Front. Eng. Manag. 2024, 11(1): 50–61
https://doi.org/10.1007/s42524-023-0275-z

RESEARCH ARTICLE

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Smart contract applications in the built environment: How prepared are Nigerian construction stakeholders?

Abstract Studies have demonstrated that advanced technology, such as smart contract applications, can enhance both pre- and post-contract administration within the built environment sector. Smart contract technology, exemplifying blockchain technologies, has the potential to improve transparency, trust, and the security of data transactions within this sector. However, there is a dearth of academic literature concerning smart contract applications within the construction industries of developing countries, with a specific focus on Nigeria. Consequently, this study seeks to explore the relevance of smart contract technology and address the challenges impeding its adoption, offering strategies to mitigate the obstacles faced by smart contract applications. To investigate the stakeholders, this research conducted 14 virtual interview sessions to achieve data saturation. The interviewees encompassed project management practitioners, senior management personnel from construction companies, experts in construction dispute resolution, professionals in construction software, and representatives from government construction agencies. The data obtained from these interviews underwent thorough analysis employing a thematic approach. The study duly recognizes the significance of smart contract applications within the sector. Among the 12 identified barriers, issues such as identity theft and data leakage, communication and synchronization challenges, high computational expenses, lack of driving impetus, excessive electricity consumption, intricate implementation processes, absence of a universally applicable legal framework, and the lack of a localized legal framework were recurrent impediments affecting the adoption of smart contract applications within the sector. The study also delves into comprehensive measures to mitigate these barriers. In conclusion, this study critically evaluates the relevance of smart contract applications within the built environment, with a specific focus on promoting their usage. It may serve as a pioneering effort, especially within the context of Nigeria.

Keywords built environment industry, digitalization, Nigeria, smart contract, technological revolution

Received Jun. 21, 2023; revised Aug. 28, 2023; accepted Aug. 29, 2023

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This work was funded by Faculty of Engineering and the Built Environment and Construction Industry Development Board (CIDB) Centre of Excellence, University of Johannesburg, South Africa (Grant No. 05-35-061890).

Open access funding provided by University of Johannesburg.

1 Introduction

The built environment sector is intricate, demanding a heightened level of sophistication in construction contract administration to enhance its performance. This demand arises from the sector's reputation for its assertiveness and proclivity for disputes. Arcadis (2016) reported a decrease in dispute value from US$51 million to US$46 million in 2014 and 2015, respectively, but an increase in dispute duration. Beyond the realm of construction project disputes, trust-related issues have confounded both social science and construction contract administration. Ho (2016) proposed a resolution in the UK, aiming to eliminate trust issues in contracts to make construction contracts trustless. This gave rise to smart contracts, reducing the need for human intervention from pre- to post-contract phases. A smart contract is an intelligent agent, representing one of the pioneering concepts of digitalization and automation. It is a computer program capable of making decisions once predefined conditions are met (Kolvart et al., 2016). These transactions are stored, replicated, and updated in distributed blockchains. The intelligence of an agent depends on the complexity of the tasks it is programmed to execute, such as payment obligations. For a smart contract to be legally recognized, it must adhere to the requirements of contract law or contract law principles. It operates on the blockchain, with its codes residing and identified by a unique address (a 160-bit identifier). The digitalization of the built environment sector through groundbreaking digital revolutions such as blockchain and smart contracts has garnered increasing attention (McNamara and Sepasgozar, 2018; 2021; Weerapperuma et al., 2023).

McNamara and Sepasgozar (2018) asserted that blockchain technology, through smart contract applications, can instill trust within the distributed ledger model. Ebekozien et al. (2023a) found that the construction industry requires more information on digital technology. With an industry value of approximately US$10 trillion annually (Bogue, 2018), the construction sector may lag behind in adopting advanced technology, particularly in developing countries. Integrating digital technology into construction activities is of paramount importance. One reason for this is its potential relevance. The incorporation of information technology is one facet of the latest digital innovations to meet the demands of the information age. The decentralization of corporate and work processes poses a challenge in fulfilling the technological requirements of companies, especially construction companies, which prioritize transparency, security, and trust in data transactions. Technological innovation has given rise to these challenges. Furthermore, in addressing issues related to firm data transactions resulting from technological advancements, a smart contract mechanism operating on a blockchain may offer a solution to organizational challenges, particularly within the built environment sector.

Dhillon et al. (2017) affirmed that blockchain technology platforms such as Hyperledger, Fabric, and Ethereum support various types of smart contract development. In the case of Hyperledger, key projects within the framework include Hyperledger Composer, Hyperledger Explorer, Hyperledger Cello, Hyperledger Indy, Hyperledger Iroha, Hyperledger Fabric, and Hyperledger Sawtooth (Aggarwal and Kumar, 2021). Kirli et al. (2022) identified challenges associated with smart contracts in energy applications, encompassing issues such as identity theft and data leakage. They also proposed measures such as fog computing (edge computing), novel settlement mechanisms, and an applicable legal framework for smart contracts. Tsampoulatidis et al. (2019) attested to the technology's diverse applications, including market prediction, digital rights management, cloud storage, e-government, utilization of the Internet of Things (IoT), supply chain management, and social media platforms. While these benefits have the potential to enhance service delivery within the built environment, studies exploring their applicability within the Nigerian construction industry are conspicuously absent. Whether these threats and proposed measures are pertinent to the Nigerian built environment industry remains uninvestigated. While the concept of blockchain-enabled smart contracts is not new, the specific challenges faced by Nigeria's construction industry have yet to be addressed. These are among the motivations driving this study. Moreover, there is a scarcity of academic literature pertaining to smart contract applications within developing countries' built environmental industries, with a particular focus on Nigeria. Consequently, this study aims to scrutinize the relevance of smart contract technology and address the challenges obstructing the adoption of smart contracts while also offering strategies to alleviate the barriers confronting smart contract applications. The researchers intend to fulfill the study's objectives through the following pursuits:

To evaluate the pertinence of smart contract technology within the built environment industry.

To investigate the impediments hindering the application of smart contracts within the Nigerian built environment industry.

To propose measures for mitigating the barriers faced by smart contract applications in Nigeria.

2 Literature review

2.1 Overview of smart contract applications

The built environment industry is one of the largest in the world economy, with over US$10 trillion spent yearly. To increase the industry's value added by US$1.6 trillion annually (McKinsey, 2017), the sector's productivity must improve. Construction digitalization through the Industry 4.0 revolution offers a means to enhance productivity. Introducing construction digitalization (Industry 4.0) into the construction industry aims to improve economic growth and increase productivity. This digitalization incorporates technologies such as robotics, drones, blockchain (smart contracts), building information modeling, machine learning, artificial intelligence, and off-site construction (Odubiyi et al., 2021). However, the impact of technological advancements and their adoption in the sector may differ from other industries, such as logistics, manufacturing, and automotive (Aghimien et al., 2020; McNamara and Sepasgozar, 2020). Despite resistance to change in the construction sector, it needs to accelerate its adoption of digital innovations (Ebekozien and Samsurijan, 2022).

Li et al. (2019) noted that the construction digitalization of the sector is still in the process of accommodating new digital technologies and the implementation of blockchain and other applications, such as smart contract applications. Smart contract applications emerged from blockchain technology (Giancaspro, 2017). A smart contract is a blockchain-driven technology that executes automated contracts and stores the created data on a blockchain (Badi et al., 2021). It operates as a self-executing contract or rules across a distributed and decentralized blockchain network (Kumar Bhardwaj et al., 2021). Essentially, a smart contract functions to enforce parties' agreements after verification without requiring third-party permission (Weerapperuma et al., 2023).

Smart contract technology is one facet of blockchain technologies, consisting of computer code programs spread across a network of nodes (Giancaspro, 2017; Wong et al., 2022; Wulandary et al., 2023). This application serves as a computerized transaction protocol that manages contract terms between multiple parties (Hiroki et al., 2016; Giancaspro, 2017). One of the significant benefits of implementing smart contracts in corporations is that, in addition to facilitating automatic payment for services deployed on the blockchain, they create a decentralized market mechanism by initiating transactions and payments between buyers and sellers without intermediaries (Wong et al., 2022). Zheng et al. (2020) identified the advantages of smart contract applications, including cost reduction in administration, savings in service costs, risk reduction, and improved business process efficiency. Smart contracts hold great potential for a wide range of applications, spanning from the industrial IoT to financial services. Giancaspro (2017) asserted that smart contracts reduce legal and transaction costs, promising commercial efficiency, transparency, and anonymity in transactions. Ahmadisheykhsarmast and Sonmez (2020) found that, in addition to the system's ability to mitigate organizational costs and the burdens of trusted intermediaries, it facilitates secure construction contract payments. These attributes make smart contract technology highly sought-after while also mitigating fraud and enhancing the quality of financial contracts (Halilbegovic and Ertem, 2020). This is achieved when contracts support stakeholders in cooperating and improving agreed contract clauses, supported by shared relevant information on the blockchain without the involvement of intermediaries (Negara et al., 2021b).

Weerapperuma et al. (2023) identified facility management, building information modeling, electronic document management, and construction supply chain management as the primary domains in the construction industry where smart contracts and blockchain technology are being implemented. Blockchain-enabled smart contracts have the potential to procure resources and automate the audit process in construction supply chain management (Nanayakkara et al., 2021). Challenges do exist in the implementation of smart contracts, particularly concerning technical and social technology issues. Negara et al. (2021b) identified various smart contract applications and frameworks developed in various implementation fields, encompassing cybersecurity, government services, software testing, the IoT, supply chain management, and geographic information systems. These include eGOV-DAO (decentralised autonomous organization), the virtual operation model (VOM), EdgeChain, Manticore, Smart contract Online Detection framework against Attacks (SODA), and D-GIS (decentralized geographic information system), as presented in Table 1. Table 1 summarizes the source, purpose, methods, simulation, field, and development status. Given the rapid growth of digitalization in the sector, the security of smart contracts requires more attention.

2.2 Hindrances facing smart contract applications in the built environment sector

Hindrances to the usage of IT applications in the built environment cannot be overstated. Studies by Ebekozien and Aigbavboa (2021), Ebekozien and Samsurijan (2022), and Ebekozien et al. (2023a) have found that many stakeholders in the sector require assistance in embracing technological innovation. Sepasgozar et al. (2018) affirmed that implementing technology could enhance organizational value, particularly through the adoption of smart contract applications. Tatum (1989) and Ebekozien and Samsurijan (2022) identified financial risks, personnel attitudes toward new technologies, the complexity of implementation, and the perception of other staff members toward digital innovation as barriers to implementation. Liu et al. (2015) categorized these barriers into five distinct categories, including the absence of a national standard, application costs, insufficiently skilled workers, organizational barriers, and legal obstacles (Rusakova et al., 2019). Aibinu and Venkatesh (2014) discovered that data inconsistency and compatibility are the most pertinent data-related barriers among stakeholders. Christensen et al. (2007) noted that stakeholders require the security of confidential data in the digital model.

Security issues are not exempt from affecting smart contract applications. Security concerns represent a significant hindrance to the adoption of smart contracts. Security flaws are associated with smart contracts, rendering them vulnerable to exploitation by stakeholders. Smart contracts, due to their ability to handle a large volume of virtual coins, attract adversaries (Luu et al.,

Table 1 Summarised smart contract framework

Framework	Source	Properties				
		Purpose	Methods	Simulation	Field	Status
eGOV-DAO	Diallo et al. (2018)	It purposes real-time monitoring and analysis of e-government services	Blockchain technology and DAO	It allocates public contracts to specific vendors	E-Government	Prototype (Research in progress)
VOM	Dolgui et al. (2020)	Blockchain-oriented dynamic modelling with VOM supports data storage	Block-oriented dynamic modelling	Scheduling control	Supply chain	Prototype (Research in progress)
EdgeChain	Pan et al. (2019)	Edge-IoT support IoP (Internet of People) applications	A device that works between IoT and the blockchain module and smart contracts	Testing a programme code	IoT	Prototype (Research in progress)
Manticore	Mossberg et al. (2019)	Open-source dynamic	Maximise code coverage in software tests	Find bugs and confirm code correctness	Software tests	Theoretical description
SODA	Chen et al. (2020)	Protects contracts from attacks	Generic online detection	Eight applications with new detection methods to detect attacks	Cyber security	Theoretical description
D-GIS	Leka et al. (2019)	Store and share geospatial data	TextStreamers to vote on storage reputation and proxy contracts	A decentralised application (DApp)	GIS	Theoretical description

Source: Modified from Negara et al. (2021b).

2016). Platforms supporting smart contract applications are susceptible to manipulation attempts by arbitrary adversaries, posing a substantial threat. Moreover, a defective smart contract, regardless of its status, cannot be rectified without reversing the blockchain. Notably, issues such as contracts lacking refund capabilities, inadequate cryptography for ensuring fairness, and misalignment of incentives represent logical challenges in smart contract security (Zou et al., 2021). Zou et al. (2021) identified several logic issues related to smart contract security, including online resource limitations, performance challenges within resource-constrained environments, limitations in programming languages and virtual machines, rudimentary development tools, and a lack of effective methods to guarantee smart contract code security.

3 Research method

The study primarily focuses on qualitative data to gain insights into the interviewees' perceptions. This approach aligns with the methodology employed by McNamara and Sepasgozar (2020), who adopted a qualitative approach to understand practitioners' perceptions of existing contract practices within the built environment industry. Data were collected through 14 semistructured virtual interviews, as detailed in Table 2, and data saturation was successfully achieved. This approach mirrors the methodology employed by Weerapperuma et al. (2023), who also utilized a qualitative approach involving ten experienced participants to collect data. Their study aimed to investigate perceived attributes and develop a knowledge framework for blockchain to enable smart contracts in the construction industry.

The virtual interviews were conducted using Zoom and WhatsApp calls. The data obtained from these interviews were subsequently analyzed through a thematic analysis. The study's focus area encompassed Lagos and Abuja. This choice aligns with the rationale provided by Ibrahim et al. (2022), who affirmed that these locations serve as commercial hubs and witness substantial construction operations. Additionally, Jaafar et al. (2021) and Aigbavboa et al. (2023) emphasized that semistructured interviews offer flexibility in obtaining a realistic understanding of interviewees' perspectives. The primary questions posed during the interviews aimed to address the study's research questions. These questions included: What is the level of familiarity or experience with smart contracts? What is the perceived relevance and benefit of smart contract technology within the built environment

Table 2 Summary of interviewees' description

ID	Participant	Location	Years of experience	Participant rank
P1	Project management practitioners	Abuja	20	Senior Partner
P2			22	Managing Partner
P3		Lagos	25	Project Manager
P4		Lagos	21	Site Operation Manager
P5	Top senior construction companies' staffers	Abuja	31	Assistant Director
P6		Abuja	36	Managing Director
P7		Lagos	28	Chief Executive Officer
P8		Lagos	22	Operational Manager
P9	Construction dispute practitioners	Abuja	32	Director
P10		Lagos	27	Principal Partner
P11	Construction software practitioners	Abuja	22	Managing Partner
P12		Lagos	21	Senior Partner
P13	Government construction agencies staffers	Abuja	22	Assistant Director
P14		Lagos	28	Director

industry? What are the factors that may hinder the application of smart contracts in the sector? What measures can be implemented to enhance smart contract applications within the Nigerian construction industry?

In accordance with the approach outlined by Teddlie and Tashakkori (2010), the study employed snowball and purposive sampling techniques to ensure the representativeness of the interviewees. As suggested by Saunders et al. (2019), snowball sampling entails selecting accessible samples to contribute to the study, while purposive sampling involves the deliberate selection of interviewees. The study sample comprised various categories of participants, including project management practitioners with backgrounds in construction and IT (P1–P4), senior management personnel from construction companies (P5–P8), construction dispute practitioners with IT backgrounds (P9–P10), construction software practitioners with construction backgrounds (P11–P12), and representatives from government construction agencies (P13–P14).

Each interview session had an average duration of 45 minutes. To refine the interview process and questions, a pilot study was conducted with three interviewees, and the researchers made some adjustments accordingly. Thematic analysis was employed to analyze the data, following the approach outlined by Ebekozien (2020). The study conducted a total of 14 interviews between November 2022 and early January 2023, ultimately achieving data saturation. To enhance the reliability and credibility of the data, the study utilized a quality assessment approach, aligning with the framework presented by Wearing (2013), as depicted in Table 3. The study employed various criteria, including reliability, credibility (Plano-Clark and Creswell, 2015), validity, transferability, and generalizability, as outlined in Table 3.

The interviewees were provided with information about the research's primary objectives and expressed their willingness to participate without feeling pressured. The study strictly adhered to ethical best practices, and the participants submitted their responses anonymously. In the data analysis process, the study employed open coding of meaning units from the collected data. Various coding techniques, including emotion, in vivo, theme, and narrative coding, were utilized, following the approach outlined by Corbin and Strauss (2015). A total of 91 codes were generated, which were subsequently reorganized based on their frequency, reference, and occurrence. From these codes, eight subthemes were developed, and these subthemes were further organized into three overarching themes. To ensure the credibility of the analysis, an independent practitioner was engaged to cross-verify the generated subthemes and themes.

4 Findings and discussion

Research into the challenges impacting the low implementation of smart contract applications within the built environment industry, particularly in developing nations such as Nigeria, is imperative. This field is continuously evolving and garnering significant scholarly attention, highlighting the undeniable significance of smart contract technology.

4.1 Theme 1: Relevance of smart contract technology

This subsection examines the relevance of smart contract applications in the built environment industry. One significant aspect of their relevance lies in decentralization, allowing operation within the built environment industry without the need for intermediaries. This is of paramount importance, as it facilitates the creation of truly decentralized systems, a concept deserving of encouragement. Participants P1, P3, P7, and P14 concur that smart contract applications represent a potent technology capable of playing a pivotal role in enabling future decentralized and transactional systems within the built environment industry, reducing dependence on human intervention. These findings align with those of Nzuva (2019), emphasizing that the implementation of blockchain technology through smart contracts diminishes the necessity for third-party intermediaries. This mechanism, in turn, enhances the productivity and profitability of enterprises by reducing associated costs, presenting a

Table 3 Quality assessment techniques

Method	Assessment strategies	Phase of research
Reliability	Consistent interviewer (the lead author)	Data collection
Validity	The adoption of a recognised method (semi-structured virtual interviews)	Data collection
Generalizability	Recognition of limitation due to sample size potential interviewer bias (focus on experts)	Data analysis
Transferability	Compare study's implications against current literature	Post data analysis
Credibility	Theme approach to establish a pattern from the data	Data analysis
	Explanation building in sequential order, objective by objective	Data analysis
Dependability	Developing semi-structured interview guidelines	Research design

Source: Modified from Wearing (2013).

positive outlook for construction companies and their collaborators (Participants P2, P6, P8, and P11). These findings are in line with conclusions of Wulandary et al. (2023), who found that smart contracts enable automatic payments for services or goods delivered without the involvement of third parties. This approach not only mitigates the potential for tampering with payment records but also ensures transparency and integrity. Additional benefits include the following:

i. Security of payment of construction contracts (majority)

ii. Eliminate or reduce payment problems in the built environment sector (P11 and P12)

iii. Novelty and transparent payment of construction projects (P5, P7, P8, and P13)

iv. Cut administrative charges and burdens of trusted intermediaries such as lawyers and banks (majority)

v. A savour to transform the industry (P1, P3, and P5)

vi. Automation (P3, P6, P9, P10, P11, and P12)

vii. Reduction in time (majority)

viii. Decentralization and operation without third parties (majority)

ix. Increased productivity and profitability (majority)

Participant P11 says, "… it offers timely and transparent payment of construction projects. This is a novelty because it guarantees the security of payment for construction works with fewer burdens of intermediaries. These intermediaries' administrative costs such as lawyers or banks are avoided during the transaction …" The findings align with the conclusions drawn by Cardeira (2015), Hughes (2017), and Ahmadisheykhsarmast and Sonmez (2020). Cardeira (2015) asserted that the implementation of smart contracts could yield cost savings within the sector by fully or partially automating contract administration. Beyond cost savings, this technology is viewed as transformative within the sector, as indicated by Participants P3, P5, P7, P10, and P13. Hughes (2017) stated that smart contract applications enable the establishment of conditions and decision inputs. Ahmadisheykhsarmast and Sonmez (2020) discovered that construction contracts automated through smart contract applications provide enhanced security for construction project payments. These applications operate as automated computerized protocols within a structured blockchain, as emphasized by Participants P6, P9, and P12.

In terms of automation and time reduction, the findings concur with the research conducted by Rusakova et al. (2019), Salha et al. (2019), Kirli et al. (2022), and Wong et al. (2022). Rusakova et al. (2019) found that blockchain technology, particularly smart contracts, can address various financial challenges in the digitalization era. Salha et al. (2019) and Kirli et al. (2022) affirmed that reduced market operation costs, time savings, and payment automation are among the benefits associated with the incorporation of smart contracts. Wong et al. (2022) also affirmed that, in addition to automatic payment for services on the blockchain, smart contracts establish a decentralized market mechanism that facilitates transactions and payments between buyers and sellers without intermediaries. The findings highlight essential attributes that should be considered in the development of smart contracts. These attributes include readability, portability, reliability, usability, compatibility, efficiency, security, and maintainability. Prior to developing smart contracts, these critical attributes should be carefully considered, as emphasized by Participants P5, P6, P8, P9, P11, and P13.

4.2 Theme 2: Issues hindering smart contract applications

This subsection highlights the obstacles faced by smart contract applications within the Nigerian built environment industry. The findings indicate that the Nigerian built environment industry is in need of catching up in terms of embracing digitalization applications. These findings align with the research conducted by Timchuk et al. (2021) and Ebekozien et al. (2023b). Ebekozien et al. (2023b) discovered that digital adoption within the industry, especially in some developing countries such as Nigeria, is progressing at a slower pace compared to the financial and manufacturing sectors. This lag in digital adoption pertains to various aspects, including the design and construction of projects, due to several underlying issues.

Twelve specific issues have emerged as significant barriers hindering the implementation of smart contracts within the Nigerian built environment industry, as depicted in Fig. 1. These issues include:

i. Identity theft and data leakage (high cybersecurity risks)

ii. Communication and synchronization issues

iii. High computational expense

iv. Lack of driving force (resistant to change)

v. High electricity consumption

vi. High complexity of implementation

vii. Lax dispute resolution system

viii. Immutability

ix. Environmental cost

x. Solidarity language limitations (software requirements)

xi. Absence of standard applicability of the law

xii. Absence of local legal framework

Among the twelve emerging barriers, identity theft and data leakage, communication and synchronization issues, high computational expenses, lack of driving force, high electricity consumption, high complexity of implementation, absence of standard applicability of the law, and the absence of a local legal framework were frequently cited by interviewees as significant hindrances to the adoption of smart contract applications within the sector. Participant

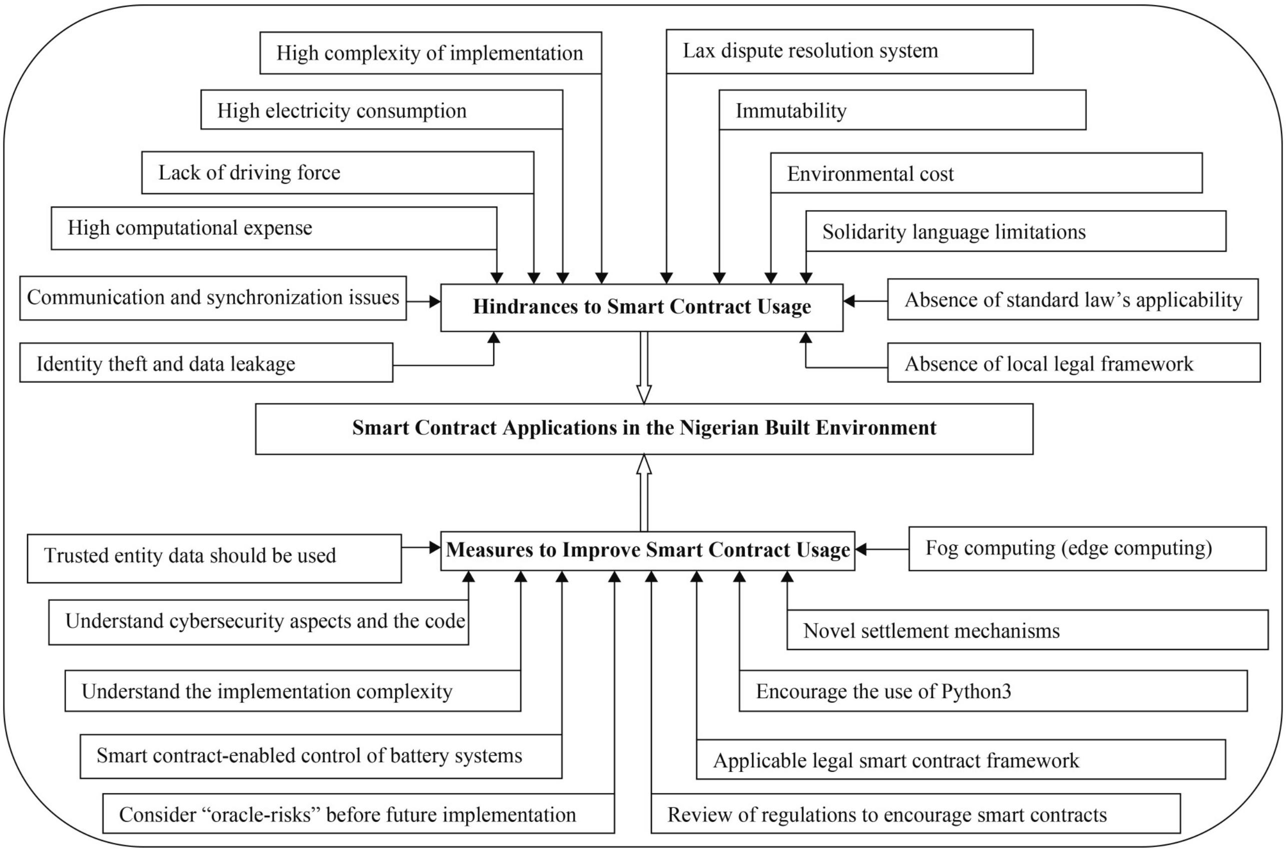

Fig. 1 Thematic network of smart contract applications in the Nigerian built environment.

P7 says, "… the absence of suitable governing standards for sharing data between key partners and stakeholders in the development process is seen as an enormous hindrance to smart contract application technology being accepted by the supposed users …" These findings corroborate the research of Liu et al. (2015), Zou et al. (2021), and Ebekozien and Samsurijan (2022). Liu et al. (2015) identified the absence of national standards, high application costs, inadequate skilled workers, organizational barriers, and legal issues as impediments to digital implementation within the sector. Zou et al. (2021) pointed out that online resources, performance issues under resource-constrained environments, limitations in programming languages and virtual machines, basic development tools, and a lack of effective security measures for smart contract code all pose significant challenges.

Ebekozien and Samsurijan (2022) recognized financial risks, personnel resistance to new technologies, implementation complexity, and the apprehensions of other staff members regarding digital innovation as barriers to implementation. Concerning the complexity of implementation, Nzuva (2019) affirmed that immutability presents a critical hindrance, as modifying smart contracts once they are scripted as code becomes exceedingly difficult. The findings also highlight limitations associated with Solidity language (software requirements) that impede smart contract implementation within the built environment sector. These limitations include insufficient mathematical functions or the absence of certain data types. Other programming languages used in developing smart contract applications include Obsidian, LLL (Low Level Languages), Vyper, Varna, Rholang, and Michelson, as noted by Participants P11 and P12. These findings align with Kirli et al. (2022), who found that Solidity lacks support for exponentiation with real numbers, rendering it unsuitable for power flow computations. Moreover, the findings reveal that many smart contracts require a substantial amount of data from sensors and smart meters. Participant P5 says, "… as more assets take an active role in the smart contract system, the system's deployment on the blockchain would be restricted by the bandwidth and computational power …" These findings are consistent with Kirli et al. (2022), who noted limitations in data computation as more assets become part of the smart system.

In terms of challenges related to dispute resolution systems, the lack of a driving force (resistance to change), the absence of standardized legal applicability, and a local legal framework, the findings align with the research conducted by Christensen et al. (2007), Aibinu and Venkatesh (2014), Gurgun and Koc (2022), and Kirli et al. (2022). Christensen et al. (2007) emphasized the importance of data security in the digital model but also noted that various legal and security issues affect stakeholders in construction projects within a digital environment. Aibinu and Venkatesh (2014) identified data inconsistency and compatibility as significant data-related barriers among stakeholders. Kirli et al. (2022) highlighted the influence of local laws and regulatory frameworks on smart contract applications, while Gurgun and Koc (2022) identified the lack of a driving force, weak regulatory systems, and inadequate dispute resolution as major barriers to adopting smart contracts in the built environment industry. Additionally, with regard to legal regulation issues, especially within the legal context of the built environment industry, the findings are in agreement with Rusakova et al. (2019), suggesting that legal regulation issues can become impediments between team members.

4.3 Theme 3: Measures to mitigate barriers

This subsection outlines measures aimed at mitigating the barriers that smart contract applications encounter in the Nigerian construction industry. Ten potential measures have surfaced as initiatives to address the challenges hindering the implementation of smart contracts within the Nigerian built environment, as depicted in Fig. 1. These measures include:

i. Trusted entity data should be used

ii. Understand cybersecurity aspects and the underlying code

iii. Understand the implementation complexity and deployment costs of the mechanism

iv. Smart contract-enabled control of battery systems against cyber attacks

v. Consider "oracle-risks" before future implementation

vi. Fog computing (edge computing)

vii. Novel settlement mechanisms

viii. Encourage the use of Python3

ix. Applicable legal smart contract framework

x. Review of regulations to encourage smart contracts in the industry

From the ten emerging measures, several were emphasized as vital for mitigating the barriers obstructing smart contract applications in the sector. These measures include the utilization of trusted entity data, a comprehensive understanding of cybersecurity aspects and the underlying code, a grasp of the implementation complexity and deployment costs of the mechanism, the establishment of an applicable legal smart contract framework, and a review of regulations to foster smart contracts in the industry. Participant P11 says, "… operators need to consider the 'oracle-risks' in future smart contract implementation because of the possible price market volatility that comes with many fluctuations …" This perspective aligns with Kirli et al. (2022), highlighting that the ability to account for oracle-risks in contract design can effectively address market volatility concerns. Careful consideration of the timing for deploying or registering a smart contract application was also deemed essential by Participants P3, P4, P7, P9, P13, and P14 to mitigate environmental and financial costs. Such deliberation is crucial for promoting sustainability. Additionally, the introduction of novel settlement mechanisms to enhance smart contract applications was recognized. Oprea et al. (2020) acknowledged that these mechanisms can alleviate imbalances in production and consumption associated with smart contracts at the individual, group, and global levels. Furthermore, these findings align with the recommendations of Roberts (2014) and Mason (2016). Roberts (2014) suggested that stakeholders, including policymakers, should endeavor to create a conducive and collaborative environment to enhance overall performance. Meanwhile, Mason (2016) advocated for the implementation of innovative legal solutions to facilitate the greater utilization of digital technology in project delivery.

The findings provide practical recommendations for addressing specific challenges in the implementation of smart contracts, beginning with identity theft and data leakage, particularly in the realm of cybersecurity. Participant P10 says, "… operators should ensure that a trusted entity generates the data received. This can be confirmed via encryption with private keys and adding hash and cryptography functions to protect the data …" These findings are in accordance with the insights of Mannaro et al. (2017), affirming that hash and cryptography functions serve as effective countermeasures against cyberattacks and threats targeting smart contracts. In response to the challenges posed by computational expenses and communication and synchronization issues, the findings propose the adoption of fog computing (edge computing) as a viable solution. Participant P6 says, "… edge computing has been tested as a well-known, trusted mechanism in many advanced countries used to process data at a local level before administering the outcome to cloud-based servers …" These findings align with the research by Gai et al. (2019), which demonstrates how fog computing can mitigate the demands on cloud-based storage and bandwidth, particularly in smart grid applications. Additionally, the findings recommend implementing the Encourage-Real-Quotation rule to address communication and synchronization challenges. Hu et al. (2019) confirmed that Encourage-Real-Quotation is a mechanism that enables operators to determine an offer after clients place bids, enhancing clearing processes and reducing the time discrepancies between bids and offers.

In response to solidarity language limitations, the findings suggest leveraging Python3 to enhance interoperability between the research application and smart contract code. Python proves effective in facilitating seamless communication across platforms, as corroborated by Kirli et al. (2021). To mitigate environmental costs and electricity consumption, the findings suggest a redesign of existing blockchain consensus protocols. This redesign aims to minimize energy consumption and enhance information quality. This recommendation aligns with the research conducted by Kirli et al. (2022) and Wahab et al. (2023). Kirli et al. (2022) advocated for the adoption of a Proof-of-Stake protocol, as seen in the Ethereum Foundation, to achieve substantial reductions in energy consumption. Moreover, for regulatory improvements to promote smart contracts, the findings emphasize the introduction of initiatives such as the project BEST (Blockchain-based decentralized energy market design and management structures) and GDPR (General Data Protection Regulation), as witnessed in developed countries such as Germany. Government support for such projects can stimulate innovation within the blockchain application industry, as noted by Finck (2018).

Finally, the findings underscore the importance of operators gaining a comprehensive understanding of code analysis, testing tools, and programming languages for smart contract development. Proficiency in these areas can effectively mitigate some of the barriers identified in Theme 2. Notable code analysis tools include Smartcheck, Slither, KEVM (Ethereum Virtual Machine in K), SmartInspect, Verx, and SIF (Sony-Interconnect-Format). Testing tools encompass Zeus, Requard, ContractFuzzer, FSolidM, ContractLarva, and Kaya. Additionally, various programming languages suited for smart contract development include Solidity, Obsidian, LLL, Vyper, Varna, Rholang, and Michelson, as highlighted by Participants P11 and P12.

5 The study's implication

The study is poised to enhance our understanding of smart contract applications within the built environment, offering a comprehensive perspective from the viewpoint of stakeholders. In the Nigerian context, beyond addressing theoretical gaps, this research stands as one of the most notable empirical investigations, engaging project management experts, senior staff from construction companies, construction software specialists, and other relevant stakeholders through a qualitative approach. The study not only underscores the significance of smart contract technology but also identifies the impediments hindering its adoption within the Nigerian built environment industry. A thorough comprehension of these hindrances is paramount for devising effective measures to encourage adoption. Given the limited number of studies examining smart contract usage, there is compelling evidence of a methodological gap. The measures proposed in this study to mitigate barriers could potentially benefit other countries grappling with similar challenges in smart contract adoption. Among the implications of this research, the recommended measures for overcoming barriers associated with smart contract applications hold the promise of enhancing their adoption within the Nigerian built environment industry. These measures carry profound implications for stakeholders, especially construction companies, as they offer the prospect of long-term benefits, including improved productivity and profitability. Consequently, these theoretical implications serve as a catalyst for stakeholders to champion the promotion of smart contract usage in construction contract administration, a pivotal step toward achieving efficiency and heightened productivity.

On the practical front, this study aligns with the digital transformation of the Nigerian built environment, propelling it toward comprehensive construction digitization. This transformation is poised to boost productivity and bolster profitability by curbing waste and costs while enhancing efficiency and production. The research seeks to inspire top-level management within construction companies and government policymakers alike. Additionally, it aims to stimulate construction scholars and researchers, particularly those focusing on the underlying factors influencing smart contract applications within other developing countries, with Nigeria serving as a primary focus. The ultimate goal is to provide invaluable insights into smart contract application systems and to enlighten key stakeholders on the imperative of creating an enabling environment for smart contract implementation. Consequently, the outcomes of this research offer substantial benefits to stakeholders within the construction industry, especially innovators and decision-makers within client organizations and construction firms. They will gain a deeper understanding of the relevance of smart contracts and the measures required to enhance their utilization in construction projects across Nigeria. Moreover, the findings will facilitate stakeholder acceptance of smart contracts as a means to decentralize and modernize the contract administration process, a pivotal step toward progress.

6 Conclusions

Construction project missions and visions can be more effectively realized through the implementation of advanced digital technology in contract administration processes in the 21st century. Several factors contribute to this assertion. Historically, contracts in the built environment have been characterized as extensive, intricate, repetitive, and challenging to comprehend. Over time, this complexity has led to disputes arising from misunderstandings or misinterpretations of contract provisions. Consequently, the digitalization of contract administration through the utilization of smart contract applications, aimed at minimizing human or third-party intervention, has become essential to mitigate these challenges. This study delves into the significance of smart contract technology and the impediments faced by smart contracts. It also offers solutions to mitigate these barriers within the Nigerian context.

To address these issues, the study identified barriers facing smart contract applications through an extensive literature review and virtual interviews with knowledgeable participants. Nevertheless, it is important to acknowledge certain limitations in this research, which could serve as areas of focus for future studies. First, this study is among the few to examine the obstacles hindering smart contract applications and provide solutions for enhancing their implementation in Nigeria. Future research endeavors may explore other sectors and make comparisons. Second, the sample size of participants was relatively small, and the study was confined to two major commercial cities (Abuja and Lagos). However, it is worth noting that the study reached data saturation. Future studies might contemplate broadening the geographical coverage and employing inferential statistics to analyze the data more comprehensively. Finally, the importance of future research aimed at gaining a better understanding of the quality model for smart contracts concerning coding practices within the sector cannot be overemphasized.

This study underscores the undeniable relevance of smart contract applications in the built environment, albeit with substantial challenges that impede their implementation. Among the twelve emerging barriers identified, issues such as identity theft, data leakage, communication and synchronization problems, high computational costs, lack of driving force, high electricity consumption, complex implementation, absence of standardized legal applicability, and the absence of a local legal framework were recurrent concerns raised by interviewees. Similarly, from the ten emerging measures proposed to mitigate these barriers, concepts such as utilizing trusted entity data, comprehending cybersecurity aspects and underlying code, grasping the intricacies of implementation complexity and deployment costs, establishing a suitable legal framework for smart contracts, and reviewing regulations to foster smart contract adoption featured prominently among the interviewees. The findings of this study can provide valuable insights for construction firms seeking to enhance contract management practices through adoption. Furthermore, improving the smart contract development process to boost acceptance and utilization is imperative, enabling operators to report inefficiencies in specific application steps.

Acknowledgements Special thanks to the participants for providing knowledgeable contributions to enhance the findings of this paper.

Competing Interests The authors declare that they have no competing interests.

References

Aggarwal S, Kumar N (2021). Chapter sixteen: Hyperledger. In: Aggarwal S, Kumar N, Raj P, eds. Advances in Computers: The Blockchain Technology for Secure and Smart Applications across Industry Verticals. Cambridge, MA: Elsevier, 323–343

Aghimien D O, Aigbavboa C O, Oke A E (2020). Critical success factors for digital partnering of construction organisations: A Delphi study. Engineering, Construction, and Architectural Management, 27(10): 3171–3188

Ahmadisheykhsarmast S, Sonmez R (2020). A smart contract system for security of payment of construction contracts. Automation in Construction, 120: 103401

Aibinu A, Venkatesh S (2014). Status of BIM adoption and the BIM experience of cost consultants in Australia. Journal of Professional Issues in Engineering Education and Practice, 140(3): 04013021

Aigbavboa C, Ebekozien A, Mkhize N (2023). A qualitative approach to investigate governance challenges facing South African airlines in the fourth industrial revolution technologies era. Social Responsibility Journal, 19(8): 1507–1520

Arcadis J C (2016). Global construction disputes report 2016: Don't get left behind. Online Report

Badi S, Ochieng E, Nasaj M, Papadaki M (2021). Technological, organisational and environmental determinants of smart contracts adoption: UK construction sector viewpoint. Construction Management and Economics, 39(1): 36–54

Bogue R (2018). What are the prospects for robots in the construction industry? Industrial Robot, 45(1): 1–6

Cardeira H (2015). Smart contracts and their applications in the construction industry. Romanian Construction Law Review, 1(1): 1–6

Chen T, Cao R, Li T, Luo X, Gu G, Zhang Y, Liao Z, Zhu H, Chen G, He Z, Tang Y, Lin X, Zhang X (2020). SODA: A generic online detection framework for smart contracts. In: Proceedings of the 27th Network and Distributed System Security Symposium. San Diego, CA: 24449

Christensen S, McNamara J, O'Shea K (2007). Legal and contracting issues in electronic project administration in the construction industry. Structural Survey, 25(3/4): 191–203

Corbin J, Strauss A (2015). Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. 4th ed. Thousand Oaks, CA: Sage Publications, Inc.

Dhillon V, Metcalf D, Hooper M (2017). The hyperledger project. In: Dhillon V, Metcalf D, Hooper M, eds. Blockchain Enabled

Applications. Berkeley, CA: Apress, 139–149

Diallo N, Shi W, Xu L, Gao Z, Chen L, Lu Y, Shah N, Carranco L, Le T C, Surez A B, Turner G (2018). eGov-DAO: A better government using blockchain based decentralised autonomous organisation. In: Proceedings of the International Conference on eDemocracy and eGovernment (ICEDEG). Ambato: IEEE, 166–171

Dolgui A, Ivanov D, Potryasaev S, Sokolov B, Ivanova M, Werner F (2020). Blockchain-oriented dynamic modelling of smart contract design and execution in the supply chain. International Journal of Production Research, 58(7): 2184–2199

Ebekozien A (2020). Corrupt acts in the Nigerian construction industry: Is the ruling party fighting corruption? Journal of Contemporary African Studies, 38(3): 348–365

Ebekozien A, Aigbavboa C (2021). COVID-19 recovery for the Nigerian construction sites: The role of the fourth industrial revolution technologies. Sustainable Cities and Society, 69: 102803

Ebekozien A, Aigbavboa C, Samsurijan S M (2023a). An appraisal of blockchain technology relevance in the 21st century Nigerian construction industry: Perspective from the built environment professionals. Journal of Global Operations and Strategic Sourcing, 16(1): 142–160

Ebekozien A, Samsurijan M S (2022). Incentivisation of digital technology takers in the construction industry. Engineering, Construction, and Architectural Management, in press, doi:10.1108/ECAM-02-2022-0101

Ebekozien A, Thwala W D, Aigbavboa C O, Samsurijan M S (2023b). Investigating the role of digitalisation in building collapse: Stakeholders' perspective from unexplored approach. Engineering, Construction, and Architectural Management, in press, doi:10.1108/ECAM-04-2023-0337

Finck M (2018). Blockchains and data protection in the European Union. European Data Protection Law Review, 4(1): 17–35

Gai K, Wu Y, Zhu L, Xu L, Zhang Y (2019). Permissioned blockchain and edge computing empowered privacy-preserving smart grid networks. IEEE Internet of Things Journal, 6(5): 7992–8004

Giancaspro M (2017). Is a "smart contract" really a smart idea? Insights from a legal perspective. Computer Law & Security Report, 33(6): 825–835

Gurgun A P, Koc K (2022). Administrative risks challenging the adoption of smart contracts in construction projects. Engineering, Construction, and Architectural Management, 29(2): 989–1015

Halilbegovic S, Ertem N (2020). An explorative paper on speculative approaches to smart contracts. Prague Economic Papers, 29(4): 469–480

Hiroki W, Fujimura S, Nakadaira A, Miyazaki Y, Akutsu A, Kishigami J (2016). Blockchain contract: Securing a blockchain applied to smart contracts. In: Proceedings of the IEEE International Conference on Consumer Electronics (ICCE). Las Vegas, NV: IEEE, 467–468

Ho F (2016). Interview: Richard Saxon

Hu W, Hu Y, Yao W, Lu W, Li H, Lv Z (2019). A blockchain-based smart contract trading mechanism for energy power supply and demand network. Advances in Production Engineering & Management, 14(3): 284–296

Hughes D (2017). The impact of blockchain technology on the construction industry

Ibrahim F S, Ebekozien A, Khan P, Aigbedion M, Ogbaini I F, Amadi G (2022). Appraising fourth industrial revolution technologies' role in the construction sector: How prepared is the construction consultants? Facilities, 40(7/8): 515–532

Jaafar M, Ebekozien A, Mohamad D (2021). Community participation in environmental sustainability: A case study of proposed Penang Hill Biosphere Reserve, Malaysia. Journal of Facilities Management, 19(4): 527–549

Kirli D, Couraud B, Robu R, Salgado-Bravo M, Norbu S, Andoni M, Antonopoulos I, Negrete-Pincetic M, Flynn D, Kiprakis A (2021). Smart contract implementation example. Github

Kirli D, Couraud B, Robu V, Salgado-Bravo M, Norbu S, Andoni M, Antonopoulos I, Negrete-Pincetic M, Flynn D, Kiprakis A (2022). Smart contracts in energy systems: A systematic review of fundamental approaches and implementations. Renewable & Sustainable Energy Reviews, 158: 112013

Kolvart M, Poola M, Rull A (2016). Smart contracts. In: Kerikmäe T, Rull A, eds. The Future of Law and eTechnologies. Cham: Springer, 133–147

Kumar Bhardwaj A, Garg A, Gajpal Y (2021). Determinants of blockchain technology adoption in supply chains by small and medium enterprises (SMEs) in India. Mathematical Problems in Engineering, 5537395

Leka E, Lamani L, Selimi B, Deçolli E (2019). Design and implementation of smart contract: A use case for geo-spatial data sharing. In: Proceedings of the 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO). Opatija: IEEE, 1565–1570

Li J, Greenwood D, Kassem M (2019). Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. Automation in Construction, 102: 288–307

Liu S, Xie B, Tivendal L, Liu C (2015). Critical barriers to BIM implementation in the AEC industry. International Journal of Marketing Studies, 7(6): 162–171

Luu L, Chu D H, Olickel H, Saxena P, Hobor A (2016). Making smart contracts smarter. In: Proceedings of the ACM SIGSAC Conference on Computer and Communications Security. Vienna: ACM, 254–269

Mannaro K, Pinna A, Marchesi M (2017). Crypto-trading: Blockchain-oriented energy market. In: AEIT International Annual Conference. Cagliari: IEEE, 1–5

Mason J (2016). Construction Law: From Beginner to Practitioner. London: Routledge

McKinsey (2017). Reinventing Construction: A Route to Higher Productivity. McKinsey&Company Online Report

McNamara A, Sepasgozar S M E (2018). Barriers and drivers of intelligent contract implementation in construction. In: Proceedings of the 42nd AUBEA Conference on Educating Building Professionals for the Future in the Globalised World. Singapore: 281–293

McNamara A J, Sepasgozar S M E (2020). Developing a theoretical framework for intelligent contract acceptance. Construction Innovation, 20(3): 421–445

McNamara A J, Sepasgozar S M E (2021). Intelligent contract adoption in the construction industry: Concept development. Automation in Construction, 122: 103452

Mossberg M, Manzano F, Hennenfent E, Groce A, Grieco G, Feist J, Brunson T, Dinaburg A (2019). Manticore: A user-friendly symbolic execution framework for binaries and smart contracts. In: Proceedings of the 34th IEEE/ACM International Conference on Automated Software Engineering. San Diego, CA: IEEE, 1186–1189

Nanayakkara S, Perera S, Senaratne S, Weerasuriya G T, Bandara H M N D (2021). Blockchain and smart contracts: A solution for payment issues in construction supply chains. Informatics, 8(2): 36–46

Negara E S, Hidayanto A N, Andryani R, Syaputra R (2021b). Survey of smart contract framework and its application. Information, 12(7): 257–266

Nzuva S (2019). Smart contracts implementation, applications, benefits, and limitations. Journal of Information Engineering and Applications, 9(5): 63–75

Odubiyi T B, Aigbavboa C O, Thwala W D (2021). A concise review of the evolution of information and communication technologies for engineering innovations. In: IOP Conference Series: Materials Science and Engineering. Ota: IOP Publishing, 012231

Oprea S V, Bara A, Andreescu A I (2020). Two novel blockchain-based market settlement mechanisms embedded into smart contracts for securely trading renewable energy. IEEE Access, 8: 212548–212556

Pan J, Wang J, Hester A, Alqerm I, Liu Y, Zhao Y (2019). EdgeChain: An edge-IoT framework and prototype based on blockchain and smart contracts. IEEE Internet of Things Journal, 6(3): 4719–4732

Plano-Clark V L, Creswell J W (2015). Understanding Research: A Consumer's Guide. 2nd ed. Boston, MA: Pearson

Roberts M (2014). Government's BIM target unachievable. Pinsent Masons Survey

Rusakova E P, Frolova E E, Gorbacheva A, Kupchina E V (2019). Implementation of the smart-contract construction in the legal system of Russia. In: Proceedings of the 6th International Conference on Education, Social Sciences and Humanities. Istanbul: 748–753

Salha R A, El-Hallaq M A, Alastal A I (2019). Blockchain in smart cities: Exploring possibilities in terms of opportunities and challenges. Journal of Data Analysis and Information Processing, 7(3): 118–139

Saunders M N K, Lewis P, Thornhill A (2019). Research Methods for Business Students. 8th ed. Harlow: Pearson Education

Sepasgozar S M, Davis S R, Li H, Luo X (2018). Modelling the implementation process for new construction technologies: Thematic analysis based on Australian and US practices. Journal of Management Engineering, 34(3): 05018005

Tatum C (1989). Organising to increase innovation in construction firms. Journal of Construction Engineering and Management, 115(4): 602–617

Teddlie C, Tashakkori A (2010). Major issues and controversies in the use of mixed methods in the social and behavioural science. In: Tashakkori A, Teddlie C, eds. Sage Handbook of Mixed Methods in Social and Behavioural Research. 2nd ed. Thousand Oaks, CA: Sage Publications, Inc.

Timchuk O G, Nikityuk L G, Bakhtairova E A (2021). Integration of innovations in the construction industry. In: IOP Conference Series: Earth and Environmental Science. Irkutsk: IOP Publishing, 012181

Tsampoulatidis I, Bechtsis D, Kompatsiaris I (2019). Chapter 8: Moving from e-Gov to we-Gov and beyond: A blockchain framework for the digital transformation of cities. In: Komninos N, Kakderi C, eds. Smart Cities in the Post-Algorithmic Era. Cheltenham: Edward Elgar Publishing

Wahab A, Wang J, Shojaei A, Ma J (2023). A model-based smart contracts system via blockchain technology to reduce delays and conflicts in construction management processes. Engineering, Construction, and Architectural Management, 30(10): 5052–5072

Wearing D (2013). Inter-Institutional Collaboration in the New Zealand Tertiary Education Sector. Dissertation for the Doctoral Degree. East Lismore: Southern Cross University

Weerapperuma U S, Rathnasinghe A P, Jayasena H S, Wijewickrama C S, Thurairajah N (2023). A knowledge framework for blockchain-enabled smart contract adoption in the construction industry. Engineering, Construction, and Architectural Management, in press, doi: 10.1108/ECAM-01-2023-0012

Wong P F, Chia F C, Kiu M S, Lou E C W (2022). Potential integration of blockchain technology into smart sustainable city (SSC) developments: A systematic review. Smart and Sustainable Built Environment, 11(3): 559–574

Wulandary K, Panuwatwanich K, Henry M (2023). Readiness and potential application of smart contracts in the Indonesian construction industry. In: Proceedings of the 17th East Asian-Pacific Conference on Structural Engineering and Construction. Singapore: Springer, 249–263

Zheng Z, Xie S, Dai H N, Chen W, Chen X, Weng J, Imran M (2020). An overview on smart contracts: Challenges, advances and platforms. Future Generation Computer Systems, 105: 475–491

Zou W, Lo D, Kochhar P S, Le X B D, Xia X, Feng Y, Chen Z, Xu B (2021). Smart contract development: Challenges and opportunities. IEEE Transactions on Software Engineering, 47(10): 2084–2106