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A BLOCKCHAIN AND DECENTRALIZED CLOUD FRAMEWORK FOR TRUST-FREE AUTOMATED PROGRESS PAYMENT OF CONSTRUCTION PROJECTS

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Abstract

The payment issues in construction projects present major challenges for successful completion of projects. In this proceeding a framework is presented for achieving trust-free automated progress payment of construction projects to eliminate or reduce the payment issues. The framework integrates blockchain, smart contracts, Building Information Modeling (BIM), robotic reality capture solutions, and decentralized cloud technologies for accomplishing automated progress payments without any involvement of the project participants. Achieving a trust-free automated progress payment system would enable secure, efficient, timely and transparent payment of construction projects and would also eliminate payment related trust issues among the project participants

Introduction

The construction industry suffers from various payment issues due to several reasons including employer's poor management of the process (Abdul-Rahman et al. 2014, Demachkieh 2019), the ambiguity of contract payment terms (Chan et al. 2021), and tactics that contractors can employ to subcontractors for accepting long payment claim periods (ERC 2015). Payment issues not only impact the majority of project participants' financial conditions destructively, but the trust between parties can also be severely damaged under certain circumstances (Manu et al. 2015). Hence, a reliable and efficient trust-free payment system is needed for resolving the payment issues and achieving successful projects.

In recent years, the advancements in the decentralized blockchain and smart contract technologies have created a significant improvement in innovation across diverse industries, including construction industry. The innovative blockchain technologies, considering their decentralized and immutable properties create a new, highly improved standard ensuring that the transactions can be executed free of trust among project participants without requiring a third party. Smart contracts complement this by integrating contractual terms directly into code, facilitating automated, self-executing agreements that diminish the necessity for manual intervention and substantially reduce the risk of disputes and delays.

The combination of blockchain and smart contracts presents a compelling solution to the enduring issues that have characterized the construction industry. By eliminating the need for third-party intermediaries, these technologies foster an environment characterized by enhanced trust and accountability. Decentralized smart contracts enable the automation of progress payments precisely in accordance with the terms set in the contract. This automation not only accelerates progress payments and builds trust among project participants but also diminishes administrative expenses and enhances overall project efficiency.

In previous research, the capability smart contract based payment systems have been demonstrated to automate transactions and enforce timely payments, mitigating the financial risks associated with delays and disputes (Ahmadisheykhsarmast & Sonmez 2020, Hamledari and Fischer 2021, Scott et al. 2024, Khalid et al. 2024). The integration of blockchain with Building Information Modeling (BIM) has been proposed as another promising advancement for efficient administration of progress payments. The state of the art smart contract based payment studies enable an advancement for achieving a trust-free automated payment system for construction projects. However, there is not a research that present a completely trust-free system for automated payment of construction projects. With this context, the main objective of this study is to present a blockchain, BIM, robotic reality capture solutions, and decentralized cloud integrated payment administration framework for achieving automated trust-free payment of construction projects.

Literature Review

The potential of blockchain and smart contracts to reduce payment problems in the construction industry was mentioned in the early studies along with the launch of decentralized smart contracts (Cardeira 2015, Wang et al. 2017, Mason 2017, Ahmadisheykhsarmast & Sonmez 2018). Ahmadisheykhsarmast & Sonmez (2020) presented a smart contract payment system to ensure security of payment of construction contracts through an

automated computerized protocol that runs on a decentralized blockchain. The system relies on owner's approval of the progress values that are provided by the contractor. Das et al. (2020) proposed a blockchain framework to facilitate semiautomatic execution of interim payments based on input obtained from contracting parties. Hamledari and Fischer (2021) proposed an autonomous payment administration application which integrated blockchain-enabled smart contracts, robotic reality capture technologies and a private InterPlanetary File System (IPFS) network that was controlled by the owner, the general contractor, and the subcontractors. The application does not guarantee security of payments. Scott et al. (2022) proposed a framework in which the project bank account (PBA) account is represented by a smart contract that controls the release of funds upon signed approvals from validating authorities. Sonmez et al. (2022) developed a BIM integrated smart contract progress payment administration system in which as-constructed BIM is used to link the real world with the blockchain. The system required the contractor to identify the completed building elements in the as-constructed BIM model and owner's approval. Scott & Broyd (2024) investigated the potential of hosting PBAs on the blockchain and its potential contribution to the UK construction industry through a focus group interview. Scott et al. (2024) developed a PBA blockchain decentralized application which required approvals of the bank, main contractor and project manager at different stages. Khalid et al. (2024) presented a BIM-blockchain progress payment system which leveraged a smart contract to addresses payment security issues by acting as an escrow account ensuring that funds are released to the contractor upon the owner's approval.

In recent years an increasing number of studies have focused on using blockchain and smart contracts to ensure security of payment of construction contracts and to automate progress payment administration of construction projects. The studies achieved an advancement for reducing the payment truss issues among the project participants. However, majority of the existing blockchain research still require approval by the project participants for execution of the payments. Few research that implement robotic reality capture technologies also rely on the trust of the project participants as the information that will be used by for the payments are controlled by these participants. Hence, the literature lacks a trust-free payment approach for construction projects. Within this context, the main objective of this study is to narrow this gap in the literature and to present a trust-free automated payment framework for construction projects.

Research Question

The research question of this study is: How can a trust-free construction payment administration system can be achieved?

Research Method

The research method of this study consists of three stages. In the first stage the limitations of existing blockchain studies within the context of a trust-free payment system for construction projects are identified. The second stage includes determination of the required technologies for achieving a trust-free payment system. Finally in the third stage the proposed framework for trust-free payment is presented.

A Trust-Free Payment Framework for Construction Projects

Limitations of the Existing Methods for Trust-free Payments

The state-of-the-art research that have used blockchain technology for improving construction payment systems including Ahmadisheykhsarmast & Sonmez (2020), Scott et al. (2024), and Khalid et al. (2024), mainly focused on security of payment of construction contracts and proposed alternatives to project bank accounts that eliminated or reduced the requirement of the trusted third party intermediaries such as banks. However, the proposed payment systems still rely on contractor's or owner's approval and are not fully automated and trust-free. The autonomous payment administration application proposed by Hamledari and Fischer (2021) used robotic reality capture technologies to automate the progress determination and approval process, however, yet did not achieve a fully trust-free payment system since the robots and the private InterPlanetary File System (IPFS) network were controlled by the project participants.

Existing research that have used blockchain technology for resolving the payment issues in the construction industry have proposed several successful applications. However, these solutions are not completely trust-free and require involvement of project participants. An automated trust-free payment system should not require involvement of any project participants at any level.

Technologies Required for Achieving a Trust-free Automated Payment System

Decentralized Blockchain and Smart Contracts

Blockchain includes a variety of unique properties simultaneously such as security, transparency, trustworthiness, decentralization, immutability, and has been used to improve numerous processes in project and construction management (Sonmez et al. 2023). Advancements in blockchain technology have made it possible to implement computerized protocols called smart contracts, which are executed automatically through a code running on the decentralized blockchain, enabling creation of decentralized, trust-free, and automated systems such as payment systems. Hence, smart contracts are a very important component of a trust-free automated payment administration system.

Building Information Modeling (BIM)

BIM facilitates the digitization of building information and also offers a collaborative platform for project stakeholders, supporting contract administration, including the management of progress payments (Sonmez et al. 2022). An automated payment system requires digitization of building information hence BIM is an essential part of an automated payment administration system. Inclusion of the payment information in the BIM model along with a smart contract would also eliminate the ambiguity of contract payment terms.

Robotic Reality Capture Technologies and Artificial Intelligence

A trust-free automated system should not have any human input during progress payment calculations and approval. Use of reality capture solutions mounted on robotic platforms would enable capturing of progress data which can then be analyzed using artificial intelligence to obtain the progress amounts without any human input (Hamledari and Fischer 2021).

Decentralized Cloud

One of the limitations of the existing blockchain based payment systems is the control of the BIM files or other payment documents by the project participants. In a trust-free automated payment system project participants should not have control on any code or document, including BIM files. This is a challenge in blockchain based automated systems since it is very expensive and inefficient to store large files on the decentralized blockchain.

In recent years decentralized cloud have emerged as a novel technology for trust-free data storage and management. Decentralized cloud operates on a decentralized network of storage providers that contribute their storage capacity. In this decentralized architecture data is distributed across multiple nodes, making it exceedingly difficult for any single entity to access or compromise the entire dataset (Daniel & Tschorsch 2022). Majority of decentralized cloud enable the data stored to be only controlled by a smart contract enabling a secure, inexpensive and trust-free alternative for development of decentralized applications such as the payment administration systems.

Decentralized Trust-Free Payment Framework for Construction Projects

The proposed framework will integrate decentralized smart contracts, BIM, robotic reality capture technologies, and decentralized cloud to achieve an automated trust-free payment platform for construction projects. The framework requires selection of a blockchain platform and a decentralized cloud storage solution.

The selection of the most suitable blockchain platform for the proposed framework was based on the blockchain platform selection frameworks of Hunhevicz and Hall (2020) and Sonmez et al. (2023). Consequently, the Ethereum blockchain was chosen as the platform for developing and deploying the smart contract module, owing to its technical maturity, widespread popularity in supporting smart contract development and its efficiency in integrating with the decentralized cloud systems. Similarly, IPFS cloud was selected as the decentralized cloud alternative due to its popularity and its guarantee for the availability of files in the network through Filecoin (Daniel & Tschorsch 2022).

The proposed framework consists of five stages. In the first stage, a 5D BIM model which includes the payment amounts of each building element along with their construction schedule is stored to the decentralized IPFS cloud as shown on in Figure 1. A BIM with a minimum Level of Development (LOD) of 300 is acceptable for the proposed framework particularly for lump-sum projects. However, LOD 350 is recommended, as it offers additional information that enhances quantity take-off with greater detail and accuracy (Khosakitchalert et al. 2020). Each BIM building element should have a unique ID so that they can be identified by the smart contact and the robot.

The second stage consists of development and deployment of the smart contract which should be performed before construction activities start. The smart contract should be coded according to the payment terms that are specified in the contract. If the contract allows, the smart contract may enable direct payments to the subcontractors to also eliminate subcontractor payment issues. The Ethereum public wallet addresses of the contractors and subcontractors that the payments will be made should be included in the smart contract along with the project wallet address. In most construction projects, interim payments are typically made on a monthly basis, so progress payments are assumed to be made monthly in the proposed framework. Since the framework uses Ethereum platform ETH, or ERC20 tokens such as: USDT, USDC, Dai, EURC can be used for payments. The required codes for the smart contract to control the IPFS decentralized cloud files and the robot should also be included in the smart contract. In the framework, Solidity is recommended for the development of smart contracts, as it is a widely adopted and well-established programming language specifically created for developing smart contracts on the Ethereum blockchain.

The third stage the smart contract determines the amount of the progress payment for the next month using the 5D BIM in the decentralized IPFS cloud and requests from the owner to deposit the required amount to the project wallet address. Once the owner deposits the amount, the smart contract locks the full amount to secure the payment for the contractor and subcontractors for the next month.

In the fourth stage the smart contract triggers and directs the robot to determine the buildings elements completed using robotic reality capture technologies for the lump-sum projects. The robot(s) could be a camera-equipped unmanned aerial vehicle or an unmanned ground vehicle or both (Hamledari and Fischer 2021). The robot should

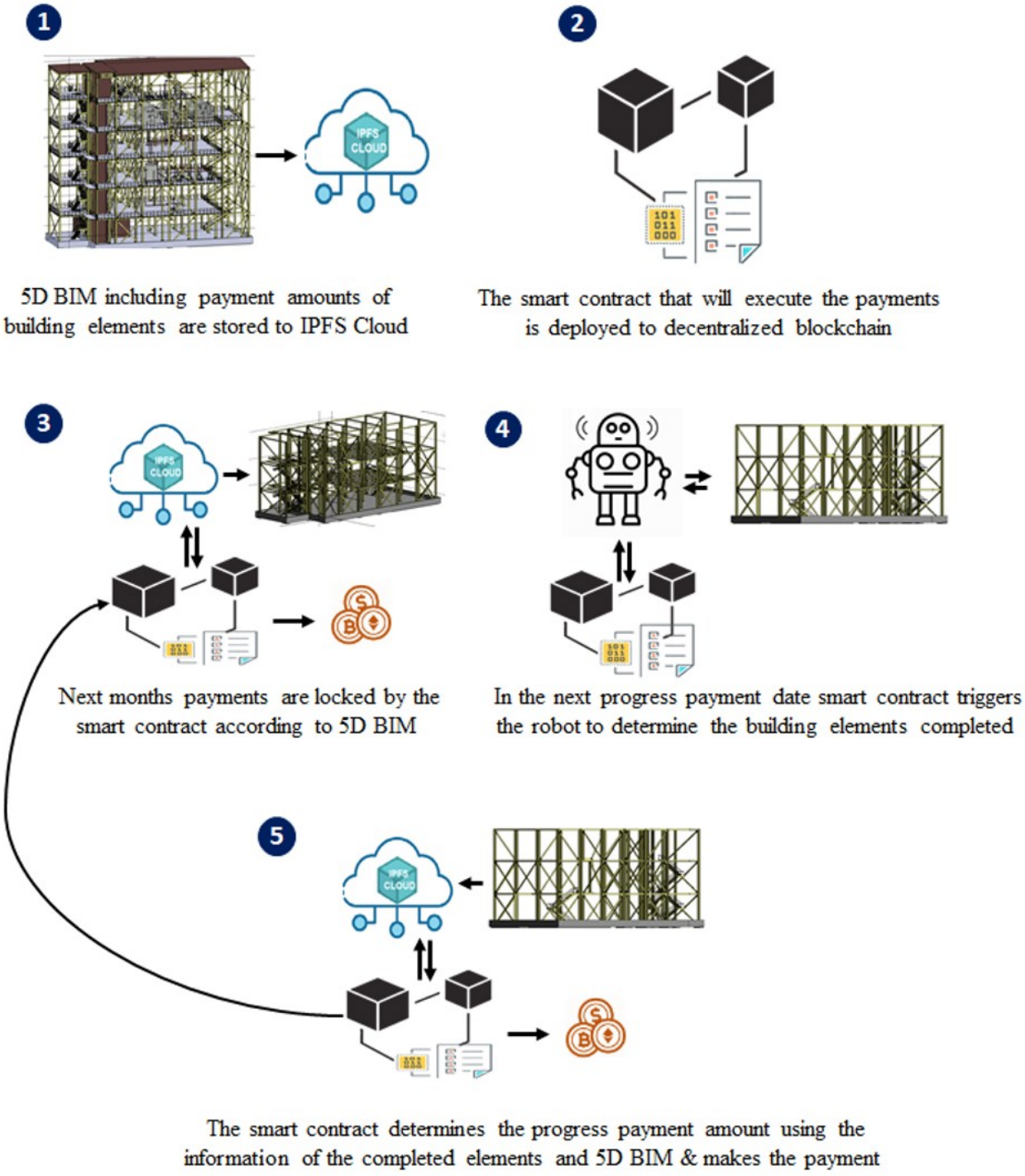

Figure 1: Blockchain framework for trust-free progress payment of construction projects

be controlled by the smart contract deployed in the Ethereum blockchain to ensure its immutability for achieving a trust-free system. The smart contract will use the 5D BIM model stored in the decentralized IPFS cloud to guide the robot. For unit price projects, the robot would determine the quantities completed to calculate the bill of quantities.

Once the progress measurements are completed, the smart contract will determine the monthly progress payment amounts based on the data provided by the robot and the 5D BIM model of the decentralized IPFS cloud. The smart contract will then transfer the payments to the contractors and subtractors wallets immediately after the progress payment amounts are determined without the owner's approval. Once the payments are made the smart contract will determine the amounts of the progress payments for the next month using the 5D BIM and will request from the owner to deposit the required amount to the project wallet address and will lock it to secure the payment for the next month. The progress payment process would

continue without any interruption according to the contract conditions that are ensured by the immutable smart contract.

Limitations and Discussions of the Proposed Framework

The proposed framework presents the required technologies and how they should be integrated for achieving a trust-free progress payment system for construction projects. However, the framework is not developed and validated as an application and lacks empirical testing and performance metrics (e.g., transaction costs or robotic accuracy), hence practical feasibility and effectiveness of the framework is not assessed. The robotic reality capture solutions that are included in this framework may misclassify the scope of construction works and may fail to accurately assess the level of progress (Hamledari and Fischer 2021). Automating progress measurement using autonomous robots introduces additional risks, including potential hardware failures and errors in data classification. Artificial intelligence or backup robots could be used to reduce or eliminate these risks. Ethereum smart contracts may include security vulnerabilities especially when they are not developed properly. Robot control hacks may also present a security threat. However, these risks may be minimized when developers consider potential vulnerabilities and use best practices and principles to create safe smart contracts along with user training (Kushwaha et al. 2022). The cryptocurrency payments also present numerous risks including extreme fluctuations lack of regulation, and lack of liquidity (Liu et al. 2022). The use of cryptocurrencies for progress payments may also conflict with local regulations or established contractual practices. Integrating multiple advanced technologies can be complex and expensive, posing significant challenges for smaller construction firms or projects with limited budgets.

Conclusions

Achieving a trust-free automated progress payment system for construction projects is challenging as it will require all the stages, documents, and codes to be controlled in a trust-free manner without the involvement of the project participants. In this study a framework that integrates decentralized immutable smart contracts, BIM, robotic reality capture solutions, and decentralized cloud is presented for succeeding the goal of trust-free automated progress payments. Decentralized cloud presents a promising solution for storing and controlling the BIM files and payment data without the involvement of the project participants.

The proposed framework presents an initial step for a fully trust-free automated progress payment system to achieve a secure, efficient, timely and transparent payment of construction projects for eliminating payment issues in the construction sector. However, development of a fully trust-free payment system involves numerous challenges. One of the major challenges is to control the robots through a smart contract. Decentralized artificial intelligence could a promising area for future research to tackle this challenge.

The proposed framework is mainly developed for lump-sum projects. However, the framework could also be implemented for unit-price projects. Implementation of the proposed framework for unit-price projects requires more detailed and accurate quantity take-off with robotic reality capture solutions, which could be a challenge with the current technologies.

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