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PROMOTING THE IPD DELIVERY METHOD IN CONSTRUCTION PROJECTS: A BIM-BASED SMART CONTRACT APPROACH

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ABSTRACT

The adoption of integrated project delivery (IPD) provides several advantages over traditional delivery methods, such as shorter schedules, efficient communication, and higher performance quality. However, its implementation is constantly hindered by many barriers. Existing studies on IPD barriers are limited to quantifying and addressing such obstacles. Additionally, hardly any studies have addressed the potential of advanced technologies in exploiting the adoption of IPD projects. Thus, this study presents an automated system that integrates blockchain, smart contracts, and BIM technologies to facilitate the implementation of IPD projects. Hyperledger Fabric and chaincodes are used to develop the blockchain network in accordance with 4D and 5D BIM models. The developed system simplifies various financial transactions throughout different phases of the IPD project implementation. The system allows non-owner participants to submit requests and review transaction records with the aim of minimizing possible conflicts. The methodology is evaluated by testing it on a real-life case study. The case study is modeled using BIM tools, and the corresponding blockchain network and smart contracts are developed. The findings prove the capability of the developed system to provide a secure and trustworthy platform for managing IPD transactions without the need for third-party involvement.

KEYWORDS

Integrated project delivery (IPD), smart contracts, BIM, blockchain, construction projects.

INTRODUCTION

The integrated project delivery method (IPD) is an innovative delivery method that overcomes many of the limitations of conventional delivery (Ahmed et al., 2021). Conventional delivery methods are characterized by fragmentation (Teng et al., 2019), lengthy processes (Ghassemi & Becerik-Gerber, 2011), and poor information sharing (Rahman & Kumaraswamy, 2004). IPD was introduced to overcome these drawbacks. The IPD system is characterized by early involvement of participants and efficient risk-sharing and compensation systems (Faris Elghaish et al., 2020). Evidence in the literature has shown that IPD has the potential to enhance project performance. For instance, Ahmad et al. (2019) indicated that IPD improves 14 project performance indicators, such as cost management, work quality, information sharing, and scheduling management.

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However, the adoption of IPD projects always encounters many barriers. Rodrigues and Lindhard (2021) have discovered many barriers to IPD adoption using case-based studies. The found barriers can be summarized as follows: 1) difficulties in estimating the limbs values (components) in various project stages; 2) establishing the culture of having the same control over the project from all participants; 3) the dilemma of having transparency and trustworthiness through the entire project; 4) behavioral barriers as most participants can expect the higher profitability. Similarly, Yee et al. (2017) have categorized all of the barriers into four main categories: contractual barriers, behavioral barriers, structural barriers, and technological barriers. The study concluded that technological barriers are the most critical barriers that hinder the adoption of IPD. To be able to exploit the merits of the IPD system, advanced technology sharing and communication systems are required (Faris Elghaish et al., 2020). Building Information Modeling (BIM) is an example of technology adoption in IPD projects. As mentioned by Salman et al. (2012), BIM can enhance the delivery of projects by providing efficient collaboration between project participants. However, it is argued that integrating advanced technologies, such as blockchain, with BIM can further address many of the IPD barriers (Lamb, 2018).

The latest advances in blockchain technology have presented chaincodes (smart contracts) as an alternative solution that overcomes the downside of the fragmented nature of construction projects (Ahmadisheykhsarmast et al., 2020). Smart contracts are digitalized contractual agreements that provide solutions for the deficiencies in the payment systems of construction projects. Blockchain platforms act as a decentralized and secure system that provides an efficient implementation of smart contracts (Sigalov et al., 2021). It records any transactions or movements of the system on blocks that can be displayed on the ledgers. More on blockchain components will be discussed in the following sections.

To this end, many studies have addressed the potential of blockchain technologies in construction projects. However, the literature lacks the following aspects: 1) the majority of studies presented a conceptualization of the blockchain framework, with no actual implementation; 2) limited studies addressed the integration between IPD and blockchain in the construction industry; 3) potential claims on a construction project are yet to be addressed on the blockchain network. Considering these gaps, this paper presents an integrated system to overcome the obstacles of implementing the IPD method. The objectives can be summarized as follows: 1) identifying and (egorizing the barriers that hinder the adoption of the IPD method in construction projects; 2) studying the potential of advanced technologies (e.g., smart contract and BIM) to overcome some of the identified barriers; 3) developing an automated system that facilities the payment transitions and minimizes possible conflicts, hence promoting the IPD approach; 4) Validating the system by applying the proposed methodology on a real case study. The rest of the paper is structured as follows: the next section provides the literature, followed by the study methodology, which is then validated. Section 4 shows the validation and case study, and section 5 provides the conclusion and recommendations.

LITERATURE REVIEW

IPD is a highly collaborative approach to project management that involves the integration of all stakeholders engaged in a project, including the owner, architect, contractor, and other key team members, within an environment of trust. IPD aims to create a team environment where all parties work together towards a common goal, which is the successful completion of the project. The process begins with the development of a comprehensive project plan, which outlines the scope, schedule, and budget of the project. The project plan is then used to guide the team throughout the project, with recurring updates and revisions made as necessary. One of the key features of IPD is the use of BIM, which helps identify potential conflicts and design issues early in the project, preventing costly delays and rework (Ashcraft, 2011). This section provides a literature review on the barriers associated with IPD adoptions, the potential of BIM, blockchain, and smart contracts in construction projects, and a discussion on which blockchain platforms to be used in the current study.

Barriers to IPD Adoption in Construction

Many studies were carried out to identify and categorize IPD barriers. For instance, Sherif and Abotaleb (2023) classified the barriers of IPD adoption into five main categories. Their study indicated that the majority of construction projects in established and developing countries face technological challenges, such as integration issues between BIM and IPD and unreliable payment systems, which are well-known obstacles to IPD adoption (Durdyev et al., 2019). Further, the adoption of IPD projects requires a high level of information sharing, efficient communication technologies, and reliable payment mechanisms (F. Elghaish et al., 2020). IPD adoption in an emerging market is also hindered by ineffective profit distribution procedures, a low level of stakeholder trust, inadequate training, a lack of technological support, a lack of legal and contractual support, procurement problems, and a lack of a collaborative environment (Othman, 2020). An extensive literature review has revealed the following barriers categories: technological barriers (Durdyev et al., 2019), financial barriers (Georgiadou, 2019), lack of adequate research on IPD (Othman, 2020), cultural barriers (Sherif et al., 2022), and legal barriers (Rached et al., 2014). Despite the variety of barriers identified in the literature, this study focuses on the technological barriers and the potential of advanced technologies, i.e., blockchain and smart contracts, in addressing them.

Potential of Blockchain and Smart contracts in construction

In recent times, blockchain technology has been introduced as a distributed ledger that can assist project teams with information decentralization and security (Assaf et al., 2022). Besides providing secure and reliable databases, it also promotes various payment transactions among project parties. Numerous benefits are perceived by the adoption of blockchain technology, such as trustworthiness, immutability, and traceability (Assaf & Zayed, 2022). Furthermore, blockchain technology has provided an efficient platform for the implementation of chaincodes (smart contracts) and automated transactions. Smart contracts can be defined as digital protocols that run on a selected blockchain network and enforce endorsement policies, as well as provide automated transactions (Ahmadisheykhsarmast & Sonmez, 2020). To this end, the association between blockchain technology and smart contracts has introduced a potential solution to address some of the IPD adoption barriers, such as the ineffective risk/savings distribution mechanisms (F. Elghaish et al., 2020).

Many studies have discussed the use of blockchain/smart contracts in the construction industry and, more particularly, in managing contracts and payments. Saygili et al. (2022) have discussed the application of blockchain in the reduction of construction disputes. Their study concluded that blockchain technology provides enforceable codes for transaction execution and efficient documentation of all of the transactions, minimizing the probability of disputes and claims. Moreover, Assaf and Zayed (2022) have studied the implementation of an integrated blockchain-based smart contracts system with BIM technology in automating the payment transaction in modular construction projects. Their study provided a claim resolution system to reduce the possible claims in modular projects. Elghaish et al. (2022) have developed a payment system to automate transactions in accordance with traditional and design-build delivery systems. Their study took into account the defects liability period (DLP) through the use of chaincodes to manage the remainder of the duties. Sonmez et al. (2022) have studied the integration between BIM models and decentralized blockchain networks to manage the project's progress payments. Furthermore, similar approaches of integrating BIM technology with supporting technologies were addressed to enhance construction procurement processes.

For instance, Aguiar Costa and Grilo (2015) proposed an e-procurement system integrated with BIM technology to reduce the fragmentation in the procurement processes throughout the project life cycle. Different blockchain platforms were used in the mentioned studies, which raises the question of what indicators must be considered when selecting the blockchain platform. The following section will discuss the suitability of different blockchain platforms in the current study.

SELECTING THE SUITABLE BLOCKCHAIN PLATFORM

Several forms of blockchain platforms are available and vary in their functionality and level of privacy (Assaf & Zayed, 2022; Li et al., 2022). Some of the most used platforms are Ethereum, HyperLedger Fabric, Bitcoin Network, and R3 Corda (Perera et al., 2020). These platforms vary in many characteristics that specify their suitability to adopt for different purposes. Generally, blockchain platforms can be permissioned or permissionless. The permissioned blockchain platform allows certified participants only (with digital identity) to join the network. Conversely, the permissionless blockchain network, such as the bitcoin network, allows anonymous participants to join the network (Li et al., 2022). The characteristics that govern the selection of blockchain platforms include the following: permissioned or permissionless, support of smart contracts implementation, confidentiality, scalability, support of consensus mechanism, and batch size (Perera et al., 2020). Therefore, the developer of the network must consider all of these characteristics prior to the selection of the platform. In this study, the chosen blockchain platform is expected to satisfy the following criteria: 1) it should be permissioned to allow the creation of private channels; 2) it should support the creation of smart contracts; and 3) it should be able to handle a large number of transactions. Therefore, considering all of the mentioned selection indicators, the Hyperledger Fabric platform was selected in this study. More on the selection of the platform and architecture of the selected one will be discussed in the following section.

METHODOLOGY

In light of the previously mentioned aims and objectives, Design Science Research (DSR) is adopted as a methodology to achieve the purpose of the study. Generally, DSR is composed of three main parts, which are problem identification, solution design, and solution evaluation (Offermann et al., 2009). As already stated, there is a deficiency in the current payment system when implementing IPD. Therefore, the solution design consists of employing blockchain technology to overcome this issue, and the solution evaluation is done by validating the model by testing it on a real case study. As *Figure 1* illustrates, the model is divided into three main stages: the conceptualization stage, the implementation stage, and the validation stage. First, the conceptualization includes identifying the research's main objectives and the theoretical framework of the research methodology. Furthermore, the implementation stage includes the development of two interconnected systems: the BIM models and the smart contract-based blockchain system. The development of the BIM models includes 3D, 4D, and 5D BIM models. These models were used to feed data to the smart contract-based blockchain system. The development of the smart contract system includes many steps: assigning certificate authority for each participant, identifying the public and private channels, identifying the endorsement policy for the transactions, developing the smart contract (chaincode) in accordance with the endorsement policy and the contract requirement, and building an end-user application to ease the interaction with the blockchain network.

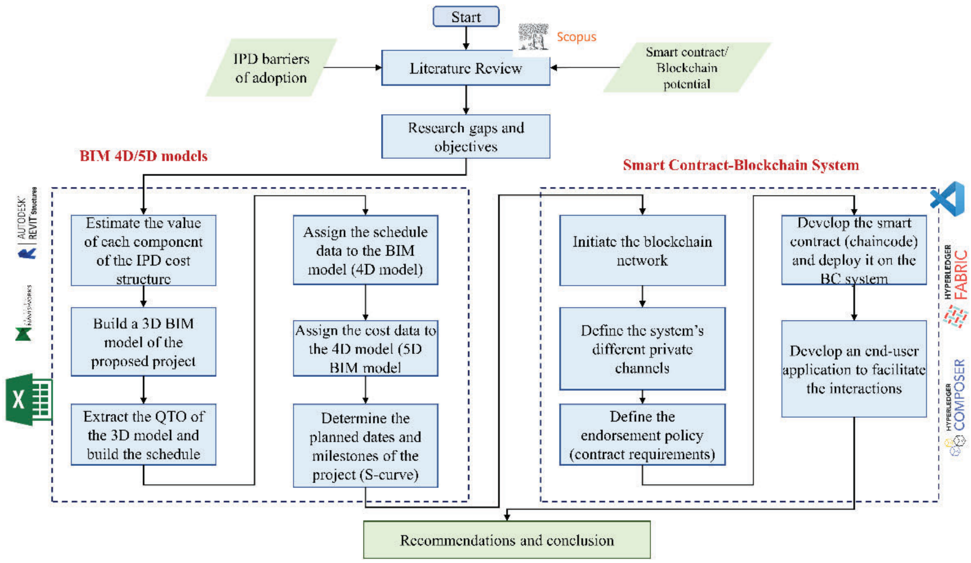

Figure 1: An overall framework of the solution design

One critical part of the developed systems is data flow. The data is considered interchangeable among the developed systems. Figure *2* shows the flow of data among different systems. The development of the 3D BIM model requires 2D drawing (if BIM was not adopted since the project's start). The quantity take-off (QTO) for all elements is exported to Excel sheets to perform the needed calculations. The 3D BIM model is then exported to Navisworks. The estimated durations and costs by Excel are also imported to Navisworks to build the 4D/5D BIM models. Milestone data and planned values are then deployed on the smart contract, as well as the endorsement policy. The endorsement policy can be defined as a protocol to check the validity of the submitted payment requests. Finally, the developed overall system is deployed on the Hyperledger Composer tool to provide an end-user application.

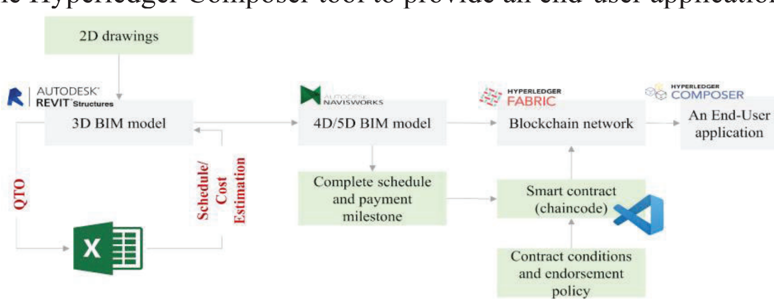

Figure 2: the flow of the data through different systems

4D/ 5D BIM Models

BIM models developed in this step contain geometric and parametric information, which is expected to assist owner and non-owner participants in estimating accurate costs and schedules (Amin Ranjbar et al., 2021). The accuracy of the estimation of the cost and schedule significantly depends on the level of model details. After the 3D BIM model development, the objects (elements), the quantity take-off (QTO) is exported to Excel sheets so that it can be processed by the project management team (PMT) office without the need for a high level of BIM experience by the employees (Amin Ranjbar et al., 2021). Needed materials, unit costs, labor resources, and equipment resources are retrieved by the participant procurement team. Navisworks tool is used to build the 4D BIM model by integrating the schedule data into the 3D BIM model developed by the Revit Structure tool. Moreover, the 5D BIM model is generated by integrating the cost data into the developed 4D BIM model on the Navisworks tool. The developed BIM model is considered to have a level of detail (LOD) of 300, as it covers the following criteria: precise information on quantities and cost and schedule data (Latiffi et al., 2015). It is worth mentioning that the payment figures for the IPD project follow the LIMBS cost structure that will be discussed in the below section.

IPD Cost Structure

This section illustrates the IPD cost arrangements and characteristics. As mentioned before, the compensation (sharing) system forms a critical part of IPD projects (Elghaish et al., 2019). IPD participants usually go through multiple validation phases prior to the start of the project to agree on the sharing ratio (Thomsen & Faia, 2009). This sharing system must specify the distribution of the risk/profits when cost overrun or underrun occurs. As addressed by Elghaish et al. (2019), integrating BIM with the IPD system can facilitate the compensation system through the early involvement of participants. This can be done by developing 4D and 5D BIM models to have a reliable budget and cash flow for all participants before deciding profit/risk ratios. Ross (2003) states that the compensation system of IPD projects generally follows the '3-LIMB' (components) method. Figure 3 illustrates the characteristics of the 3-LIMB method.

Ross (2003) explained LIMB 1 as the direct costs paid by the contractor plus the overheads of this particular project. The reimbursement of LIMB 1 is guaranteed for the contractor and is not subject to the value of LIMB 3. LIMB 2 represents the agreed profits and general office overheads. Unlike LIMB 1, LIMB 2 is subject to the condition of the submitted payment request by the contractor. In other words, if the submitted value exceeds the target value, the reimbursed cost will be subtracted by the risk share ratio stated in the contract. The final reimbursed cost should not be less than LIMB 1. Each of the mentioned LIMBs is calculated based on a set of equations. The following sections will illustrate the equations included in calculating each LIMB.

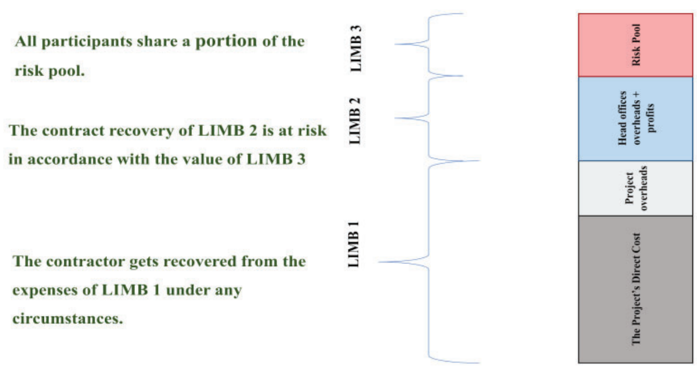

Figure 3: the cost structure of IPD projects

IPD Cost Estimation

This section demonstrates the formulation of each LIMB in the IPD system. The presented equations are retrieved from (Elghaish et al., 2019), (Faris Elghaish et al., 2020), and (Ross, 2003). Equation 1 shows the estimation of the LIMB 1 value. It is worth mentioning that the quantity of work used to estimate the direct cost is extracted from the 3D BIM model.

$$LIMB1_{ij} = \sum_{j=1}^{n} (CoDA_{Kj} + CoIA_{Kj}) \qquad \text{Equation 1}$$

Where $CoDA_{Kj}$ is the direct cost for contractor i to perform activity k in work package j. On the other hand, $CoIA_{Kj}$ is the indirect cost incurred by contractor i to perform activity k.

Furthermore, the estimation of value for $CoDA_{Kj}$ can be calculated using Equation 2, as mentioned by (Assaf & Zayed, 2022).

$$CoDA_{Kj} = \sum_{k=1}^{n}(MC_{kt} + LC_{kt} + EqC_{kt}) \qquad \text{Equation 2}$$

Where MC_{kt} is the material cost for activity k at a particular time t, LC_{kt} is the labor cost for activity k in a particular time t, EqC_{kt} is the material cost for activity k at a particular time t. On the other hand, $CoIA_{Kj}$ is generally calculated as a ratio of $CoDA_{Kj}$, considering the fixed and variable indirect costs.

As mentioned above, LIMB2 accounts for the pre-defined profits and general office overheads. The office overheads can be calculated in accordance with the approach followed by Elghaish et al. (2019). The profit ratio is applied to the total cost calculated in LIMB1 and was added to the equation following the illustration of the IPD cost structure by Ross (2003). Equation 3 shows the method followed to calculate LIMB2.

$$LIMB2_{ij} = \sum_{k=1}^{n}(NOA_{OK} \times MVOCD_k) + \%PR \times LIMB1_{ij} \qquad \text{Equation 3}$$

Where $LIMB2_{ij}$ represents the profits and office overhead cost for contractor i to perform work package j. NOA_{OK} is the number of operations O needed to perform activity k's overheads. Further, $MVOCD_k$ represents the cost of one operation needed to perform activity k. $\%PR$ represents the pre-agreed profit ratio in the contract.

LIMB 3 value represents the amount of money saved (or additionally incurred) compared to the target value specified in the contract. The value of LIMB 3 is added to the risk pool of the project and shared with all of the nonowner participants in accordance with the adopted compensation system. The value of LIMB 3 can be calculated as in Equation 4.

$$LIMB3_{ij} = MVP_{ij} - (LIMB1_{ij} + LIMB2_{ij}) \qquad \text{Equation 4}$$

Where $LIMB3_{ij}$ is the monetary value added to the risk pool and incurred by contractor i to perform work package j. MVP_{ij} is the monetary value planned in the contract to perform work package *j*.

THE BLOCKCHAIN NETWORK

As mentioned above, many blockchain platforms are available and can be adopted across various industries (Perera et al., 2020). To achieve the study objectives, three main indicators were used to select the appropriate blockchain platform. These indicators can be summarized as follows: First, the chosen platform should support the involvement of smart contracts (chaincodes). The smart contract feature is an essential component of this study as it defines how the automated transactions are executed. Second, the chosen platform should be permissioned and allow the creation of private channels. Channels provide privacy between two participants when needed, such as sharing information between the owner and contractor. Third, each platform has a block size that determines the maximum number of transactions that can be included in one block. The Hyperledger Fabric platform was selected for the study to build the blockchain network. Many components are included in the Hyperledger Fabric platform, among which, seven main components are considered to reach the research objectives. These components are the peers, ledgers, smart contract(s), orderer(s), channels, end-user applications, and certificate authorities (CAs).

SMART CONTRACT AND PERMISSIONS

This subsection illustrates the formation of the smart contract. The smart contract specifies the endorsement policy by which the submitted transactions are evaluated. The transactions included in this study reflect the payments in the context of IPD projects and cost plus with target value contracts. However, the developed smart contract can be reconfigured to suit any delivery method and contract type. Many functions are included in the created smart contract and can be summarized as follows: 1) to validate the submitted transactions against the identified endorsement policy; 2) submit payment by the contractors to the owner; 3) pay the valid payment request by the owner to the contractor; 4) calculate the limbs and allocate the right transactions to all participants. Furthermore, the developed network is permissioned, meaning that not all participants have the ability to view each component of the network. These permissions are used to enforce access control for participants. For instance, contractor *i* does not have access to submit transactions to other contractors in the network. Figure 6 shows a sample of the permissions given to participants in the Hyperledger Fabric network.

IMPLEMENTATION AND RESULTS

This section presents a case study of a residential building constructed in Cairo, Egypt. The building has ten floors and a floor area of 600 m2. The presented case study is used to validate the proposed methodology. The project was done using cost-plus (with target value). Autodesk Revit was used to develop the 3D BIM model. Figure *4* shows the developed BIM model. The QTO of the project is exported to Excel Sheets, and the total cost and duration were calculated.

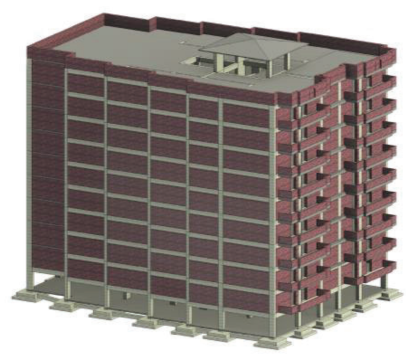

Figure 4: the 3D BIM model

4D/5D BIM MODELS

The developed schedule was added to the 3D BIM model to develop the 4D BIM model. Autodesk Navisworks tool was used to develop the 4D BIM model. Figure 8 shows the developed 4D model. Bar charts are presented for each activity to demonstrate the calculated durations. Furthermore, the cost data was integrated with the 3D BIM model to develop the 5D BIM model. Figure *5* shows the 5D BIM model. The 4D and 5D BIM models are used to estimate the target values for the project (schedule and cost).

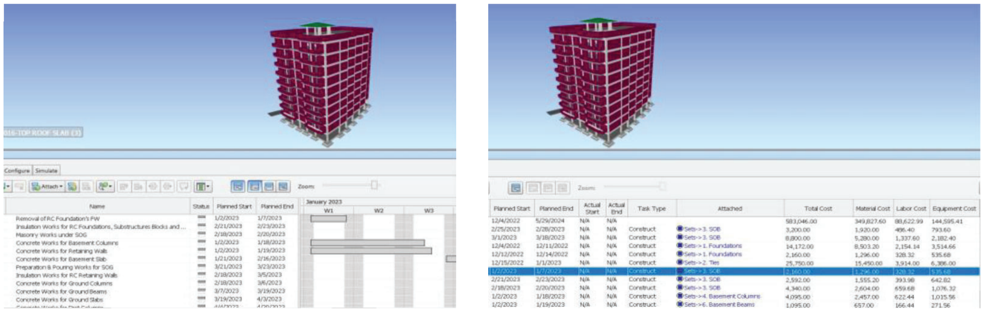

Figure 5: the developed 4D/5D BIM models by Navisworks tool

DEVELOPING THE SMART CONTRACT

In the proposed system, the contractor submits a payment request following the agreed milestones of the project. Therefore, the project PMT develops an S-curve specifying the planned dates and costs (targets). The contractor is expected to submit this payment request on the blockchain system, and the submitted request will be evaluated based on the endorsement policy. The contractor's reimbursement of the incurred cost depends on the target cost for the corresponding milestone. The cost overrun will be shared with each participant in accordance with the agreed sharing ratio. Similarly, the savings will be shared with all participants according to the sharing ratio. The developed smart contract has many functions. Figure 6 shows the transaction part of the smart contract. The smart contract code was written using two main languages: JavaScript and Hyperledger Composer. The code automatically calculates the three values of limbs. It also uncovers whether there are cost savings or cost overruns in accordance with the target values. Moreover, the code acts when the target cost is exceeded and modifies the reimbursable cost according to the cost structure of the IPD approach. Other functions of the code are claims submissions and extending the completion date by the owner. The following section will illustrate the outputs of the developed system.

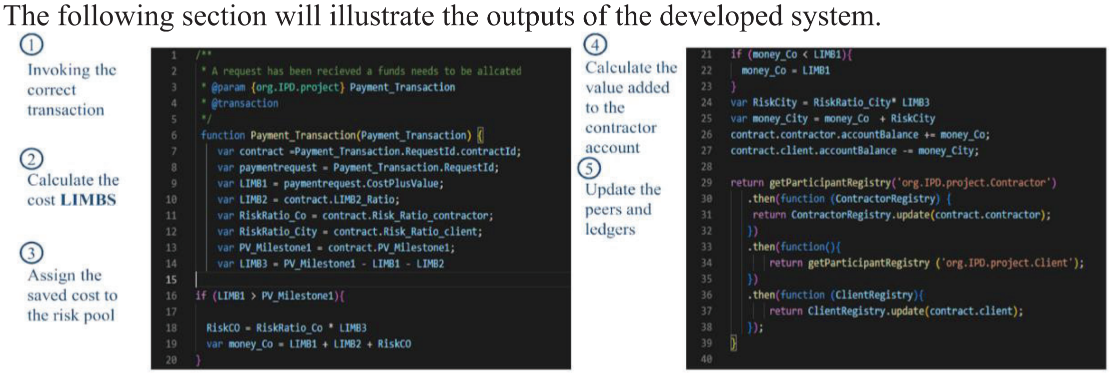

Figure 6: the transaction code on the smart contract

END-USER DEVELOPED APPLICATION

All of the code is integrated into the Hyperledger Composer tool to facilitate interactions among all participants. Figure *8* shows the interface of the end-user application. The system allows only specific participants to add private channels, which must be verified by the network orderer. The accessing participant is only eligible to read, create, update, and delete assets that are within their scope. This access control is implemented using the ACL feature of Hyperledger Composer. Transactions are governed by hash values, meaning that any amendment of a previously invoked transaction can be easily located on the network, enhancing the trustworthiness among participants.

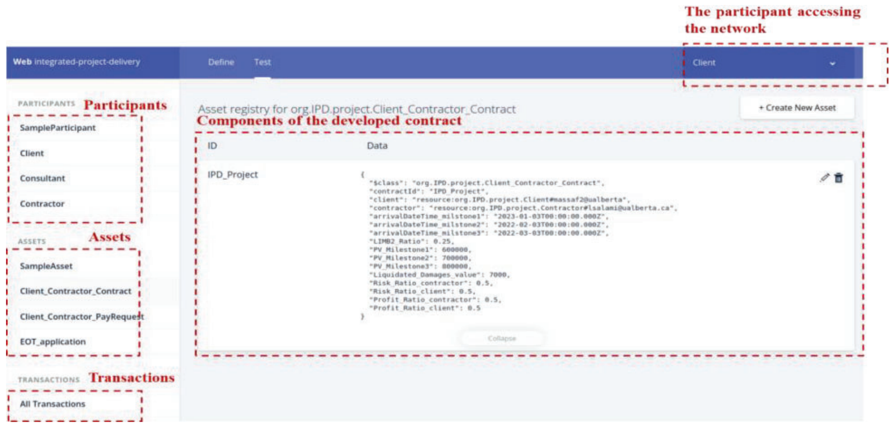

Figure 7: the interface of the developed end-user application

Figure 8 shows a closer look at the formed contract on the network. The contract specifies all the attributes of the IPD projects and is accessible to all the individuals that are part of it. It specifies the included participants, target values, target costs, and sharing ratios. Furthermore, this efficient documentation of the transactions and movements can help minimize possible conflicts and disputes. Despite the contribution of IPD in minimizing possible conflicts, claims still exist according to the clauses mentioned by CCDC-30 (2018) that need to be minimized.

Figure 8: the developed smart contract presented on the blockchain network

CONCLUSIONS

This study is motivated by the lack of research on practical solutions to the technological barriers of IPD adoption in construction projects. It presents an integration of the IPD delivery system with innovative technologies to overcome deficiencies in payment systems, which forms a barrier to IPD adoption. The proposed approach develops 5D BIM models that feed various data, such as milestone dates, into the developed blockchain network that uses the Hyperledger Fabric platform. A smart contract representing the cost structure of the IPD project is developed and employed on the developed blockchain network. The developed smart contract enforces an endorsement policy that verifies the validity of the submitted transactions by the project parties. Additionally, the developed blockchain network provides access control, allowing the corresponding participants only to submit (or issue) transactions. The model provides fair profit and risk-sharing among project participants.

This study contributes to the body of knowledge by: 1) providing a secure automated system that can promote the IPD adoption in construction projects; 2) providing efficient documentation that can help minimize possible claims; 3) developing a system that can be reconfigured to suit other contract types and delivery methods; 4) providing an automated sharing of risks and gains through smart contracts, without the need to involve third parties. Despite the contributions provided by the presented study, it still includes some limitations. The development of the smart contract is considered complex and could include human errors. Furthermore, the developed system supports only extension of time claims. Future research may also consider more types of claims submission, such as loss of productivity claims. Future studies can also focus on integrating financing strategies, such as joint ventures, in the developed system.

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