee et al., 2021). Disputes can result from external factors, but more often than not, emanates from contractual-related issues such as payments-related, delays and liquidated damages, and variations, among others. Most of these problems can be resolved using blockchain-enabled smart contracts ad evident in extant literature (David, 2022). A blockchain technology-based smart contract (BCT-SmContract) framework developed by (Wahab et al., 2022) revealed that a contract execution rate of 90% can be achieved and 100% precision in the project status information can be guaranteed, which helps to improve stakeholders' relationship and reduced conflicts.

Other applications areas of Smart contracts based on the review include (i) Quality management (Sheng et al., 2020), (ii) Safety management (Wu et al., 2022), (iii) Energy and Environmental Management (Shu et al., 2022), and (iv) Procurement management (Pishdad-Bozorgi and Yoon, 2022).

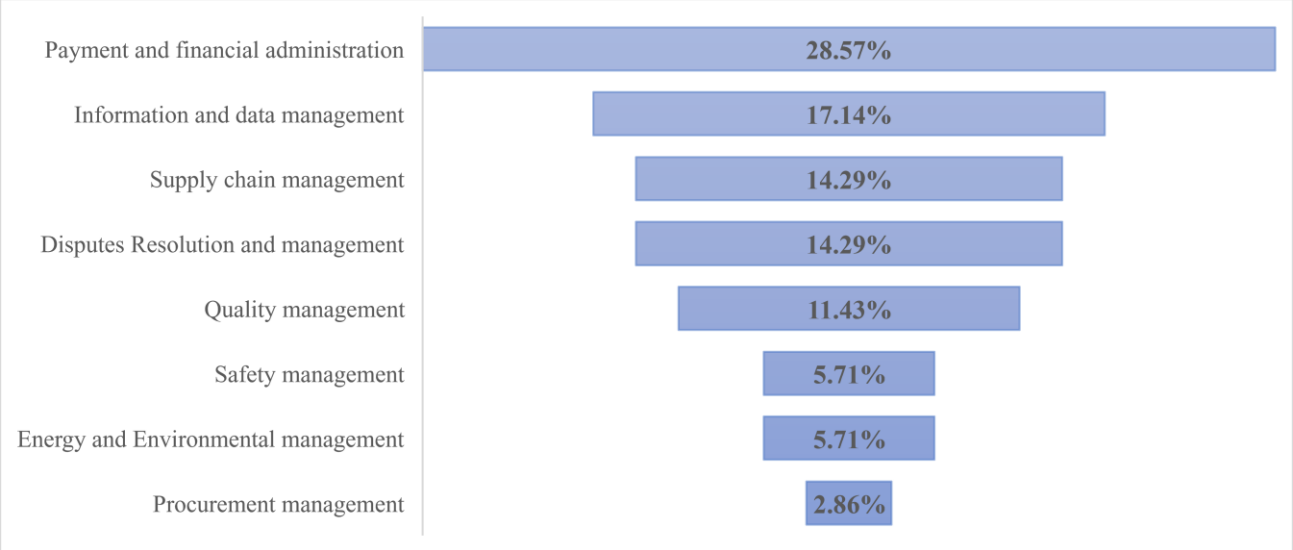

Figure 2: Distribution of Smart contract application areas in construction

4.0 Literature gaps and Future research directions

Smart contracts and public-private partnership (PPP) projects: Successive governments across the world have leveraged PPPs in the delivery of high-capital-intensive infrastructures by leveraging the private sector capital and expertise. PPP improves services delivery, reduced government spending, improves economic outlook, and enhanced risk management and sustainability (Cherkos and Jha, 2021), these are some of the merits that make PPP more attractive than the traditional system (Pellegrino et al., 2019). Despite these benefits, PPPs arrangement have failed and projects terminated as a result of performance issues (Patil and Laishram, 2016), non-achievement of value for money by the public (Soomro and Zhang, 2015), lack of trust and transparency, poor quality, ineffective procurement and environmental performance issues (Nel, 2014). Ameyaw and Chan (2015) found that poor contract design and non-adherence to contractual provisions leads to crisis and disputes that negatively impact long-term infrastructure projects procured via PPPs. Even though, PPP has assumed a global dimension, it is still vulnerable and not a "failureproof business" (Xu et al., 2014).

Smart contracts promise to overcome these challenges as they help to secure and guarantee payment and enforce contractual compliance that is needed to ensure a sustainable long-term relationship that exists between the private and public sector partners in PPPs (Lu et al., 2021). Lu et al. (2021) posits that blockchain-enabled smart contracts guarantee transparency and traceability and immutability in the supply chain in long-term PPPs projects. Automation of compliances, guarantee for performance and transparency of transactions that this technology provides could help improve PPPs performance and reduce numerous failures that has been reported, especially for long-term infrastructure projects under the PPP route. Despite the critical importance of the Smart contract, most studies have been centred on traditional contractual settings (Das et al., 2020), and its potentials in PPPs/PFI is yet to be explored in literature. In addition, over 70% of PPP projects failed/terminated/ or are re-municipalised at the operational phase owing to poor services/quality and payment related issues (Tariq and Zhang, 2022). Studies on leveraging blockchain-enabled smart contract to overcome these challenges is lacking in literature. The application of Smart contracts in long-term infrastructure PPPs/PFI is a critical literature gap that has remained unexplored by researchers

and academics in the built environment. Smart contracts would guarantee better PPP project performance as it will drive future contracting of long-term Infrastructure projects in the globe.

Blockchain-enabled smart contracts and waste management: Construction waste constitute a major drawback to the attainment of environmental, social, and economic sustainability (Eze et al., 2021). It impacts construction performance (Tongo et al., 2020), and could be in form of a waste of time, resources, and materials. There is however the absence of reliable records of the huge quantities of materials that are consumed in the sector and the waste management approach applied is unreliable. This is a prompt for the capitalisation of modern, disruptive technologies to achieve a sustainable waste management system (Mandiˇcák et al., 2021). Al-Mashhadani et al. (2021) confirm that digital technologies could improve the problems of materials efficiencies. The role of technologies in construction waste management is an underexplored area in literature (Sepasgozar et al., 2021). Most technology application studies in waste management in construction have been centred on BIM (e.g., Liu et al., 2015, Dantas et al., 2019). However, studies on blockchain-based smart contract adoption in construction waste management are lacking. Thus, in meeting the SDG goals and improving project performance, there is a need for studies that would explore the potential of blockchain-enabled smart contracts in construction waste management.

Blockchain-enabled smart contracts and risk management: Owing to the busy construction business environment, achieving effective risk management by the stakeholders is difficult. It is even worst as the scale and complexity and duration of projects increases. Poor risk management is behind the non-attainment of the project's bottom line (Iqbal et al., 2015). Smart contracts provide real-time records of risk events, track deviant sources, and provide immutable and decentralised records of construction processes outcome. Studies on BIM adoption in construction, and integration of BIM and VR in risk management have been studies (Merzliakov and Reshetkina, 2020; Alirezaei et al., 2022), however, the application of Smart contracts in risks management in the construction sector is lacking.
Other application areas include blockchain-enabled smart contracts in Refurbishment projects.

5.0 CONCLUSIONS

Industry 4.0-driven technologies are at the centre of driving sustainable construction contact administration and delivery. Blockchain-enabled smart contracts are at the core of these technologies. This paper adopted a systematic literature review of smart contract studies in construction to determine the application areas of smart contracts and the gap in the application for future research.

The study revealed that construction management researchers tend to look at financial aspects when studying blockchain technologies and smart contracts. And indeed, there is often a stronger association with e.g. the fields of automation and computing in construction. Other leading areas of research on the application blockchain technologies and smart contracts in the construction sector are; information and data management, supply chain management, and dispute resolution and management and quality management. Automation in Construction is the most productive source of blockchain-enabled smart contract studies. Most studies on blockchain and smart contracts emanate from Asia, Europe and the US. Studies on blockchain-enabled smart contract applications in long-term PPPs projects are missing. Also, other unexplored areas in the literature include risk management, waste management and in management of refurbishment projects.

While this paper presents some critical areas for future research, its reliance on the Scope and WoS databases is a key limitation. Furthermore, a focus on journal articles published in English is another limitation of the study. Therefore, future studies might consider other databases or the addition of more databases, and multiple sources (e.g, conference, book chapters) and expand the language to include other. This study will serve as a basis to further the studies on smart contract usage in overcoming the problems associated with the identified unexplored areas.

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