Integrated Building Information Modeling and Blockchain System for Decentralized Progress Payment in Construction Projects

Abstract

Purpose: The debate around automation through digital technologies has gathered traction in line with the advancement of Industry 4.0. Blockchain-powered construction progress payment has emerged as an area that can benefit from such automation. However, the challenges inherent in real-time construction payment processes cannot be solely mitigated with blockchain. Including building information modeling (BIM)-based schedule information stored in decentralized storage linked with a smart contract (SC) can allow the efficient administration of payments. Accordingly, this study presents an integrated BIM-blockchain system (BBS) to administer decentralized progress payments in construction projects.

Methodology: A mixed-method approach is adopted, including an extensive literature review, development of the integrated BBS, and a case study with 13 respondents to test and validate the BBS. This study proposes a BBS that extracts the invoices from BIM and pushes them to the decentralized app (dApp) for digital payment to the contractor through the Ethereum blockchain. Solc npm package was used to compile the backend smart contract. Next.js was used to create the front end of the dApp. Web3 npm package is paramount in developing a dApp. Thirteen construction professionals working on the case study project were engaged through a questionnaire survey to comment on and validate the proposed BBS. A descriptive analysis was conducted on the case study data to apprehend the responses of expert professionals.

Findings: The proposed BBS creates an SC, enables sender verification, checks contract complaints, verifies bills, and processes the currency flow based on a coded payment logic. After passing the initial checks, the bill amount is processed and made available for the contractor to claim. Every activity on dApp leaves its trace on the blockchain ledger. A control mechanism for accepting or rejecting the invoice is also incorporated into the system. The case study-based validation confirmed that the proposed BBS could increase payment efficiency (92.3%), tackle financial misconduct (84.6%), transparency and audibility (92.4%), and payment security (61%) in construction projects. 46.2% of respondents were skeptical of the BBS due to its dependency on cryptocurrencies. A further 23.1% of respondents indicated that the price fluctuation of cryptocurrencies is a major barrier to BBS adoption. Others highlighted the absence of legal frameworks for cryptocurrencies' usage.

Originality/Value: This study opens the avenue for the application of dApp for autonomous contract management and progress payments, which is flexible with applications across various construction processes. Overall, it is a

potential solution to the endemic problem of cash flow that has devastating consequences for all project stakeholders. This is also aligned with the goals of Industry 4.0, where process automation is a key focus. The study provides a practice application for automated progress payment that can be leveraged in construction projects across the globe.

Keywords

Blockchain; smart contracts; construction automation; building information modeling; payment automation; progress payment.

1. Introduction

A streamlined and uninterrupted management of finances is vital for the well-being and overall profitability of the construction business (Li et al., 2019). However, the global construction industry struggles with financial management (Ameyaw et al., 2023). Hence, delays in payment to the contractor are not uncommon even when they fully meet their contractual obligations (Abdul-Rahman et al., 2014). Such payment discrepancies have a deterring effect on the project's progress, leading to contractors' frustration, demotivation, burnout, and payment delays to subcontractors (Durdyev & Hosseini, 2020; Ramachandra & Rotimi, 2015). The extant literature provides some remedies to non-payment of progress claims, such as legislative and administrative actions. The former includes charging orders, caveat registration, liquidation proceedings, statutory demands, and summary judgment (Azman et al., 2014; Ramachandra & Rotimi, 2015). The latter can be achieved using project bank accounts (Griffiths et al., 2017) and by providing cash management training (Peters et al., 2019). However, such solutions are often proven to be ineffectual (Abdul-Rahman et al., 2014), as delayed payments continue to be a major cause of project delays, impacting the efficiency of the construction process (Shibani et al., 2022). Such delays are caused by intentional or unintentional acts of project stakeholders, including delays in invoice approvals, payment settlement, and release of retention money (Ramachandra & Rotimi, 2015). To address this, an End-to-End (E2E) automated process based on cutting-edge technology is needed to ensure the timely dispersal of funds to the contractor upon completion of work.

Technologies such as building information modeling (BIM) are becoming a key driver for digitalizing and improving the operating procedures of the construction industry (Chen et al., 2015). BIM has been successfully utilized to make progress payments. BIM has been integrated with blockchains to administer construction progress payments (Sonmez et al., 2022). It has been integrated with intelligent contracts to pay for construction progress claims in Malaysia (Salleh et al., 2020). It has also been used to generate bills of quantities (BoQs) and automated progress-based invoices for pertinent payments (Ye et al., 2020). Regardless of the integration partner, the mechanism for using BIM for progress payments remains more or less the same. That is, BIM is used to either collect information on the work done and the actual progress or solicit BoQs to compile payment information. This information is then processed through external applications or integrated partners such as blockchains or other financial tools to enable payments to contractors (Sonmez et al., 2022). Such BIM-based digitalization extends to all project phases: planning, designing, constructing, operating, and maintaining assets through their lifecycle (Zawada et al., 2024). It has been leveraged to enhance project costs and time (Zheng et al., 2021), preserve cultural heritage (Argasiński, K., & Kuroczyński, 2023), and develop material passports (Atta et al., 2021).

Digitizing the manual payment process is not enough to achieve reliable automation as the payment still relies on centralized control, which is synonymous with traditional systems (Hamledari & Fischer, 2021a). Therefore, alternative solutions must be sought to complement such automation. A candidate technology for additional automation is blockchain. Blockchain technology has proven effective in automating practices in the financial sector (Li et al., 2019). It can be leveraged to do the same in construction for progress payments (Çevikbaş & Işık, 2021). Blockchains leverage smart contracts (SC), which are self-executing contracts that can automate business logic (Hunhevicz & Hall, 2020). Buterin (2014) integrated SCs with blockchain technology, the underlying technology of cryptocurrencies (Zhang et al., 2023). Cryptocurrencies are different from traditional money, as central banks do not control them; instead, they are decentralized. SCs combined with cryptocurrencies provide a reliable means of conditioning payments (Cardeira, 2015). Therefore, blockchain is a meaningful advancement in curbing payment security issues (Chong & Diamantopoulos, 2020). Unlike the traditional system, payment via SCs is conducted without intermediaries (Nawari & Ravindran, 2019b) or human involvement (Ibrahim et al., 2022). This reduces bureaucratic procedures, making the construction payment process faster, simpler, and cheaper (Titov et al., 2021).

Several payment systems have been proposed to materialize the benefits of the blockchain. However, in most studies, the systems were discussed figuratively, with very few systems actually developed or prototypes presented. Among the few examples, a blockchain-enabled SC payment system was proposed, which utilizes the progress payment data by virtue of reality capture technologies (Hamledari & Fischer, 2021a). However, it was prone to inaccuracies while capturing progress data. To address this limitation, the blockchain-based system was integrated with BIM, where BIM was used to push the site progress data to the blockchain (Sonmez et al., 2022). The limitation of the system was the high deployment cost of smart contracts, which needed to be fed with the details of the individual BIM objects. This aspect makes the proposed system unsuitable for large projects, as the cost of deployment of SCs is proportional to the number of BIM objects. Also, proposed blockchain payment systems require extensive coding or IT-related tasks, which is not a skill associated with construction site staff, making it hard to implement such systems. So, despite incremental advancement in this concept, the use of blockchain-based systems remains a distant dream. To address this, a system that requires minimal coding, leverages BIM data, and integrates it with blockchain ledger technology is needed. Accordingly, the current study presents an integrated BIM-blockchain system (BBS) that integrates BIM and blockchain technologies and uses a decentralized app (dApp) for secured progress payments to the contractor via cryptocurrency, which subsides on bureaucratic hurdles and nonvalue-adding procedures.

The proposed BBS requires no programming knowledge (for site staff), minimal deployment, and operational costs to make it a functional system. The current study also validates the integrated BBS through a case study project to show how the prototype works and test its practicality. Traditional isolated approaches are unproductive in delivering trusted networks that deter stakeholders' confidence in such approaches. In comparison, the proposed integrated BBS enhances the stakeholders' trust (including clients, contractors, and consultants) by enabling autonomous contract management and progress payments. This increases transparency, reduces payment issues, and improves collaborations.

2. Literature Review

2.1. Issues in construction progress payments

Traditional payment systems are prone to anomalies and inefficiencies, leading to late or non-payment (Li et al., 2019. The construction payment system is centralized, having sometimes unwanted human intervention (Hamledari & Fischer, 2021a), bureaucratic procedures, and other barriers that make it vulnerable to systematic manipulation. The traditional payment system is time-consuming with information-intensive paperwork (Ameyaw et al., 2023) and follows a cascading nature of fund disbursement (Ahmadisheykhsarmast & Sonmez, 2020). Hence, a single point of failure leads to non-payment. Data loss, errors, and information asymmetry are often noted in construction documentation, resulting in payment irregularities and disputes (Ciotta et al., 2021). In some construction projects, parties use misleading payment clauses such as pay-when-paid or pay-if-paid that further encourage systemic manipulation. Many of the identified issues can be neutralized by leveraging the digital capabilities of the BIM (Ciotta et al., 2021). For example, Feng et al. (2017) presented a BIM-based framework for effectively creating payment requests. It provides the necessary database for the automation of processes, thereby adding value to the overall construction payment process. However, the security of BIM models has been raised as a concern that necessitates the need for additional measures.

2.2. Blockchains for construction progress payments

Blockchain can solve the security vulnerabilities of BIM-based payment management systems and is, therefore, a potential FinTech to address the security of payment complications faced by the construction industry. Blockchain is essentially a chain of blocks containing data. The concept of blockchain originated with the inception of Bitcoin (Zhang et al., 2023)Click or tap here to enter text., which uses this ledger technology to store the digital transactions conducted on its network. Integrating SCs with blockchain technology commenced the era of the second generation of the blockchain (Buterin, 2014). SCs allow users to customize the payment by associating certain conditions for releasing funds, hence acting as an escrow bank account (Hamledari & Fischer, 2021a) where funds can get locked and released upon completion of the agreed obligation (Nawari & Ravindran, 2019a). Several studies proposed blockchain-based frameworks for the construction sector to promote transparency, automatic payment of retention money, and automation of the payment cycles through SCs (Wu et al., 2022). Involving banks in blockchain technology can raise concerns about decentralization and transparency (Zhang et al., 2023).

A dApp is a web application that reports back to the blockchain (Truong et al., 2021). Like any regular web application, a dApp constitutes a backend and a front end. The backend of the dApp consists of an SC deployed on the blockchain. Ahmadisheykhsarmast & Sonmez (2020) developed an SC-based dApp using the ganache blockchain, a fake blockchain. Such blockchain uses a simplified consensus mechanism for faster block times and addresses the security vulnerabilities of the real world. Blockchain can address the payment challenges in terms of payment security and transparency. However, a sole blockchain-based payment system can not address all the complexities of construction payment systems, such as the provision of real-time progress data to the system or validation of the claimed completed work on site. For automated payment applications, blockchain and SCs may act as a subsidiary technology (Li & Kassem, 2021). However, they must work in tandem with other real-time progress monitoring technologies such as BIM.

Blockchains are dependent on BIM for high-end payment applications. According to Chong & Diamantopoulos (2020), a system integrating BIM and blockchain technologies will help address the payment problem holistically. Researchers have used various blockchain techniques and BIM-based contracts for transferring information, payment plans enacted with SCs, and automated billing in construction (Ibrahim et al., 2022). Published studies have emphasized the need for further development, especially in dealing with the challenges of setting up rules for SCs and the proper deployment platform. Researchers have investigated the potential of automating progress payments by combining reality-capturing technology with SCs and integrating blockchain-enabled SCs with robotic reality-capture technologies (Hamledari & Fischer, 2021a). However, the pertinent studies also highlighted several limitations regarding the practical implementation of such systems, including the missing focus on dApps. Against this backdrop, the current research aims to develop an integrated BBS payment system that is practical and realistic. Further, it bridges this gap by presenting a fully functional dApp for payment administration and integrating it with BIM to provide real-time project data.

3. Research Methodology

A mixed-method approach is adopted in the current study. It is one of the most popular approaches used in construction management studies due to its inclusive scope (Fellows and Liu, 2021). The main motive for choosing a mixed research design is to achieve triangulation (Akotia et al. 2023). This can eliminate shortcomings of mono methods, which reduces potential biases in the results (Liang et al., 2021). A mixed method approach involves a mix of qualitative and quantitative approaches (Creswell, 1999). Accordingly, in the current study, a systematic literature review (SLR) was conducted using Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA). The SLR was used to identify issues and challenges of traditional progress payment methods in construction. The PRISMA guidelines presented by Moher et al. were followed when conducting the SLR. Articles were retrieved from Scopus repositories following the guidelines (Moher et al. 2009). Following the SLR, an integrated BBS was developed using numerous algorithms. Subsequently, in the next stage, a case study was performed through a questionnaire to validate the developed BBS model. Through the questionnaire, both quantitative data (scale of 1-5) and qualitative (open discussions based on structured questions) were obtained, hence constituting a mixed method. Overall, a triangulation approach was adopted where factors retrieved from the literature were used to develop the BBS and later validated through experts' rankings and opinions, thus constituting a mixed-method approach.

The proposed payment system was designed for the Design-Bid-Build (DBB) projects. Firstly, through visual programming and a PHP webpage, an algorithm was developed to create an invoice from a sample BIM model. Afterward, a dApp was developed, referred to as "payment dApp". For the development of the mentioned dApp, blockchain was selected using the design decision framework of Sonmez et al. (2021), and SC logic was determined based on FIDIC red and silver books (FIDIC, 2017b). Subsequently, the SC of the dApp was coded using the solidity programming language. Next.js framework was utilized to develop the front end of the dApp. The payment is transferred securely using dApp on the Ethereum network. In the final step, the developed system was tested and implemented on a sample case study project, and pertinent data on user experience was gathered through a survey. The research methodology is summarized in Fig. 1.

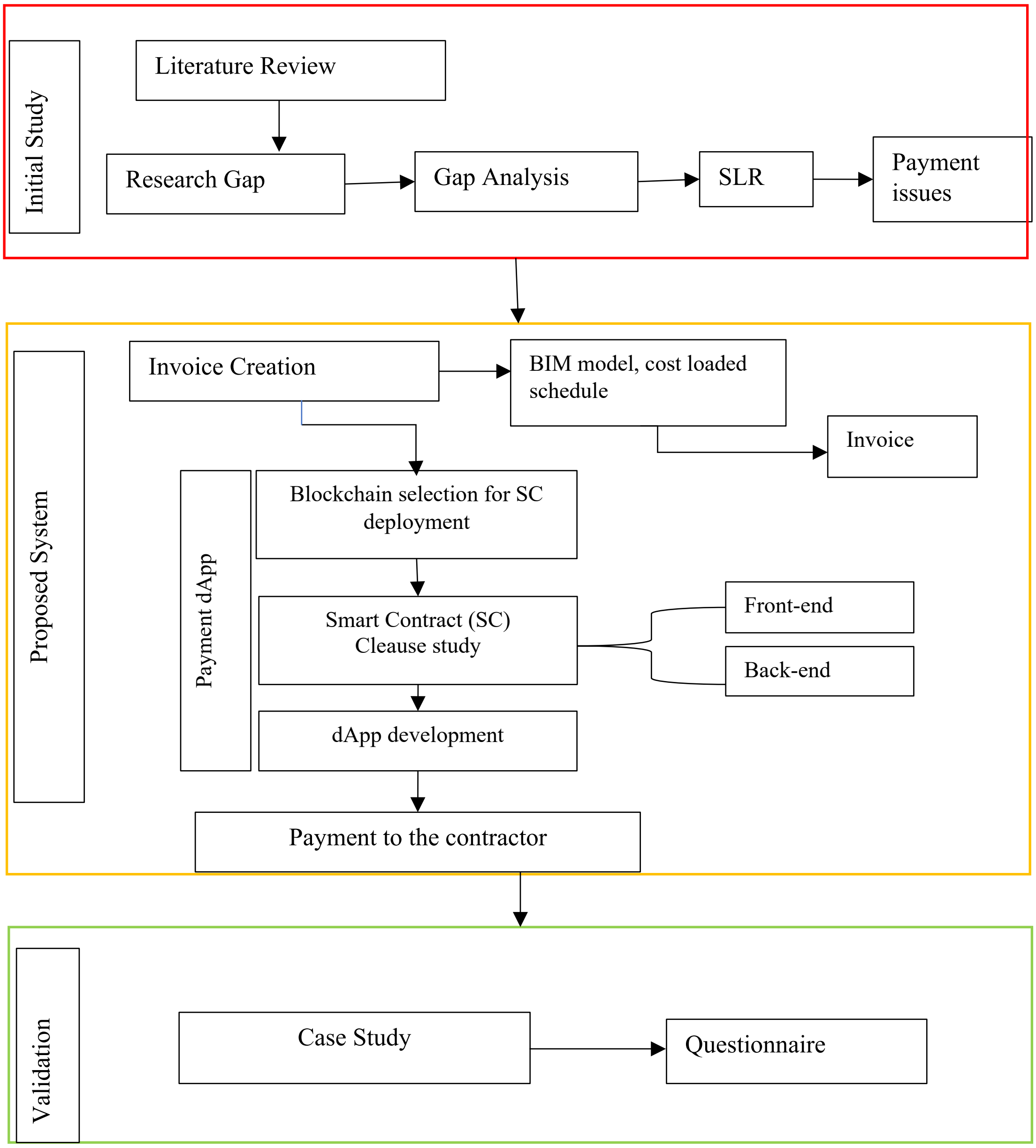

Fig. 1. Research Methodology

4. Systematic Literature Review (SLR)

To find the article, a broader terms identifying the issues of traditional payment method in construction was used. However, very few articles initially explored for abstract and title screening were related to the topic of payment methods in construction. Therefore, a wide search for peer-reviewed articles was conducted on the Scopus online databases using relevant keywords such as “payment methods in construction”, “integrated building information modeling and blockchain”, and “smart contract in construction”. All the search spanned from database inception from 2010 to 2023 and included only articles in English. The selection criteria were based on the PRIMSA statement (Moher et al., 2009). The search mainly focused on the mapping existing literature on integrated BIM and blockchain system for payment in construction. To be included, the article must have been (a) published in English, (b) linked with integrated BIM and blockchain, (c) engineering category, and (d) related to construction industry. To improve the quality and reduce irrelevant studies, articles that are related to integrated BIM and blockchain payment system and smart constracts in the construction were deleted in the eligibility stage. The initial search resulted in 152 articles. All duplications were checked thoroughly. After the filtration of duplicate records, 12 articles were removed from the study. Furthermore, the title and abstract were screened to assess for the inclusion criteria. To ensure the relevancy and suitability of the articles titles were read thoroughly. Most of the articles were related to claims, disputes, safety, risk management, project management, 101 articles were further deleted and 39 remained. In addition, abstract were read for remaing articles, 12 articles were further excluded. To ensure the quality, a full text review was subsequently carried out and few more articles were excluded that fail to meet the inclusion criteria. Finally, 24 articles were included in the current review following PRISMA statement (Moher et al., 2009). It was found that numerous studies concentrate on blockchain, smart contracts, and BIM approaches separately. Only four studies focused on integrated BIM and blockchain payment systems for smart contracts in construction. Among these four studies (Celik et al., 2023; Chung et al., 2022; Sonmez et al., 2022; Yu et al., 2024), Celik et al., (2023) indentifies the integration of BIM and Blockchain through life cycle and supply chains; Chung et al. (2022) reviews the application and adoption of integrated BIM and blockchain in construction industry; Sonmez et al., (2022) empirically examined the potential adventage of integrated BIM and smart contract system for payment process in the construction, and Yu et al., (2024) reviewed the potential integration of blockchain and building information modelling (BIM) in the construction sector. None of these studies developed a integrated framework system including BIM and blockchain for smart contract and payment system.

5. System Architecture and Working Mechanism

Figure 2 shows the working of the proposed system, which can be divided into two phases. First, a BIM model was created using Autodesk Revit as a BIM platform. Relevant data from the BIM model was extracted and imported into Primavera P6 (a scheduling software) to create a cost-loaded schedule. The cost-loaded schedule was imported into an off-chain database. Afterward, a web page was developed where the invoice was generated using the cost-loaded schedule. Finally, the developed invoice is imported into the dApp, which acts as an intermediary between the client and the contractor and assists in the payment administration process. The main sections of the system, i.e., invoice generation, payment app (dApp) deployment, and payment to contractors, are discussed below.

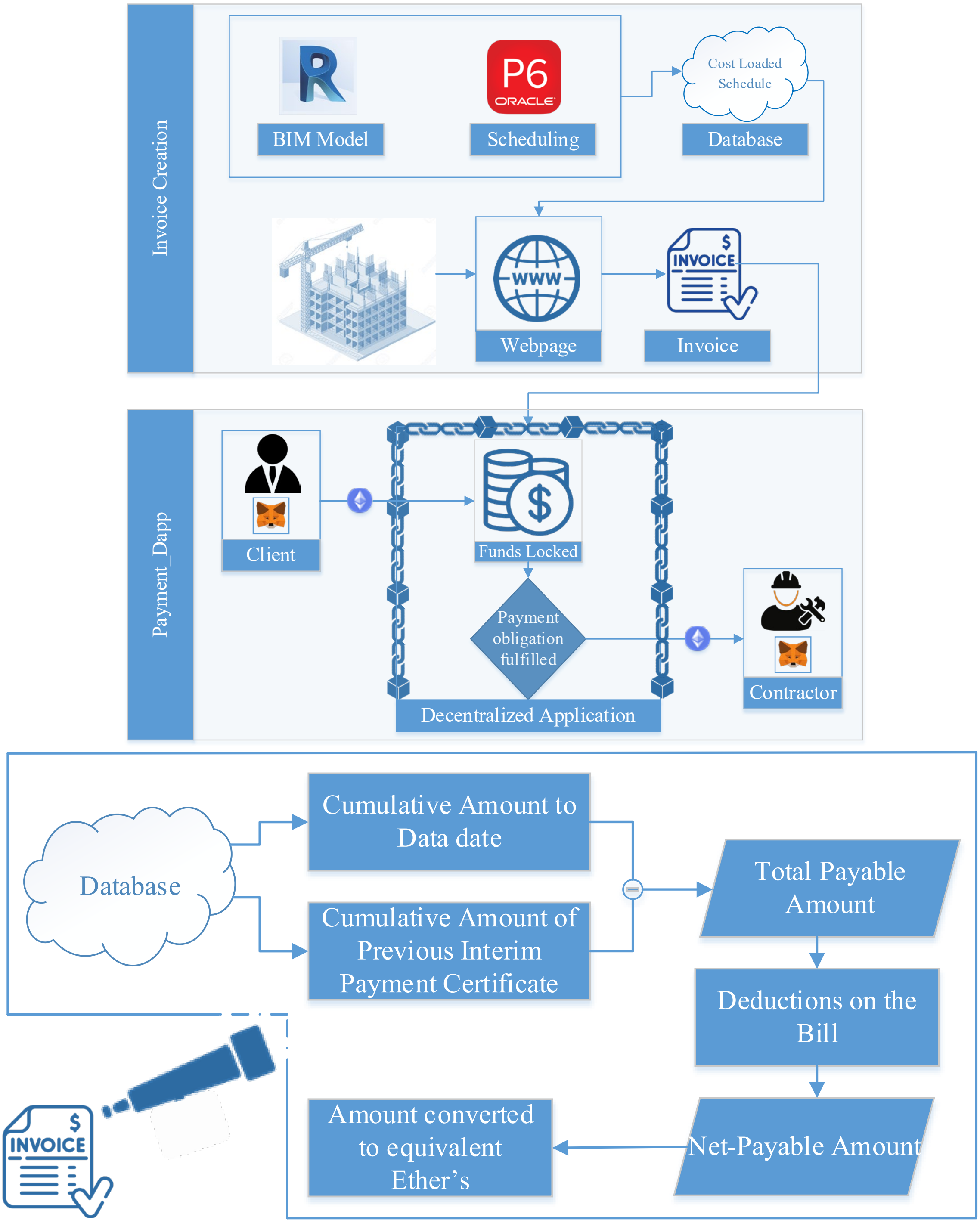

Fig. 2. System Overview and Invoice creation mechanism

5.1. Invoice Generation

Monthly invoice is generated using BIM through the proposed BBS. The system uses the BIM model as a medium for generating digital BoQs. The quantities for each BIM object are cost-loaded. In the BIM model, the unit cost for each object is incorporated at the bidding time. Then, by calling a Revit API, the information on the descriptions of elements, quantities, and costs is exported as an Excel file. The extracted data is uploaded into scheduling software to create a project schedule. This schedule acts as a cost-loaded schedule that is subsequently uploaded to the SQL database.

PHP, a scripting language for web development, is used to display the generated monthly invoices on the web portal in the current study. The web portal interacts with the SQL database and filters relevant activities based on finish dates. The current system date is a cutoff date for activities included in the invoice. If the activity involving an element is finished earlier than the cutoff date, it will be included in the current invoice. Otherwise, the activity will be skipped and included in the subsequent invoice. In this manner, a cumulative sum of the total work completed until the invoice date is obtained. As invoices run cumulatively, the total payable amount ($P_{\Delta T}$), the cumulative amount for a particular month is obtained by subtracting the cumulative amount of that month from the previous month, using equation (1). Relevant deductions, such as retention money, taxes, etc., are applied to the invoice amount. By incorporating the deductions in the total payable amount, a net-payable amount to be paid to the contractor is obtained (see equation 2).

$$P_{\Delta T} = P_T - P_{T-1} \tag{1}$$

$$NP = P_{\Delta T} - D_{\Delta T} \tag{2}$$

where; P_T = Value of total work done till the end of current period T or cutoff time for invoice generation.

P_{T-1} = value of total work done till previous period T-1 when the last payment was made.

$P_{\Delta T}$ = Amount for the work done between the last payment @ T-1 and current period T.

$D_{\Delta T}$ = Deduction for taxes, advances, retention, etc., based on the contract.

NP = Net payable amount to the contractor after removal of deductions

The currency value exchange in the proposed system is conducted in an Ether coin, a cryptocurrency, and the native coin of the Ethereum blockchain. The value of crypto coins is not consistent, as the exchange rates for cryptocurrencies are uncertain and volatile. As a workaround, the currency on the invoice in this study is fixed as USD. The net payable USD amount is converted into an equivalent Ether coin by multiplying it with the exchange rate. This extraction is conducted by calling an Ajax query. A separate SQL database is created to house the data related to generated invoices. The invoice creation process is summarized in Fig. 2.

5.2. Payment dApp development

The first significant decision in developing dApp was to select a blockchain network. There are three main categories of blockchain: public, private, and consortium. Data on a public blockchain is accessible to everyone, making it immutable and decentralized. Hence, public blockchains were selected for deploying the SC for this research as they depict decentralization and transparency (Sonmez et al., 2021). Then, for the selection of the blockchain platform, the design decision framework developed by Sonmez (2021) for project management applications was used. Public-EOSIO and public-Ethereum blockchains were suggested as potential platforms for smart contract deployment by the design decision framework. Among these two, the Ethereum blockchain was chosen for deployment as it is a more established network and is one of the most popular blockchains for deploying smart contracts (Sonmez et al., 2022).

A smart contract constitutes the backend of the dApp. The next step was the development of SC logic. The primary considerations for the SC logic were to address the security of payment issues. Another consideration was to devise a prudent payment logic that can be standardized. Various project management contracts were analyzed to define the smart contract logic. Accordingly, FIDIC conditions for payment were identified as potential logic to be used in the current study. Clause 14.4 of FIDIC Red and Silver Books 2017 discusses the schedule of payments. It discusses a non-binding estimate to be submitted quarterly to the client by the contractor. The rationale for this is that the client learns about the estimated financing requirements in a particular quarter and arranges that amount beforehand.

SC was coded in the solidity programming language, which is a backend language used to develop smart contracts using Ethereum technology. Solc npm package (*Solc-Js*, n.d.) was used to compile the SC to extract its bytecode, which is a machine-readable language. The package was deployed through the Ethereum Testnet Rinkeby (RNET) blockchain using the Infura service (ConsenSys, 2018). This service helps in accessing a node on the blockchain. The proposed system makes use of two distinct SCs. The central SC contains payment logic, while the other SC helps in creating an instance of the central SC. This way, the hassles of manual deployment and writing code for an individual unique project are eliminated. The bytecode of the instance generator SC can be called by the dApp user, which will enact a copy of an SC comprising the payment logic. The newly generated instance of SC needs to be fed with project details to be customized for different projects.

The developed SC initially asks for a quarterly estimate from the contractor, as shown in Fig. 3. Following on, the client will deposit the funds in the SC based on the given estimate. After depositing funds, the contractor will start executing the job. The contractor will raise the monthly statement using the developed PHP webpage, and the bill will be forwarded to the SC. It will apply the preliminary check on the bill and examine the billing period, which must be over 30 days. It will also check if the bill amount exceeds the minimum bill limit, which will be specified when initiating the SC. For client confirmation, a front-end webpage for interacting with the deployed SC has also been developed. The client can view the invoice amount and confirm its transfer through the front-end webpage before any payments can be made. The payment process is initiated upon fulfillment of the contract conditions, as explained in the next section.

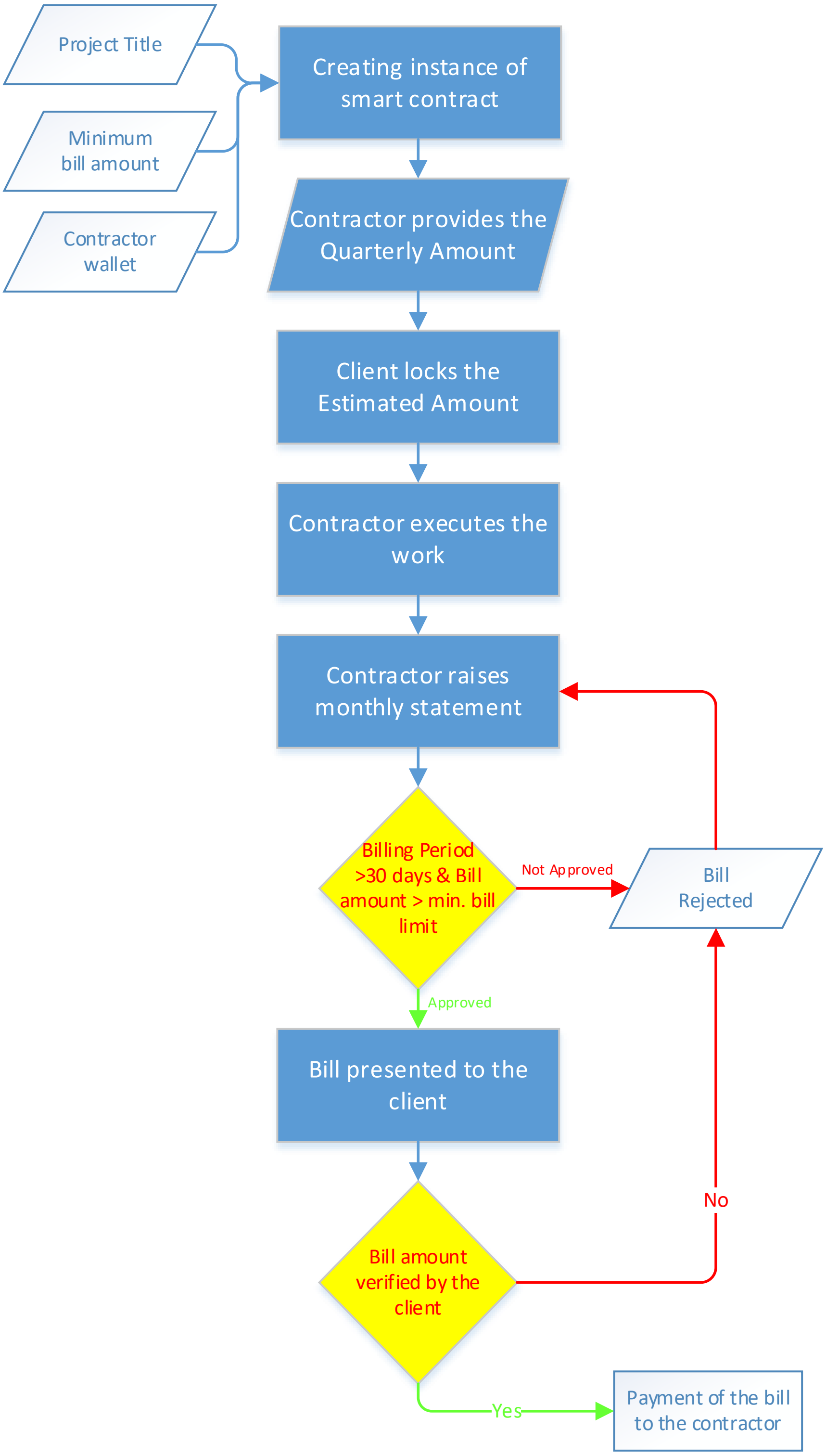

Fig. 3. The logic of smart contracts used in the current study

Next.js, an open-sourced JavaScript framework, was used to create the front end of the dApp. The front end constitutes a dashboard that provides preliminary information about the project and several other landing pages for viewing, approving, and claiming bills. Next.js wraps up the react framework and builds a bunch of functionalities around it. It has features like server-side rendering, routing, hot module reloads (HMR), etc., hence making the next.js by far the most straightforward and robust approach for developing dApp's front ends. Web3 npm package (*Web3*, n.d.) is paramount in developing a dApp. Through the web3 library, developers get programmatic access to the Ethereum network to extract data from the blockchain and access functions of the SC. The payment administration process through the dApp is presented in Fig. 4.

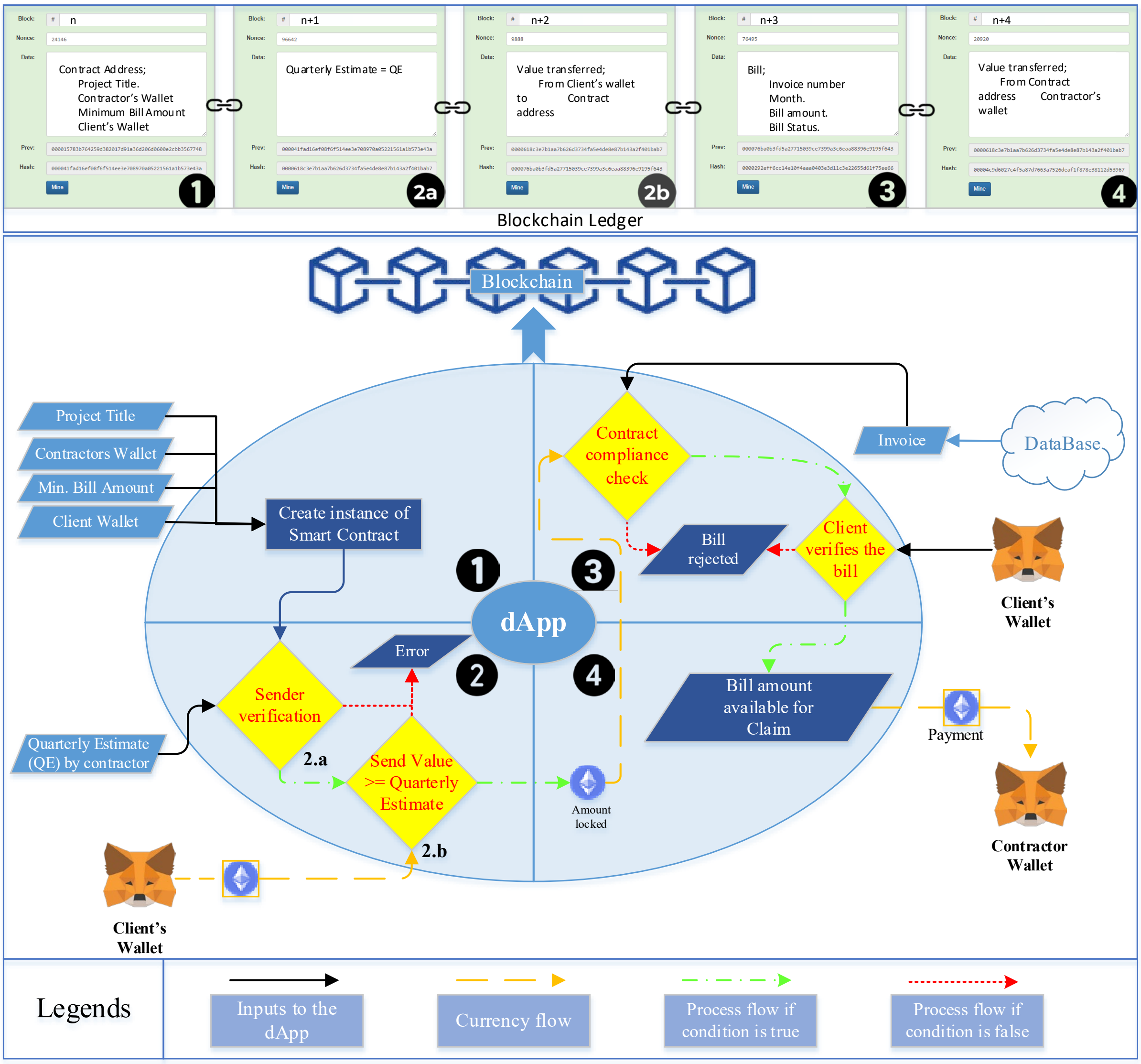

Fig. 4. The payment administration on Payment dApp.

As shown in Fig. 4, the payment administration on Payment dApp can be divided into four steps. In step 1, the client creates the instance of an SC for the project. Step 2 consists of two processes. In 2a, the contractor provides their estimate. Subsequently, the client submits funds through the dApp in 2b. In step 3, the invoice is uploaded on the dApp, and pre-determined compliance checks are applied. Once the checks are done, the bill amount is processed and made available for the contractor to claim in step 4. Every activity on dApp leaves its trace on the blockchain ledger that relevant stakeholders with necessary security clearance can view.

5.3. Payment to the Contractor

A separate SQL database hosts the data related to generated invoices. The data fields of this database consist of invoice number, month, commutative amount, payable, and net payables. For uploading invoices on dApp, a connection between the SQL database and the input form of the dApp was created using the serverless-MySQL library (*Serverless-Mysql*, n.d.). Controlled input tags were created in the dApp to fetch data directly from the database. Only the final net payable amount, along with the metadata, were exported to the dApp from the SQL database. Upon passing the initial screening of the SC, the bill awaits final verification of the clients on dApp. If the client approves the bill, it gets uploaded onto the blockchain, and the bill amount becomes available for the contractor to claim into their wallet; otherwise, the client can reject the bill. This way, a control mechanism for accepting or rejecting the invoice is embedded into the proposed system.

6. Case Study

The developed system was validated through a real construction project as a case study. The case project, which is based on a DBB delivery method, is a commercial building located in a 2440m2 area in Islamabad, Pakistan. The contract cost of the project was 1.8 million USD. A BIM model was developed for the case project using Autodesk Revit ® 2022 software. The unit cost of each element was added to the model. The total cost of the element was computed by multiplying the required quantity by the unit price stored in the BIM model. Afterward, all data elements were imported into the Primavera P6 for scheduling to develop a cost-loaded schedule.

The developed dApp consists of a dashboard programmed with input data for developing contract instances. It uses input tags to add and lock in the amount for the work. The amount locked in the dApp can also be seen on the dApp's dashboard, as shown in Fig. 5. The metamask wallets were hypothetically assigned to the contractor and the client. The deployment cost of the SC for the case project was 0.00178 Ether or $2.76. At the beginning of the second quarter of 2022, the contractor provided their estimated amount for the potential work. The client locked this amount in the SC, and the contractor started executing the construction work. Upon completion, the request for progress payment for July 2022 was initiated by the contractor using the webpage shown in Fig. 6 (a). Work worth $40,148 was performed till this point. The total deductions were $7,026, including 10% retention money and 7.5% taxes. Therefore, the net-payable amount was $33,122. At an exchange rate of 1568.432 eth/$, an IPC of 21.117 ethers was presented to the client's interface on dApp for approval, as shown in Fig. 6(b).

The input tags of the dApp data comprised of invoice number, billing month, and payable amount. Next, the client verified the bill with their metamask wallet, which invoked the SC to make the bill amount available for the contractor to claim it into their metamask wallet. The contractor claimed the bill amount from dApp (see Fig. 6 (c)). Accordingly, the bill's status was changed to paid in the system. Transactions on the Ethereum blockchain take about 20 seconds to complete and are published on the blockchain ledger instantly (see Fig. 5). Upon receiving the payment in Ethers, the contractor can convert it into their local currency or any other currency (if needed).

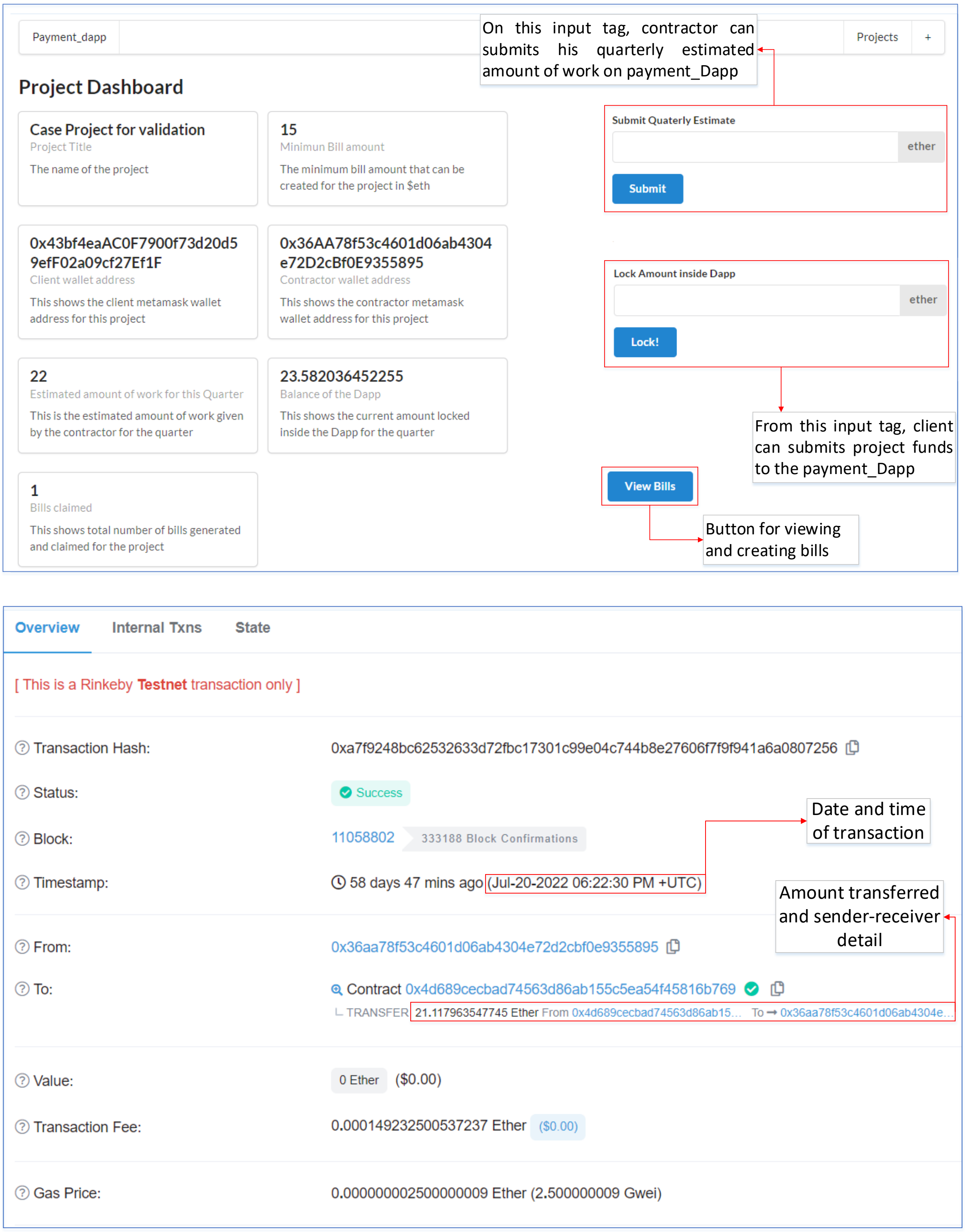

Fig. 5. Dashboard of the case project on dApp and Payment receipt on the blockchain ledger

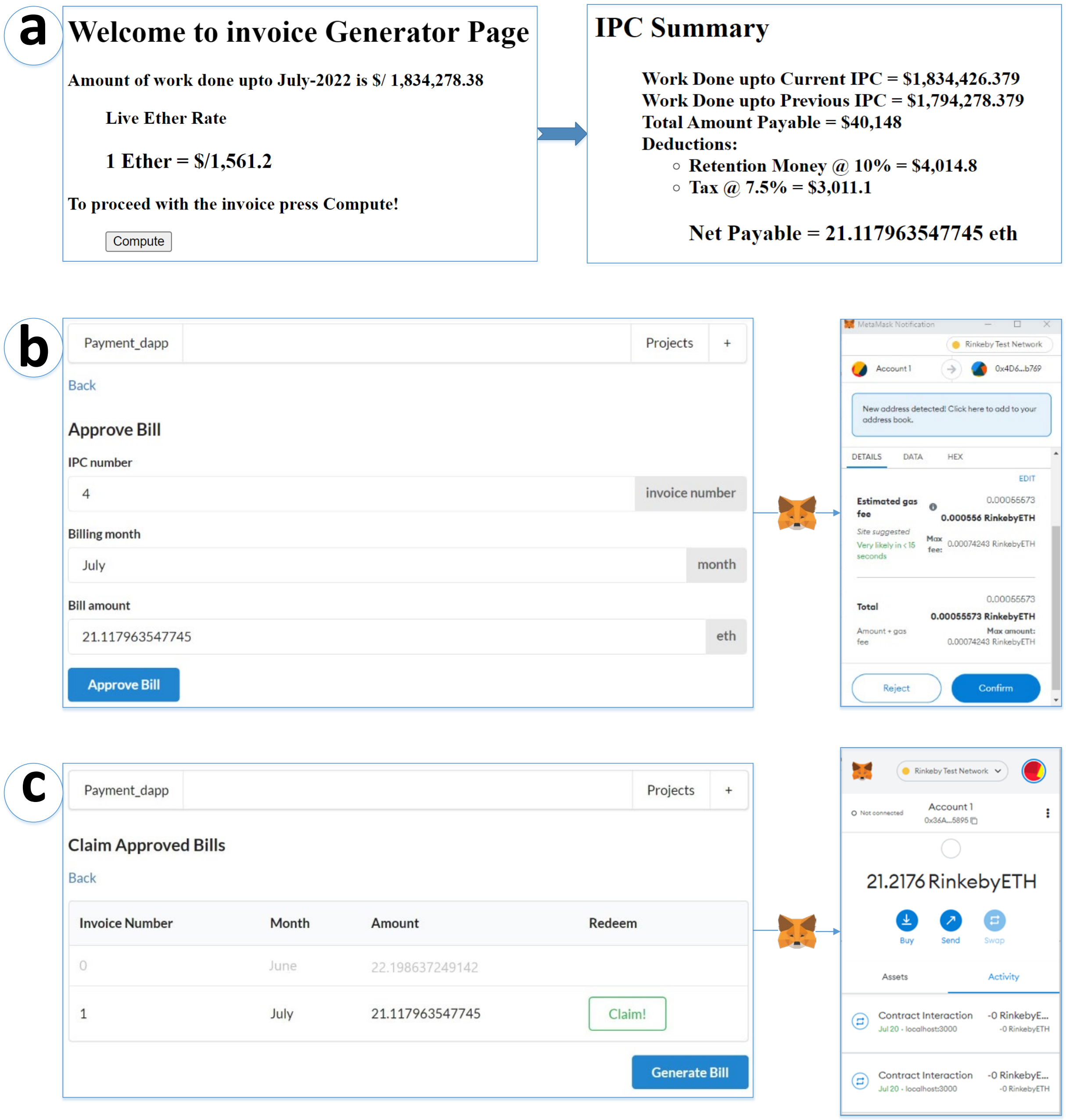

Fig. 6. (a) Invoice generator web page and invoice summary (b) Client interface on dApp for bill verification (c) Contractor's interface on dApp for claiming bill amount

7. Validation of the proposed BIM-blockchain system

A survey was distributed to 13 construction professionals working in the case study project to validate the proposed BBS. Several criteria were used to select the construction professionals. These include

1) The professionals must be familiar with BIM and blockchain,
2) The professionals must have at least two years of experience in the construction industry and
3) The professionals must have a bachelor's or above education level.

The professionals included quantity surveyors, planning engineers, procurement managers, site engineers, project coordinators, and deputy directors. For experimental studies that involve a case study-based validation part, a sample size of six to 12 respondents is considered sufficient (Guest et al.2006). A study on BIM used structured interviews with six professionals to investigate BIM implementation across different case studies (Alsorafa and Ergen, 2021). Similarly, data were collected from five professionals in another BIM study conducted in Hong Kong (Zhang et al., 2013). Another study on BIM-based tool implementation used data from five BIM experts to support their findings (Liu et al., 2020). Considering these examples, the sample for the current study is deemed adequate.

A short presentation was provided to the project participants, explaining the proposed BBS operations to them. In the next step, the professionals were asked to evaluate the likely benefit achieved using the payment dApp of the proposed BBS for progress payments. Eight questions were included in the pertinent survey. These questions were formulated to capture the professionals' views on the proposed system and its efficiency in addressing the limitations of traditional payment systems. The responses were sought on a five-point Likert scale ranging from "strongly agree," "agree," "neutral," "disagree," to "strongly disagree." The questions and pertinent responses are summarized in Table 1

Most of the professionals agreed or strongly agreed that the proposed BBS can help accelerate the payment process (92.3%), followed by its usefulness in tackling financial misconduct (84.6%) and simplifying the process of audits and traceability (92.4%). 61% of the participants agreed that the security of payments issue could be solved using the proposed BBS. 53.9% of participants agreed or strongly agreed that the proposed BBS eliminates the need for information-intensive paperwork. Similarly, 76.9% agreed with the statement that the BBS will have an overall positive effect on the payment culture used in construction projects.

In the last part of the survey, the professionals were asked to highlight the limitations of the proposed BBS and suggest any potential modifications to make the system more practical. 46.2% of the professionals were skeptical of the BBS because of the use of cryptocurrencies, as they lack a legal or regulatory framework in many countries, especially in developing countries such as the one where the case study project was located. 23.1% of professionals pointed out that the price fluctuation of cryptocurrency will act as a major barrier to its wider adoption and acceptance. The professionals also highlighted that an error in the BIM model might disturb the whole procedure and can have serious financial repercussions. One professional suggested integrating the proposed BBS with other technologies to work effectively in a complex real-world environment.

Table 1. Questions of the survey and responses of the participants

No.	Question	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
1	The proposed system eliminates the need for information-intensive paperwork for IPC generation. (Digitization of the invoicing process)	38.50%	15.40%	46.20%		
2	The proposed system is less prone to human error.		46.20%	53.80%		
3	The proposed system helps resolve the security of payments/trust issues among the involved parties.	46.20%	15.40%	15.40%	15.40%	7.70%
4	The proposed system can help accelerate the payment process.	61.50%	30.80%		7.70%	
5	The administrative burden can be lessened on the organization by this payment system.	23.10%	46.20%	30.80%		
6	This payment system can help end financial misconduct (corruption).	30.80%	53.80%	15.40%		
7	This system can help in payment audits and traceability.	46.20%	46.20%	7.70%		
8	This system can positively affect the construction industry and help improve the payment culture.	23.10%	53.80%	23.10%		

8. Discussions

The SC deployed on the Rinkeby Ethereum blockchain provides a realistic and predictable environment for testing the Ethereum application (Howell, 2023). The case study confirmed the transparency and audibility of the BBS proposed in this research. The BBS not only ensures transparency but also increases the efficiency of the process by accelerating the payment processes. Projects fail due to delays in payment. Therefore, a transparent system such as the BBS proposed in this study will benefit all stakeholders, including owners, contractors, and consultants, in the continuation of business.

Similarly, another review study supports the findings of this study, such as BIM-blockchain integration in the construction industry, which helps to improve working collaboration and reduce numerous issues (Zhang et al., 2023). It will also provide liquidity to continue the day-to-day operations of projects. The dApp inherent in the proposed BBS provides an efficient and transparent progress payment administration mechanism. The findings align with Amin et al. (2021), who presented BIM as the solution to the endemic problem of cash flow in construction projects (Amin et al., 2021).

The developed BBS focuses on DBB projects and uses interim payment certificates for invoicing. The integration of the BIM model for progress payment calculation allows payments based on planned schedules, curbing potential corrupt practices in the construction industry. This aligns with a study of BIM-integrated supply chain management in Nigeria. In the referenced study, the transaction costs were reportedly minimized, and forgery and modification of contract data were controlled (Ebekozien et al., 2023).

The SC of the developed BBS only requires one-time deployment. It leverages a two-contract system, where one contract triggers the deployment of the other contract containing payment logic. This feature allows the creation of any number of instances of the SC for various projects directly from the dApp front end. It also eliminates the need for manual deployment for each new contract. Accordingly, participants can approach the website (dApp) and create an SC with a few clicks using the proposed BBS for any construction project. This essentially enables project participants to use dApp to administer project payments and correspondingly yield the benefits of blockchain technology. It also eliminates the need for extensive coding or IT-related tasks. Therefore, this study can easily be applied to practice as contractors are getting familiar with the BIM model. This aligns with a study conducted in Egypt, which highlighted that a BBS will not only enable instant payment but also enhance real-time dealing among different parties (Kamel et al., 2023).

Through an optimized logic and structure of SC, coupled with the use of an off-chain database to avoid data congestion on the blockchain, the BBS managed to reduce the deployment and the gas/operational fees. As for the case study, it costs 0.00178 ETH to create an SC instance. Locking and subsequent release of funds cost 0.000556 ETH and 0.000149 ETH, respectively. Overall, it costs less than $5 to complete a payment cycle, making the BBS viable for construction projects.

Overall, this study contributes an integrated BBS to the body of knowledge that exploits the characteristics of BIM and blockchain in a dApp that can easily be applied to any construction project. However, the proposed system is not colossal, and the engaged professionals highlighted certain limitations. The contract administration team on construction sites is generally not well-versed in technology. Most participants suggest excluding the use of cryptocurrency for progress payments. Others suggest developing invoices by some other means, as most of the time, actual work lags behind the schedule. Also, an error in the BIM model may compromise the BBS. These challenges need to be addressed in subsequent studies to achieve a holistic implementation of the proposed BBS.

9. Conclusion

Late or non-payments are regularly reported shortcomings of the traditional payment system that continue to undermine the construction project's overall well-being. The manual processes further exacerbate the situation. To address this, automated and digitized processes are needed for construction progress payments. Accordingly, the current study presented an integrated BBS to tackle progress payment issues in construction projects. The proposed BBS leveraged a dApp that addresses payment security issues by acting as an escrow account and ensuring prompt funds are released to the contractor upon the client's approval. Thus, acting as a trustworthy intermediary between contractual parties. This study presents a fully functional dApp that reports to a real Ethereum network, unlike previous studies, which use a ganache blockchain that doesn't mimic real-world vulnerabilities. As such, protocols use a much-simplified consensus mechanism for faster block times. Also, the presented SC in the study requires minimal deployment and upkeeping costs. The SC was designed using an optimized payment logic for progress payment administration, making it viable for construction projects. The proposed BBS eliminates overheads associated with the payment process and removes bureaucratic systemic barriers. A case study was used in the current study to validate the proposed BBS. Thirteen respondents from the case study project were engaged through a detailed questionnaire. The results confirmed that construction professionals have a constructive, positive attitude toward the proposed BBS.

The results highlight that the proposed BBS can increase payment efficiency (92.3%), address financial misconduct (84.6%), transparency, and audibility (92.4%), and enhance payment security (61%) in construction projects. However, the proposed system is not colossal, and the field experts have raised some concerns. For example, 46.2% of respondents were skeptical of the BBS due to its dependency on cryptocurrencies. The main reason for this skepticism was the absence of legal frameworks for using cryptocurrencies. Such issues are more pronounced in developing countries. Similarly, 23.1% of respondents indicated that the price fluctuation of cryptocurrencies is a major barrier to BBS adoption.

In terms of operational limitations of the BBS, the system is designed to work for the DBB projects, where the scope is clear upfront. In the scenario of change orders, the preliminary work would require an overhaul, which will not sit well with the proposed BBS. Also, the BBS was only applied to a single case study in a developing country and may need further testing on more complicated projects. A more comprehensive project validation on different projects with varying levels of complexities will help expose the vulnerabilities of the BBS, which in turn helps make the system more robust.

To enable wider adoption of the BBS, the lack of legal status and fluctuation in cryptocurrency prices needs to be addressed. These issues can be addressed using stable coins or the use of NFTs (non-fungible tokens) pegged against real-world commodities. It is expected that with the inflow of smart money in crypto market capitalization, these digital coins will mature and reach their par value. Further, the technological skills of site staff and over-reliance of the BBS on the accuracy of BIM models are other impediments to BBS adoption.

A future study on the use of DAO (decentralized autonomous organization), which offers a much more flexible architecture than a regular SC, for payment administration can be conducted. Such DAOs can restructure and reorganize their code along the way. So, a DAO-based payment system can be modeled to be used for the whole life cycle of the project, extending from the bidding phase to the release of the final retention money. It can also tackle disputes if any arise along the way.

Data Availability Statement

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

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Disclaimer

There is no conflict of interest.

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