Leveraging Smart Contract in Construction for Supporting Timely Project Delivery

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Abstract. Timely identification, analysis, and verification of contract compliance are necessary for reliable construction workflow, but these operations often require an extensive amount of time investment. Blockchain provides a secure, decentralized method of managing information that can address numerous challenges in the construction industry. Smart contract, an algorithmically-specified contractual transaction protocol, allows for automatic execution based on predefined conditions, which can facilitate real-time communication and collaboration among stakeholders. Therefore, this study aims to explore how smart contracts can improve efficiency, transparency, and accountability in the construction industry by automating contract execution, ensuring compliance, and reducing disputes. A construction smart contract framework was proposed by integrating hyperledger fabric and building information modelling (BIM) within an integrated project delivery (IPD) model. The benefits and limitations of using smart contracts in construction are identified, and further recommendations for smart contract implementations are discussed.

1. Introduction

The construction industry has long been plagued by inefficiencies, delays, and lack of transparency, which have hindered its ability to deliver projects on time and within budget (Liu et al. 2023). In recent years, blockchain technology has appeared as a promising solution to address these challenges. It has gained significant attention in many industries (e.g., finance and healthcare) due to its potential to provide secure and transparent methods of recording and verifying transactions (San et al. 2019). The application of blockchain technology in the construction sector has been explored in various areas such as supply chain management (Gurtu et al. 2019), quality control (Lin et al. 2020), and project financing (Tian et al. 2020).

Smart contracts, which are self-executing agreements with the contract terms directly written into code, have been one of the most popular blockchain applications. It has the potential to redefine and streamline the traditional cumbersome and inefficient contractual process in construction. By automating contract terms and enforcing compliance through self-executing codes, smart contracts can eliminate the need for intermediaries and reduce the risk of disputes and delays. The benefits of smart contracts can be amplified, when combined with other construction technology and methods such as building information modelling (BIM) and integrated project delivery (IPD), which enables real-time collaboration, data management, and decision-making throughout the project lifecycle (Elghaish et al. 2020).

A number of existing efforts have started to explore the possible applications of smart contracts in construction. For example, Swan et al. (2015) have applied the smart contract technology in the procurement phase of construction projects, which eliminated the need for third-party mediators like banks, resulting in decreased fees and administration costs. By embedding the payable amount and due date of goods in the smart contract, both parties can ensure that the money is locked in the system until the due date of payment. The self-executing feature of smart contracts allows for automatic release of payment to the client's cryptocurrency account, as verified by both parties within the system.

However, despite the importance of existing efforts, significant knowledge gap still exists. The development of smart contracts in construction requires a deep understanding of complex construction contracts and substantial technical expertise. Existing smart contracts in the market are mostly from a general domain (e.g., finance, game, or notary). However, the complex nature of construction projects, which involves numerous parties participating in the contractual process and various local regulations, makes the general smart contract systems not suitable to apply in the construction industry.

To address this knowledge gap, this paper explores the potential of blockchain and smart contracts in construction and discusses how their integration with BIM and IPD can create a more efficient and collaborative construction process. Leveraging these technologies can propel the construction industry towards increased efficiency and transparency. Smart contracts could empower all project participants with decision-making abilities regarding resource allocation and contractor selection. This may lead to a more inclusive and equitable industry that minimizes conflicts and promotes timely project delivery.

2. Background

2.1 Blockchain and Smart Contracts

Blockchain technology is a decentralized and distributed system for recording and verifying transactions without relying on a centralized authority. The underlying technology of blockchain is based on the concept of a shared and tamper-proof digital ledger, which allows for the creation and validation of digital transactions in a secure and transparent way (Nawari et al. 2019). It uses consensus algorithms and cryptography, which ensure that each block in the chain is secure and immutable, preventing any unauthorized modification of the ledger (Elghaish et al. 2020).

Smart contracts are computer programs that facilitate the execution and enforcement of agreement terms between parties. These contracts are stored and run on a blockchain network, offering necessary security and transparency to guarantee proper execution. Hyperledger fabric is an open-source blockchain network that provides private, permissioned, and customized enterprise-level blockchain solutions, which includes modular architecture, pluggable consensus protocols, and privacy-preserving features. It offers an ideal platform for implementing blockchain and smart contract-based solutions in supply chain management, to automate the execution of complex business processes and create secure and transparent digital agreements that are recorded on the blockchain. For example, Christidis et al. (2016) applied hyperledger fabric and smart contracts in the healthcare industry. This work combines blockchain, smart contracts, and hyperledger fabric for a secure and transparent platform to manage patient data, clinical trials, and medical supply chains. It also facilitated the automation of patient consent forms and data sharing agreements.

2.2 Blockchain in Construction

Blockchain and smart contracts are increasingly being explored for their potential in enhancing construction management and boosting overall efficiency. For example, construction supplies can be monitored using smart contracts to ensure compliance with quality and safety standards and regulations (Swan et al. 2015). In an effort to enable a seamless flow of information and transactions across the construction supply chain, as well as improve collaboration and coordination among project stakeholders, BIM has been highlighted as a critical technology that can be integrated with blockchain and smart contracts. For example, BIM models can be stored on a blockchain platform, which allows all stakeholders to access and update the most current version of the model in real-time. Smart contracts can also be used to automate BIM-related processes, such as model validation and clash detection, which can help reduce errors and delays in the construction process (Narayanan et al. 2016). Overall, the integration of blockchain, smart contracts, and BIM has the potential to revolutionize the construction industry by increasing transparency, improving collaboration, and reducing the costs and time associated with traditional construction processes.

2.3 Hyperledger Fabric

Hyperledger fabric is a permissioned blockchain platform that is gaining popularity in the construction industry due to its suitability for developing smart contract applications in complex project environments. It is a consortium blockchain platform that allows multiple organizations to participate in a shared ledger while maintaining control over their own data and identities. The platform provides a modular architecture that supports the development of customized smart contracts that can address specific business needs and requirements.

Hyperledger fabric has several advantages and features that make it suitable for use in the construction industry. First, it is a permissioned blockchain platform, which means that it offers a higher level of privacy and security than public blockchain platforms such as Bitcoin or Ethereum. This makes it particularly attractive for the construction industry, which deals with sensitive data such as project plans, budgets, and schedules. Second, it provides a flexible consensus mechanism that allows project participants to define their own consensus rules and validation criteria. This makes it possible to create customized smart contract applications that can address specific business needs and requirements in various construction projects. Third, it supports the integration of existing enterprise systems and applications through its modular architecture and flexible application programming interface (API). This makes it possible to create smart contract applications that can interact with existing construction management software systems such as BIM and enterprise resource planning (ERP) systems. It also provides a scalable and reliable infrastructure that can support large-scale construction projects with multiple stakeholders.

3. Knowledge Gaps

The use of smart contracts in the construction industry has gained attention in recent years due to its potential to improve project efficiency, reduce costs, and increase transparency. Once the pre-agreed conditions are met, the system executes the contract automatically without the need for intermediaries, such as lawyers or arbitrators.

However, there are still a number of issues that need to be addressed before smart contracts can be effectively developed and implemented in the construction industry. One of the biggest challenges is the complexity of construction contracts, which may be difficult to translate into general smart contracts. Construction contracts are complex due to their multi-party nature, with various stakeholders involved, and their need for local legal and regulatory compliance. On one hand, construction projects involve complex interactions among various parties, such as contractors, subcontractors, owners, and regulators. The specific requirements and constraints of different parties need to be adequately addressed by the smart contracts. For example, construction projects often involve physical work and the use of tangible materials, which requires additional tracking and verification mechanisms that are not typically included in general-purpose smart contracts. On the other hand, construction projects may be subject to various regulations and safety standards that need to be incorporated into the smart contract design. Therefore, there is a need for the development of a smart contract system that is specifically tailored to the construction industry and its unique requirements to effectively utilize this technology in construction projects. This would involve careful consideration of the various stakeholders involved, as well as the specific regulatory and safety requirements that must be addressed.

Second, there is a lack of awareness and understanding of smart contracts among stakeholders in the construction industry. Construction industry has historically been slower to adopt new technologies compared to other sectors. Many industry professionals, such as project owners, architects, engineers, contractors, and subcontractors, may not be familiar with the potential advantages, limitations, and applications of smart contracts. This lack of understanding could hinder the widespread adoption and implementation of the technology, as well as pose significant challenges in the development of best practices and standards.

Third, there are technical limitations that need to be addressed in the development and implementation of smart contracts in the construction industry. One of the limitations is the scalability of smart contracts, as they may become slow and inefficient as the number of participants and transactions increase. There may also be challenges in terms of security, standardization, and interoperability with existing systems and processes.

4. Proposed Construction Smart Contract Framework

This paper aims to develop a workable solution for an automated smart contract framework in the construction industry by integrating hyperledger fabric and BIM within an integrated project delivery (IPD) model. IPD is recognized for its unique compensation system that fairly distributes gain and pain ratios among all project participants. This type of project delivery method requires a cooperative contracting relationship that links individual success for achieving project objectives, and thus well-suited for smart contract application. In an IPD model, all parties involved in the project must agree on a suitable compensation scheme that determines the proportions of cost overrun, cost underrun, and other fees within the agreed total budget. An IPD contract comprises three components: 1) the reimbursement of project costs and all project implementation costs (guaranteed); 2) the overhead costs and profit for all participants (at-risk); and 3) the pain-to-gain ratios defined in the contractual agreement. To this end, this research proposes a framework as a solution that combines blockchain, BIM, and IPD to streamline information flow for transactions in building projects. The framework is divided into three main portions, each of which corresponds to a different IPD stage. Step 1 presents the setup of the blockchain network prior to deployment during the IPD pre-construction phase. Step 2 presents the management of all IPD transactions during the building phase, which enables contractors to monitor progress without physically attending meetings. Step 3 presents the profit distribution between owner and non-owner parties during the close-out phase, which uses specific BIM dimensions to provide cost information for the payment schedule.

The proposed framework presents the input and output at each IPD stage and the corresponding development status of the blockchain network as shown in Fig. 1. The framework was developed using readily available tools including the IBM Blockchain Cloud Beta 2 platform and the IBM VSCode extension for blockchain. Further experiments will be conducted to verify the validity of the proposed framework.

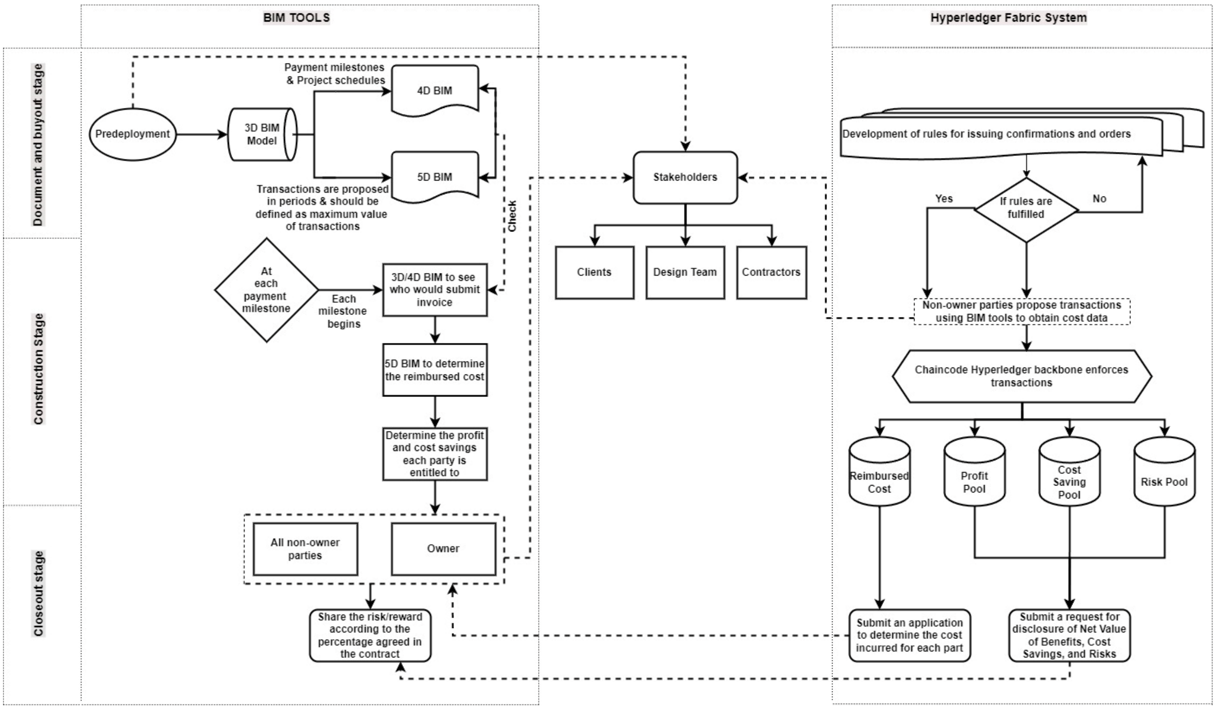

Fig. 1. Interoperability between BIM, IPD, and blockchain system

Step 1: Documents and Buyout Stage

The primary goal of the first step is to improve the transparency, security, and information exchange among project participants. Three crucial elements are included in this step: 1) developing network components, 2) defining endorsement policies, and 3) establishing ordering policies. Each IPD core team member serves as a peer node in the blockchain network. A blockchain network is composed of multiple such peer nodes. For example, the peer node that places orders for transactions is called the orderer peer, and the vital decision maker is called the consultant peer. Endorsement policies identify the relationships among the peer nodes, which aims to create a transaction channel for one party to endorse another. Every transaction made by non-owner parties must be endorsed by the owner parties and consultant peers, with the endorsement policy including a timestamp. Ordering policies determine the transaction recording path, including the involved peer and the specific channel. The trajectory of endorsed transactions is predetermined when selecting the channel to deliver transaction data.

Pools for reimbursable costs, profits, and cost-savings are the three IPD financial intensive functions, and the IBM Blockchain Cloud Beta 2 platform offers particular capabilities to record proposed financial transactions. In the proposed framework, any transaction initiated by non-owner parties should receive the owner's approval. Therefore, to increase transparency and security for the IPD parties, the profit pool should be capped at a specific financial amount for each milestone.

The ordering process follows the project schedule in chronological order and the unique relationships among the IPD project team members. The framework also includes two channels: a primary channel and a second, secret channel. Both channels are used to facilitate transactions between all parties; while the secret channel is used among all non-owner parties to privately communicate with the owner, which is mainly used when mistakes occur and the owner needs to employ negative transactions to recuperate the money spent.

Step 2: Construction Stage

In the construction stage, hyperledger fabric was used to process the transactions. A hyperledger fabric transaction process consists of four key stages. First, non-owner parties who have completed their work initiate transaction requests in accordance with the project schedule. The chaincode function is activated through the API, which is accessible to any network member via the IBM Blockchain Cloud Beta 2 platform. The transaction is then sent to the pre-identified peers for endorsement according to the endorsement policies.

Second, compliance checking of all transactions with the endorsement policy is conducted, which outlines the transaction's maximum amount and projected timeframe of invocation. Once endorsed, the transaction is returned to the sender to initiate the ordering process.

Third, endorsed transactions are sent to the sender (i.e., the ordering peer node), where they are sorted chronologically as per the ordering guidelines set forth in the pre-deployment phase. The transactions are then grouped into a block based on their timestamp and packaged for peer commitment. The chaincode architecture defines the number of transactions, the sender, the value, and the name of the trade package. In the IPD smart contract, the chaincode architecture is arranged and programmed as function parameters for each of the three suggested transactions: cost savings, profit, and reimbursed costs.

Finally, all packed and ordered transactions are broadcast to the pre-selected peer nodes in accordance with the ordering policy. All peers must be made aware of any alterations to the final financial statements of the three main IPD transactions. This is particularly important if there are negative transactions initiated by the owner party with the intent to correct any issues highlighted in an earlier financial statement. The smart contract automatically takes into account risks and delays. The construction project must be finished according to the schedule, which is specified in the smart contracts through programming language. If there are delays during the construction phase, the smart contract will not continue with the payment, and the schedule needs to be updated with owner's permission before any transaction can be initiated again.

Fig. 2. presents the phase-wise payment process of the proposed framework. The smart contract is first initialized through the IBM Cloud Blockchain Beta 2 platform. A trustworthy network is built under the control of a selected Certification Authority (CA), who is in charge of maintaining trust within the network. Member service providers (MSPs) are then established for access control and identity management. Every channel in the network has unique endorsement policies that specify the number of peer endorsements required for the successful execution of a transaction. A smart contract can then be developed using IBM VSCode extension. It is activated on selected peers, allowing them to take part in transaction execution and validation based on pre-defined business logic. This process accelerates the payment process in construction projects by facilitating communication between stakeholders and enabling the execution of various actions as defined by the smart contract.

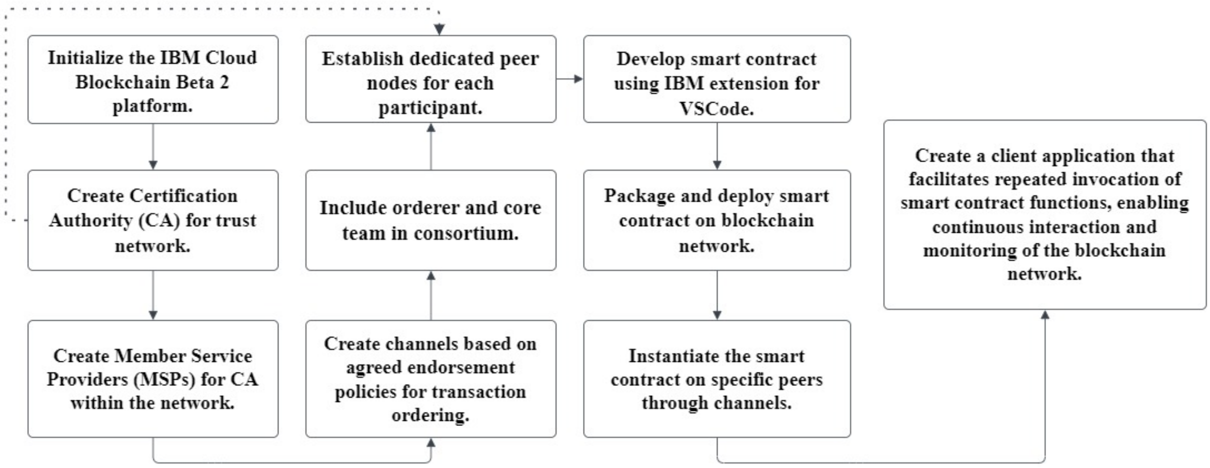

Fig. 2. Phase-wise payment process of the proposed framework

Step 3: Closeout Stage

In the project's closeout stage, the same process as per the previous milestones is followed, with a particular focus on monitoring the project's overall profit using the ordering project system. The total profit transactions correlated with each activity should be assembled and recorded in a solitary ledger. Additionally, every profit node or pool must maintain these ledgers for future reference, with each ledger linked to the one before it to ensure data consistency.

Step 4: Integration of IPD, BIM, and Blockchain

The chaincode hyperledger fabric system sets the number of peers and functionalities for the IPD smart contract format by integrating crucial BIM data in the pre-construction stage. These data include the start and finish dates for each trade package, the total cost, and the highest predicted earnings for non-owner parties. In the construction phase, non-owner parties use the recovered 5D BIM values to access the smart contract functions. These values include resources used to complete the agreed-upon job, the profit-at-risk percentages, and cost reductions. In the closeout stage, each partner calculates the net amount of all profits, cost savings, and repaid costs, with the share payable based on the risk/reward ratios determined during the buyout stage. With 5D BIM data, each party's performance is evaluated, enabling a comparison of planned and actual earnings. Everyone participating in the chaincode hyperledger fabric is prohibited from modifying the obtained percentages in order to preserve trust among the remaining partners, especially those who might leave the construction site early.

5. Conclusion

The implementation of digitization in the construction industry is a widely accepted solution to enhance process optimization and automation. However, the industry still heavily relies on traditional paper contracts and communication methods, which often results in a lack of transparency and time-consuming process. By integrating smart contract and BIM within an IPD framework, this research developed an automated financial system for the construction industry. The adoption of smart contracts in this context can significantly enhance collaboration, transparency, and efficiency in managing financial transactions, contracts, and payments. In the proposed framework, smart contracts are integrated with 5D BIM that linked cost and payment information with the construction processes. This innovative approach to financial management could result in significant time and cost savings. In addition, this system offers a noteworthy advantage in the form of its endorsement policy, which employs rigorous algorithms that precisely define the decision-making process for the IPD core team members. This includes identifying the relevant decision-makers and documenting the outcomes of previous decisions, which helps to streamline and expedite the decision-making process.

In their future work, the authors will focus on quantifying the cost-benefits of blockchain applications in construction and exploring their integration with digital project delivery. This would include enhancing the current semi-automated linkages between BIM data and blockchain networks to facilitate fully automated endorsement processes. Addressing this constraint could lead to more efficient and effective endorsement procedures, which would be beneficial for stakeholders in various industries. As the construction industry continues to evolve, it is crucial to embrace new technologies and explore innovative solutions to improve construction processes and outcomes.

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