Automated Construction Payment Using Blockchain-Enabled Smart Contracts and Building Information Modelling

Matarneh, S.T.[1], Elghaish, F.[2,] Rahimian, F.[3,] Dawood, N.[3]

[1] Al Ahliyya Amman University, Faculty of Engineering, P.O. Box 19328, Al-Saro, Al-Salt, Amman, Jordan
[2] Queen's University Belfast, School of Natural and Built Environment, University Rd, Belfast BT7 1NN, UK
[3] Teesside University, Centre for Sustainable Engineering, Southfield Rd, Middlesbrough TS1 3BX

Abstract: The potential of blockchain in the construction sector has been recognized in existing literature, as well as its capacity to be integrated into construction projects to automate financial transactions for increased transparency, security, and control. Permissioned blockchain, according to existing research, can be utilized to create a business network among project participants due to its features being compatible with the nature of the construction sector. This article lays out a framework for introducing permissioned blockchain technology, notably Hyperledger fabric, into the construction delivery process. The suggested framework comprises explicit procedures that show how to develop a network during the pre-construction, construction, and closeout stages. The suggested framework also displays the flow of financial transactions across the envisaged financial system. Because of the capabilities of Building Information Modelling/Management (BIM) and cost planning. As a result, the framework determines the data needed to enter the blockchain financial system from 4D/5D BIM. The benefits of employing blockchain in the construction business were emphasized in a systematic literature review, which also selected the best blockchain platform. The framework can also be used by academics and industry practitioners to recognise the architecture of smart contracts (chaincode) in the construction sector, such as formulating endorsement and validation policies. Finally, the findings of this article will be used to develop a proof-of-concept prototype that will be used to test and confirm the suggested conceptual framework's applicability using a real-world case study.

1. Introduction

Blockchain is defined as a distributed ledger for the bitcoin cryptocurrency (Swan, 2015). Blockchain, on the other hand, has evolved into a full system for sharing and storing data on highly secure networks (Andoni et al., 2019). Many organisations that advocate that blockchain be used to improve the overall construction process (ICE, 2018; Lamb, 2018; Kinnaird et al., 2018). Moreover, blockchain research has become a trend during the last few years (Turk and Klinc, 2017; Li et al., 2018). Mason (2017) and Mason and Escott (2018a) emphasized the necessity of incorporating certain blockchain capabilities, such as smart contracts, into construction industry projects to automate payments. Following the researchers' recommendations, construction and engineering firms such as Arup have expressed a strong desire to integrate blockchain technology into the construction sector to improve performance in a variety of areas, including payment automation, supply chain management, and smart cities (Kinnaird et al., 2018). Furthermore, BIM has become a mandatory process in many countries. As a result, studies have looked into the integration of blockchain with BIM, such as Mathews et al. (2017a), who propose the integration for increasing trust among project participants in the construction industry. Besides, blockchain and BIM are advised for creating a comprehensive smart environment – digital built plan – for the construction industry (ICE, 2018; Lamb, 2018; Kinnaird et al., 2018).

Despite the high level of recognition for the importance of blockchain, payment automation in the construction industry has yet to be developed/presented as a practical application. The literature study is employed in this study to investigate the current state of blockchain/smart contract deployment in the construction industry and critically analyse the proposed potentials as well as the reality of the highlighted challenges. After that, a conceptual framework will be developed to outline detailed steps through the project delivery stage, such as how the blockchain consensus mechanism can be established during the pre-construction stage and how the closeout stage will be revolutionised by embracing blockchain technology. In this essence, this research aims to advance the use of blockchain and smart contracts by formulating a conceptual framework. It explains how smart contracts can be used and exploited through the project delivery process (pre-construction, construction, and closeout stage). In addition, the suggested framework takes into account the link between the BIM process and the automated payment smart contract framework's proposed workflow.

2. Blockchain in construction

The construction industry has been slow to incorporate blockchain and smart contracts in its practices. However, multiple attempts have been made to use them by constructing business models at various points of the project's lifecycle (Elghaish et al., 2021). The engineering and construction stages of blockchain research are the most active. Several studies, for example, looked at the security of payments during the engineering and construction stages and found that blockchain-based smart contracts are an effective way to resolve interim payment difficulties in building projects (Ahmadisheykhsarmast and Sonmez, 2020; Chong and Diamantopoulos, 2020; Das et al., 2020). Other research focused on construction quality information management and indicated that blockchain implementation can improve construction quality information management by allowing information traceability (Sheng et al., 2020; Zhang et al., 2020; Zhong et al., 2020). Some studies have focused on multi-stage applications and investigated blockchain applications during the entire project lifecycle. For example, Pattini et al. (2020) looked into the capabilities of blockchain in information flow management in construction projects and found that it might be useful in the design, bidding, construction, and maintenance stages. The use of blockchain and smart contracts in the construction contracting process was also highlighted. Researchers found that they have the potential to reduce transaction costs (Dakhli et al., 2019), reduce paperwork (Mason and Escott, 2018b), increase trust (Wang, 2017), facilitate immediate payment (Wang, 2017), secure payments (Salar, 2018), reduce construction disputes (Saygili et al., 2022) and improve procurement practice (Maciel, 2020).

3. Blockchain/smart contracts-BIM integration

Today information is exchanged and shared digitally in construction projects but the contracts that regulate them are often overlooked. Throughout the project's lifecycle, different stakeholders transact with each other during the project's lifecycle using collaboration platforms such as BIM with having any direct contractual relationship among themselves. As a result, there is a lack of design liability control, resulting in claims and conflicts. Furthermore, the reliance on numerous software packages by collaborative platforms such as BIM results in data exposure to third parties, data corruption, data integrity, and data loss (Pradeep et al., 2021). Various academics have looked into blockchain technology and smart contracts in order to address these challenges. According to several studies, blockchain technology has the potential

to improve BIM workflows in construction projects by providing consistent and immutable design records (Nawari and Ravindran, 2019; Pattini et al., 2021; Mohammed et al., 2021). Hargaden et al. (2019) discussed the potentials of blockchain technology in the construction industry and its adoption feasibility through use cases. The authors discussed the use of smart contracts and the viability of integrating them with BIM. Fitriawijaya et al. (2019) investigated the possibility of blockchain in maintaining BIM data within the model from the design stage until the operation stage. Zheng et al. (2019) designed a "bcBIM" system where project participants exchange hash values of BIM models in blockchain as data proofs. To keep all participants informed of the project status and changes, Parn and Edwards (2019) advocated using blockchain technology in a single data environment to keep all project participants up to date on project progress and changes (CDE). Liu et al. (2019) presented a conceptual architecture for storing BIM data in a blockchain network and exchanging it for long-term collaboration during the design and construction phases. Dounas et al. (2020) developed a framework of decentralised architectural design using BIM agents connected over the Ethereum blockchain to enhance the building information modelling processes. For utilizing blockchain technology in IPD projects, Elghaish et al. (2020) developed a framework to automate financial transactions. In order to visualize the flow of information, the framework focused on connecting the three processes of IPD, blockchain, and BIM. Similarly, Hamledari and Fischer (2021) developed a methodology for monitoring project progress that that integrates blockchain/ smart contracts and robotic reality capture technologies. Erri Pradeep et al. (2021) investigated the potential of blockchain technology in information exchange to allow auditability exchanged records audits and improve design liability controlling. Suliyanti and Sari (2021) demonstrated how BIM data can be securely transferred on a blockchain utilizing Hyperledger fabric. Tao et al. (2021) discussed how blockchain might be used in conjunction with BIM to improve the collaborative design process. To secure data sharing and maintenance, the authors used the blockchain network to act as several common data environment containers. Tao et al. (2022) developed a framework for blockchain and BIM to boost design collaboration process. To ensure transparency, traceability, and immutability throughout its fragmented supply chain management, Li et al. (2022) developed a service-oriented system architecture of blockchain, IoT and BIM for the data-information-knowledge-driven supply chain management in modular construction. Finally, to improve information visibility, traceability, and boost collaboration in working environment, Wu et al. (2022) developed a blockchain-enabled IoT-BIM platform for off-site production management in modular construction.

Table 1 below shows the selected articles related to the integration of blockchain/smart contracts and BIM in construction projects. Although various attempts have been made in the previous five years to examine blockchain/smart contract applications in the BIM context, more research into payment automation utilizing these technologies is needed.

Table 1: Blockchain/smart contracts integration with BIM

Authors/Year	Method	Aim
Mathews et al. (2017b)	Literature review	To look at the possibilities of blockchain in terms of providing feasible solutions to the issue of trust in a collaborative procurement system.
Amaludin and Taharin, (2018)	Literature review	To demonstrate the benefits of using blockchain technology to solve problems in the Malaysian construction industry.
Jiang (2018)	Literature review	To explore the applications of BIM, IoT, and blockchain technologies in construction industry.
Liu et al. (2019)	Conceptual framework based on literature review	To improve data traceability and reusability for sustainable collaboration.
Parn and Edwards (2019)	Mixed methods analysis of reports review and case studies analysis	To boost building information modelling (BIM) implementation in infrastructure asset management.
Shojaei et al. (2019)	Conceptual framework based on literature review	To highlight the potential of integrating smart contracts, blockchain, and BIM.
Zheng et al. (2019)	Practical BIM system model based on blockchain in mobile cloud with big data sharing.	To present the possibility of auditing BIM data to control historical modifications.
Pradeep et al. (2020)	Literature review	To develop a set of basic functional requirements for efficient integration of blockchain and BIM tools.
Dounas et al. (2020)	Practical framework of BIM and Ethereum blockchain integration.	To improve the building information modelling processes.
Elghaish et al. (2020)	Practical framework that combines three processes of BIM, IPD, and blockchain.	To facilitate payment management and risk/reward sharing practices in IPD.
Xue and Lu (2020)	Practical framework of BIM and blockchain integration.	To track the gradual semantic modifications in BIM progress cycle.
Erri Pradeep et al. (2021)	Practical framework of blockchain and BIM using a design science research method	To define challenges facing design liability control and information security.
Hamledari and Fischer (2021)	Practical framework integrating blockchain/ smart contracts and robotic reality capture technologies.	To automate the progress of decentralized payments.
Tao et al. (2021)	Practical framework of blockchain, IPFS and a smart contract algorithm in BIM environment.	To secure decentralized design collaboration.
Li et al. (2022)	Practical framework of blockchain, IoT and BIM platform (BIBP) integration.	To the supply chain data transparency, traceability, and immutability.
Tao et al. (2022)	Practical framework for blockchain and BIM	To streamline design coordination process.
Wu et al. (2022)	Practical framework of a blockchain technology, IoT and BIM.	To provide solutions to overcome "single point of failure" problem of IoT networks.

4. Methodology

To gain a comprehensive understanding of a topic, a systematic literature review is highly recommended (Webster and Watson, 2002). Literature review supports in identifying research gaps, and to develop conceptual models to guide future research (Langley, 1999). Thus, in this study, literature review was utilized to identify research gaps and investigate potential solutions. Existing studies related to blockchain adoption in construction industry were reviewed. Then, research gaps were identified, and a conceptual framework is developed to propose a robust solution for integrating blockchain and smart contracts in BIM environment in construction projects to automate payments through the project's lifecycle.

5. Framework development

The three primary stages of a construction project are: pre-construction, construction, and closeout. There are a numerous number of transactions between various participants among these three stages. BIM provides a platform for sharing and exchanging information between different participants during the project's lifecycle. Thus, BIM should be a leverage for sharing not only project's component information, but also financial information. The existing literature review shows the potential of blockchain technology in maintaining immutable transaction records. Therefore, the blockchain technology along with smart contacts are proposed in this conceptual framework to automate payments between projects' participants among the project's lifecycle as shown in Figure 1.

Pre-construction stage:

During the pre-construction stages, project's participants decide to use the blockchain to manage financial tasks including payments, retentions, etc. Then, the endorsement policy will be developed to define the duration of implementing financial tasks, the monetary value of the construction package task, and to assign responsibilities. These established conditions will be later coded to be utilised for data validation in blockchain mechanism. This validation is called the consensus mechanism which consists of a set of algorithms to process the validation of invoked and stored data in the blockchain network (Wang et al., 2018). Defining responsibilities and roles in this stage is essential to limit the possibility of tampering any data of general blockchain. As a result, the permissioned blockchain requires a consensus process and has pre-defined counterparts. To automate the consensus mechanism, a quantified data should be available to serve as validation points. BIM has an essential role in this stage as a shared platform for each construction package prices thru the 5D BIM model. These estimated prices are linked to the timeline (4D BIM) to allow payment's scheduling for all project's parties.

Construction stage

Throughout the construction process, according to the scheduled payments, the blockchain administrator can assign who is the data sender/receiver at each payment milestone. Accordingly, the contractor performs as a data sender by sending invoices and the owner performs as a data receiver. Thus, the endorsement policy should consider the owner and architect as the main endorser for any invoked transaction. Generally, the Hyperledger fabric's consensus mechanism validates the transaction in two layers (1) endorsement policy (who should accept the transaction), and (2) the data-blocks allocation through specific channel. To validate the consensus mechanism, the agreed conditions will be checked for each block (transaction) automatically in terms of payment milestone date, the value of the invoice and the

maximum amount of contract. One the transaction is validated; it will be sent to the concerned parties' ledger. BIM plays a vital role in this stage in terms of checking payment due by comparing the actual performed works again the planned works using 4D and 5D BIM. In this stage, project's parties will use smart contracts to invoke transactions to record data or request a payment. Endorsed transactions should be ordered using channels to be recorded in the correct ledger.

Close out stage

At the close out stage, the blockchain plays a significant role in closing out the project by providing a historical record of financial data. Participants can use API to invoke query transactions to get all recorded financial data. This will allow them to estimate the final payment precisely. The proposed framework suggests an automated platform for receiving, validating, recording, and displaying immutable transactions of payments through the project's lifecycle. Furthermore, the proposed framework suggests an improvement to the payment and cashflow management in construction projects by offering consistent historical transactions.
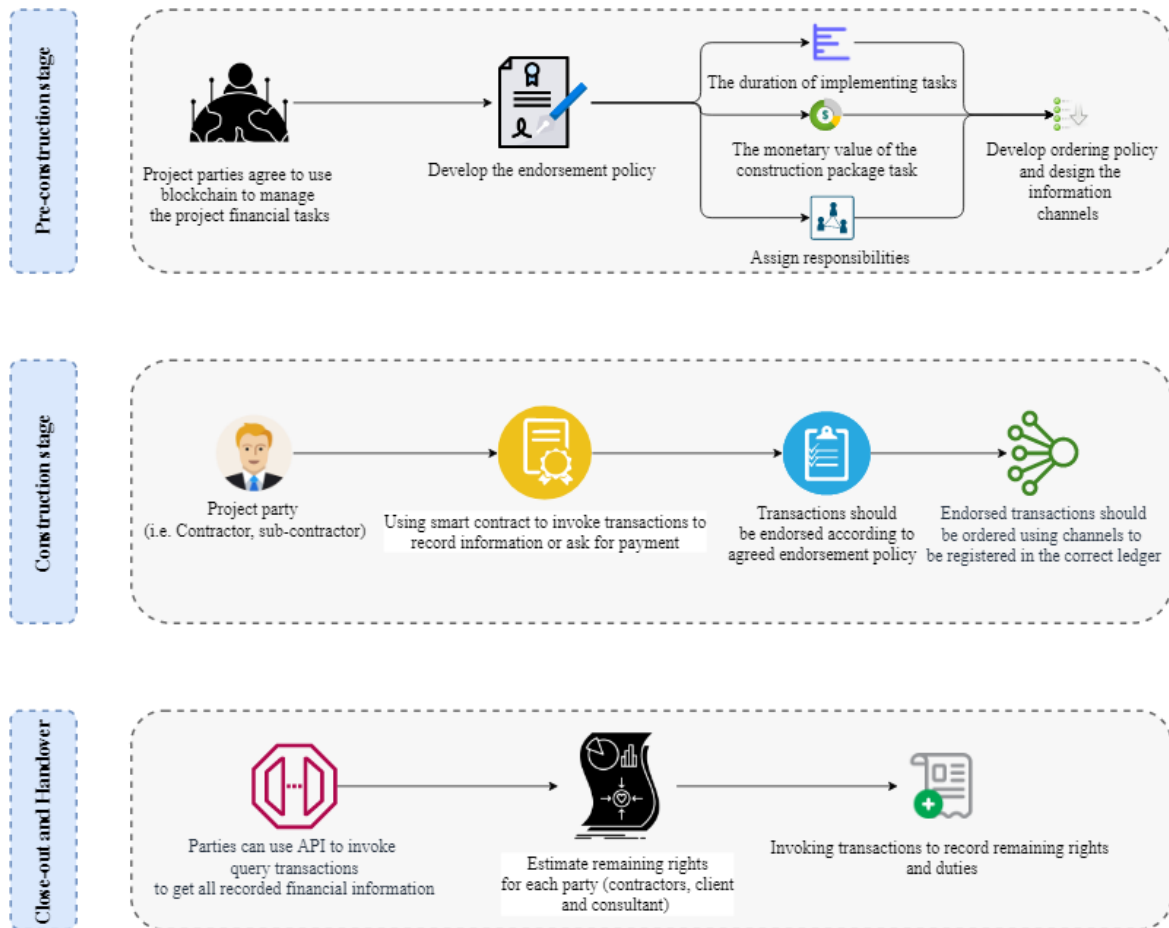

Fig. 1. The automated payment conceptual framework

Model architecture

Fig. 2 demonstrates the framework architecture with detailed tasks. Thus, it can be used as a departure point for developing a practical solution to employ permissioned blockchain, smart contracts and BIM in construction projects. This model can be a point of departure to develop practical solution-based BIM and blockchain to automate the payment process.
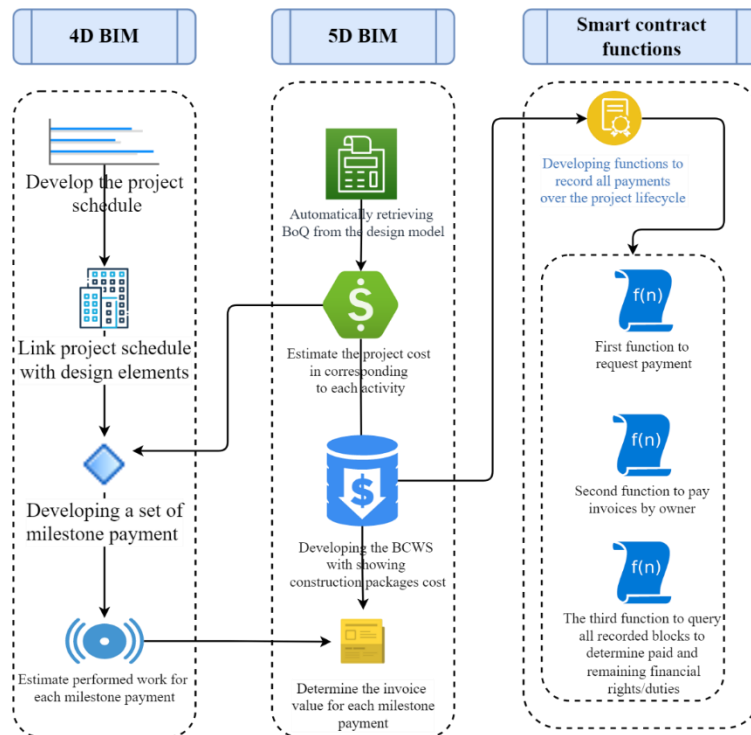
Fig. 2. The model architecture

6. Discussion and conclusion

Extant literature review survey shows that the Hyperledger fabric is a user-friendly blockchain platform for automated payments through the project's lifecycle. Given, The Hyperledger fabric is a modular consensus mechanism that allows project participants to develop a consistent mechanism relying on the project terms and conditions (Androulaki et al., 2018; Brandenburger et al., 2018; Dhillon et al., 2017), therefore, it can be used to develop a wide range of solutions to minimise fragmentation in construction process. The Hyperledger fabric's applicability originates from a partnership between Hyperledger (Linux), IBM, Oracle, and SAP, which allows for a seamless implementation (Van Mölken, 2018; Vukolić, 2016). The critical analysis of the existing research in blockchain within the construction industry focuses on developing a theoretical foundation that may be utilised as a starting point for moving forward. These theoretical bases can be extended to explore further the application of blockchain/smart contract in construction or to develop prototypes to validate the conceptual frameworks. As such, this study attempts to draw a practical application to blockchain/smart contracts by outlining the essential functional requirements during the pre-construction stage, such as establishing the consensus mechanism. In addition, the proposed framework addressed the construction stage carefully by presenting the data flow (i.e., who is the data sender and receiver). Finally, because the existing research did not give enough investigation into financial transactions during the closeout stage, the closeout stage is taken into account in this study. It is worth noting that this is where the majority of claims and disputes arise. Thus, the proposed framework suggests a set of tasks to be implemented with smart contracts to minimise potential claims and disputes. This could come to reality by exploiting the functionality of smart contracts to add more functions and record all types of financial issues (i.e., advanced payments, regular payments and retentions).

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