Potentials of 5D BIM with Blockchain-enabled Smart Contracts for Expediting Cash Flow in Construction Projects

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Abstract

The low level of digitization in sharing information and the fragmented processes in the construction supply chain negatively affects cash flow across the supply chain, resulting in non- and late-payment issues. Even though a cloud-based 5D BIM platform and Blockchain-enabled smart contracts have the potential to address the issues, their applications for expediting the cash flow are still in their exploration stages in the construction industry. The main objective of this study is to contribute to this transformation by examining one of the most advanced cloud-based 5D BIM platforms, MTWO, to analyze its potential in expediting cash flow when used in conjunction with the blockchain-enabled smart contract. This study contributes to the body of knowledge by proposing an improved way of processing pay applications that leverage blockchain-enabled smart contracts with the 5D BIM platform to expedite the construction projects' cash flow through a semi-automatic payment process.

Keywords –

5D BIM; Automation; Blockchain; Smart Contract; Construction Payment

1 Introduction

According to the McKinsey Global Institute report [1], the construction industry is one of the largest industries in the world economy, with about $10 trillion in annual expenditures. However, the industry's productivity has trailed that of other sectors with about $1.6 trillion in gaps of opportunity to close. This low productivity results from the low level of digitization in sharing information and the fragmented processes in the construction supply chain (CSC) involving various stakeholders who represent different interests and requirements [2]. These issues negatively affect cash flow across the CSC, resulting in non- and late-payment issues, and thus negatively affecting the productivity of construction projects. According to the 2019 Construction Payment Report [3], the cost of slow payments is staggering and involves: (1) higher construction costs, (2) inability to get bids from the best subcontractors (Subs), (3) project delays due to stopped work, (4) discount losses of a minimum 3.7% for not paying faster.

To address the issues of low digitization and fragmented processes and to expedite the cash flow, a cloud-based 5D Building Information Modeling (BIM) platform can be leveraged. A cloud-based BIM platform enables the various stakeholders in construction projects to have higher levels of cooperation and collaboration by providing an effective real-time communication platform [4]. 5D BIM is the most recent BIM technology in which the construction project stakeholders can link a cost database to the construction activities and schedules (4th D BIM data) combined with a 3D model [5]. It enables the stakeholders to conduct model-based cost estimating, tendering, procurement, and cost control [2]. Despite these valuable capabilities of a cloud-based 5D BIM platform, its utilization for expediting the cash flow in construction projects is still rare in the construction industry.

In addition to a cloud-based 5D BIM, applications of Blockchain-enabled smart contracts can expedite the cash flow in construction projects [2, 6-11]. Blockchain is a technology that enables the stored data to be immutable and traceable. A smart contract is a digital contract using blockchain for data immutability and traceability. Using the data stored in blockchain, the smart contract makes the contract execution process automatic and enforces the fulfilment of obligations. Using these capabilities allows an automatic payment process to expedite the cash flow in construction by combining BIM with Blockchain-enabled smart contracts [2, 7, 9].

However, the integration of 5D BIM with blockchain-enabled smart contracts for expediting cash flow in construction projects is still in its early research stages. The primary purpose of this study is to investigate the potentials of a cloud-based 5D BIM by analysing one of the most advanced cloud-based 5D BIM platforms, MTWO. In addition, this study also investigates how blockchain and smart contracts can improve and enhance the capabilities of 5D BIM to facilitate and expedite the payment process in construction projects. Finally, based on the analysis and investigations, this study proposes a system architecture of a 5D BIM integration with blockchain-enabled smart contracts for expediting cash flow in construction projects. The proposed system enables all the stakeholders including the owner, architects, GC, and Subs to have complete access to the construction progress data along with 5D BIM models. It also enables a semi-automatic interim payment process using 5D BIM data from the models and a blockchain-enabled smart contract.

2 Literature Review

2.1 Late- and Non-payment issues in Construction Projects

The late- and non-payment issues are prevalent and critical issues in the construction industry throughout the world [12-15]. Peters et al. [16] investigated the causes, effects, and solutions for late- and non-payment issues in small- and medium-sized construction companies in developing countries. The study found that the critical factors leading to the payment issues involve the client's poor financial management and delay in payment certification. Consequently, the issues result in cash flow problems, difficulties in procuring materials and equipment, problems acquiring funds from financial institutions, inability to pay wages, and damage to the reputation of contractors [16]. They found that training in cash flow management and speedy dispute resolution are effective solutions to mitigate and prevent the payment issues in construction projects. Xie et al. [17] studied the impact of payment delays on the progress of a construction project by investigating the two links in payment chains (i.e., from owner to general contractor (GC) and from GC to subcontractor (Sub)). In their study, they regulated four payment policies including 1) Shortening the payment period at both links in the payment chain, 2) Shortening only the payment period from the GC to Sub, 3) Increasing the advance fund provided to the subcontractor by the GC and 4) Increasing the percentage of interim payments to be paid to the Sub by the GC. By quantitatively simulating the above four policies, the study found that shortening the payment period at the two links will expedite the flow of funds and mitigate the pressure on contractors in providing advance funds in terms of amount and duration, making them powerful measures to ensure smooth progress in a construction project. Wu et al. [18] also pointed out that non-payment is a common complaint from contractors in the construction industry. As a solution to the problem, they developed a framework to improve regulative measures that address payment problems. Through an analysis of late- and non-payment dispute cases, Ramachandra and Rotimi [19] found placing charging orders, caveat registration over built properties, and issuance of bankruptcy and liquidation notices have been effective methods in mitigating payment disputes. Nevertheless, the authors admitted that the payment problem is still prevalent within the industry and thus suggested that the rational starting point for real solutions to the payment problem is changing the attitude of upstream construction parties (i.e., Owner and General Contractor), followed by adherence to provisions within the payment-related legislation and contract forms.

As evidenced by the literature review, most of the studies are limited to focusing on investigating the causes of late- and non-payment issues and the negative impacts on construction projects. Even though several studies proposed methods of mitigating and preventing the issues, the approaches have been limited to a regulatory or legislative framework. Additional studies focusing on practical process improvement to facilitate and expedite cash flow is also necessary.

2.2 Potential of Blockchain-enabled Smart Contracts in Expediting Cash Flow

2.2.1 What is Blockchain and Smart Contract?

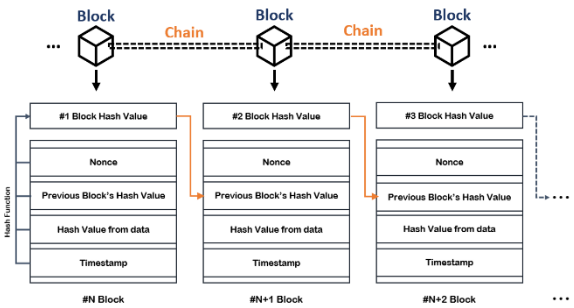

Figure 1. Linkage between the data blocks in Blockchain

Blockchain is a technology that provides an immutable and decentralized digital ledger consisting of the linked blocks with transaction data [20-22]. The data in each block are encrypted via a hash function and transformed to a hash value [21, 22]. Each block also has its own hash value made by the nonce, previous block's hash value, hash value from the transaction data, and timestamp, which creates a chain between two different blocks (Figure 1). Consequently, if someone wants to modify the data in an existing block, they should modify the data along the entire chain. They also must create a corresponding change in the next block, which includes the changed hash value of the modified block. However, it is technically prevented from "consensus protocol" such as Proof-of-Work or Proof-of-Stake [20]. In addition, the data transaction record is replicated and distributed to every participant node, thus creating a decentralized ledger [23]. As a result, the data stored into blockchain is immutable and cannot be falsified or tampered with. In this environment, the users are able to trust the immutability and traceability of the data.

Given the immutability and traceability of data in Blockchain, blockchain enables the users to trust the data stored in Blockchain and use it as a basis to execute automated smart contracts [24, 25]. Smart contract is a computer protocol intended to digitally facilitate, verify, and enforce the negotiation or performance of a contract [26]. Smart contracts provide the contract terms and conditions with an automatic process, facilitating the fulfilment of obligations without human intervention [26]. The immutability and traceability of Blockchain, and smart contract system have the potentials to promote trustworthiness in information shared in the project and expedite the payment process and the cash flow in construction projects.

2.2.2 Blockchain-enabled Smart Contract for Expediting Cash Flow

The potential of blockchain-enabled smart contract in improving the payment issues in construction projects has been examined by a couple of studies [6, 10]. Nanayakkara et al. [6] conducted discussions with construction professionals and validated that blockchain-powered smart contract solutions can significantly mitigate the payment and related financial issues in the construction industry, including partial payments, non-payments, cost of finance, long payment cycle, retention, and security of payments. Hamledari and Fischer [10] validated why blockchain-based and decentralized smart contracts can provide reliable automation of progress payments by conducting a case study.

Leveraging the advantages of blockchain and smart contracts, other studies have designed a new framework or developed a new system for timely and transparent payment of construction projects. Luo et al. [8] proposed a framework for a semi-automatic construction payment system using smart contracts and blockchain technologies. The framework includes the decentralized environment-based sequential approval process by stakeholders such as an engineer, architect, and owner in processing construction interim payments, which can streamline the cash flow in construction projects. Ahmadisheykhsarmast and Sonmez [27] also proposed a smart contract payment security system (SMTSEC) for expediting the payment process. By using a smart contract in processing the interim payment in construction projects, the system provides a secure, efficient, and trustworthy platform for security of payments of construction contracts, without requiring a trusted intermediary such as lawyers or banks. Both studies [8, 27] suggested that future research can focus on integration of BIM technology with smart contracts to enable completely automated payments based on the construction progress. Sigalov et al. [2] and Ye et al. [9] presented the concept of implementing smart contracts for automated, transparent, and traceable payment processing for construction projects. They combined BIM technology with blockchain-enabled smart contracts to enable the automatic payment processes in construction projects. Hamledari and Fischer [7] also proposed an autonomous payment administration solution utilizing blockchain-enabled smart contracts and robotic reality capture technologies. In the solution, the construction progress is captured, analyzed, and documented respectively using sensing, machine intelligence, and as-built BIM models. Based on the captured progress, the payment is automatically processed following the smart contract terms and conditions.

While these studies highlight the overall value inherent in using a blockchain-enabled smart contract systems combined with BIM technology for expediting cash flow in construction projects, they have not fully addressed the changes need to be made to the workflow processes to realize this value. First, all the stakeholders including the owner, architects, GC, and Subs should have complete access to the construction progress data along with 5D BIM models. Second, the legal payment documents developed based on the BIM data should be confirmed by each responsible stakeholder. Third, the automatic payment should be based on the construction progress data from the BIM technology linked with the payment documents. Accordingly, a new system architecture and workflow needs to be developed to facilitate a semi-automatic payment process, by enabling all the users to access the construction performance data, confirm the responsibility fulfilled, and provide access to official payment documents.

3 Methodology: Case Analysis of Payment Process Workflow and 5D BIM Technology

This new system architecture is developed by case analysis of current workflow and by leveraging the advantages of the cloud-based 5D BIM technology in the payment process of construction projects.

3.1 Current Cash Flow using AIA Contract Documents and Prompt Payment Codes

Current cash flow in construction projects has a linear flow from owner to suppliers. In the projects using American Institute of Architects (AIA) contract documents, the suppliers, subcontractors, a general contractor transfers the information related to their payment by using documents including an AIA payment application (G-702) and an AIA continuation sheet (G-703). Based on the transferred documents, the architect reviews the relevant information, and the owner approves the payment. The documents can expedite payment and reduce the possibility of error [28]. Especially on the AIA payment application, the contractor can show the status of the contract sum for the portion that is completed, including the total dollar amount of the work completed to date, the amount of retainage (if any), the total of previous payments, a summary of change orders, and the amount of current payment requested [28]. Along with the payment application, the AIA continuation sheet divides the contract sum into portions of the work in accordance with the predefined construction schedule [29].

In addition to the payment documents, there exist the Prompt Payment Code (PPC) for construction projects in each state in the United States. In this research, the code for Georgia state (GA) is used. The GA code § 13-11-4 (a) describes the time limit for payment to contractors is 15 days, and § 13-11-4 (b) describes the time limit for payment to subcontractors is 10 days.

The payment process workflow using AIA contract documents and abiding by the GA PPCs is illustrated in Figure 2. This current cash flow heavily relies on paper documents and has fragmented stages across the CSC. In this setting, it is difficult for the architect and owner to check the construction performance in detail, thereby delaying the process. In addition, all the stakeholders do not have a single source of truth regarding the construction data, thus leading to misunderstandings or miscommunication regarding the construction schedule and cost estimates. Accordingly, even though prompt payment codes exist, they cannot eliminate the non- and late-payment issues.

3.2 Cloud-based 5D BIM Technology

3.2.1 5D BIM Platform Example: MTWO

5D BIM platform enables all the construction stakeholders to access construction progress data, thus minimizing misunderstandings or miscommunication regarding the construction schedule and cost estimates. The MTWO, which is investigated in this study, is one of the most advanced cloud-based 5D BIM software and provides the ability to use scheduling analysis tools. It provides several modules for scheduling construction works and estimating costs, which can be leveraged to facilitate and expedite cash flow in construction projects. The scheduling modules provide effective tools for the planning of activities such as the Gantt Chart and the Line of Balance. The Gantt Chart shows each construction job or activity with multiple version combinations: planned, current, and the combination of planned and current versions. In addition, it provides relationships, constraints, and events for each construction activity, enabling a critical path analysis for managing the variability of the plan. The Gantt Chart analysis provided by MTWO is illustrated in Figure 3. The Line of Balance shows the activities in different locations along the project time. It facilitates the rescheduling of the planned activities and the control of the necessary resources by allowing the users to detect the collisions of activities and time. The Line of Balance analysis provided by MTWO is illustrated in Figure 4. Both analyses are created based on the 3D BIM model of the project.

In addition to the schedule analysis tools, the scheduling module includes the construction performance measurements indicating the degree of completion for each activity in percentages or quantities in a tabular view. Through this capability, the users can conduct forecasting and plan-actual comparisons. The cost estimation modules enable the users to generate the cost estimate including quantity determination from the 3D component. The users can filter or organize the cost estimate under their own cost management structures and according to each field like quantity-wise, cost-wise, or

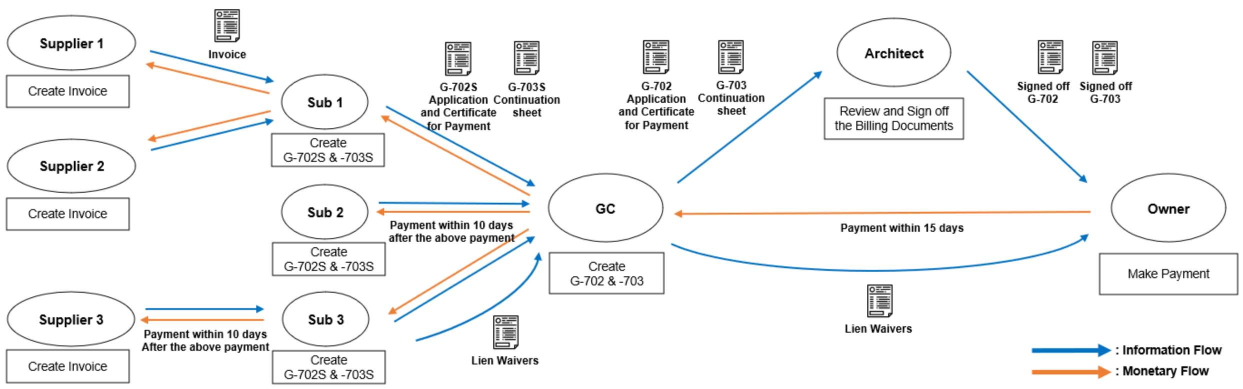

Figure 2. Payment Process using AIA Contract Documents and GA Prompt Payment Codes (PPCs)

assigned parameters-wise. When these cost estimate data are combined with the scheduling data from the scheduling modules, the 5D BIM platform enables the users to conduct a 5D simulation showing the construction progress simulation in a 3D model based on the planned and actual schedule in the Gantt Chart and the cost and budget simulation (Figure 5).

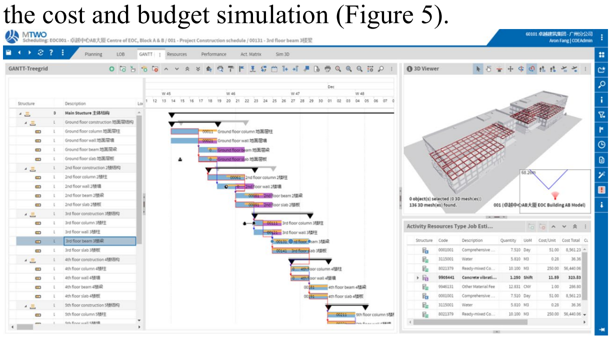

Figure 3. MTWO Gantt Chart Analysis [30]

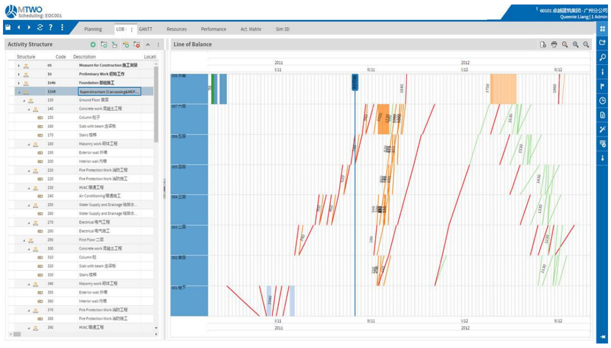

Figure 4. MTWO Line of Balance Analysis [30]

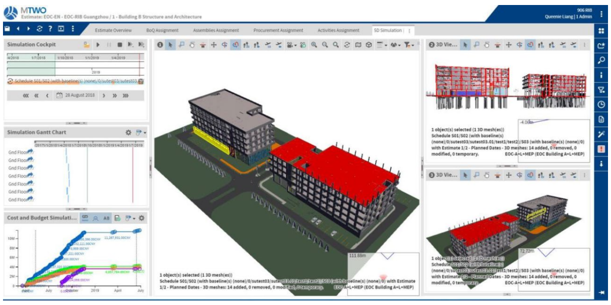

Figure 5. MTWO 5D BIM Simulation [30]

3.2.2 Potential and Limitation of 5D BIM

By leveraging the scheduling and cost estimate modules, the GC can process the raw data from the architects into the information for managing construction schedules and progress payment. First, the raw data including drawings and 3D BIM models from the architect are transferred to the GC. Next, the GC input the raw data into the 5D BIM software. From the estimate module, the GC can have the information including quantity take-off, bill of quantities, and cost estimates. From the scheduling module from 5D BIM software, the GC can have the information including the planned and current schedules and the overall construction progress and progress lines. The information associated with the cost estimates and scheduling can be used by the subcontractors to develop the invoice and the documents for the progress payment as well as by the GC to develop the progress payment application. In addition, based on the digital documents, the architect can confirm the application and create certificate for the payment.

In summary, the 5D BIM modules facilitate developing the progress payment documents with digital data based on the 3D Model, which can expedite the cash flow by reducing paperwork overload. In addition, the stakeholders including the owner, architect, GC, Subs, and even suppliers can have access to the single source of truth in 5D Digital Twin, representing both the initial plan and in-progress schedule and cost estimate performance. These advantages are the main strengths of the 5D BIM software.

However, 5D BIM technology also has its own limitations. The GC, Subs, and architect need to process the information provided by the 5D BIM software to develop the progress payment invoice, payment application, and certificate for payment, which means the administrative procedures to develop the documents of the payment application and certificate remain. Even though the GC and architect develops the documents of application and certificate for payment by using the 5D BIM data provided by the 5D BIM platform, the owner cannot see the connection between the executed performance data along with the 3D model and the documents of payment application and certificate, which means the knowledge inequality among the stakeholders has not been eliminated. Another challenge is that 5D BIM cannot enforce the payment due. Accordingly, just-in-time payment is not ensured even if the project is using the 5D BIM technology. These limitations can be a new opportunity for expediting cash flow in construction projects. When the digital data related to construction schedule and cost estimates can be used as a resource for automatic payment using smart contract system, just-in-time payment can be ensured.

As introduced in the previous section, blockchain is a technology that provides data traceability and immutability [20, 21], which enables the users to trust and utilize digital data in business life [31, 32]. A smart contract is a digital contract using blockchain to automatically facilitate, execute, and enforce a contract [25, 26, 33]. If the 5D BIM data associated with the cost estimates and schedules can be verified and stored into blockchain at certain key milestones for data traceability and immutability, it can then be leveraged as a single source of truth for an automatic payment system using smart contracts. This is an opportunity for the 5D BIM technology to be used for managing the interim (progress) payment and expediting cash flow in construction projects.

4 Expediting Cash Flow: Utilizing 5D BIM in conjunction with Blockchain-enabled Smart Contracts

4.1 System Architecture Framework

Upon analysis of the current workflow in the payment process and realizing the potential and limitations of 5D BIM platform in facilitating the creation and approval of pay applications, this study proposes a futuristic system architecture framework that utilizes 5D BIM and blockchain-enabled smart contracts.

The proposed system facilitates and expedites the cash flow in construction projects. First, the system enables all the stakeholders to access the construction progress data and 5D BIM models in real-time using a cloud-based web application. This advantage expedites the payment process by removing misunderstanding and miscommunication issues in confirming the construction progress. Second, the system automatically develops payment documents based on the cost estimates and scheduling modules of the 5D BIM platform. This advantage removes manually and linearly processing payment documents. In addition, the digital payment documents will be linked with the 5D BIM model, thus facilitating the performance examination.

After the examination, each stakeholder creates a digital signature on its responsible document, and the signed documents are uploaded to the web-based decentralized application (Dapp) using blockchain-enabled smart contracts, making the documents immutable and traceable. In this stage, the owner buys the cryptocurrency to ensure the operation of the smart contract. Next, the smart contract in the system examines whether all the documents are signed and whether or not the predefined stage of work is completed. To examine the construction performance, the system leverages the progress data extracted from the 5D BIM software, which uses an XLSX format. If all the conditions in the smart contract are met, then the payment is processed automatically. This contract execution based on digital data removes the financial institutions like a bank in processing the payment, thus expediting the payment process. The smart contract conditions, XLSX data used in the smart contract, and the signed payment documents are stored in the blockchain to make them immutable and traceable. In this process, the size of the XLSX data can be reduced by encoding it with a hash function (e.g., SHA-256) and changing it into the hash value. The entire process is illustrated in the system architecture, Figure 6.

4.2 Limitations and Future Studies

This study is focused on developing a system architecture for a framework on smart contract-enabled 5DBIM for expediting cash flow. Even though the development is based on the research gaps identified in the literature review and the analysis of the current workflow and the potential of 5D BIM and blockchain-enabled smart contracts, empirical validation of the system is also needed. Accordingly, future studies will develop a pilot system based on the system architecture and validate the effectiveness by conducting a case study using the system in real-world construction projects.

Future studies should also consider the operating costs of the smart contract. When the smart contract is

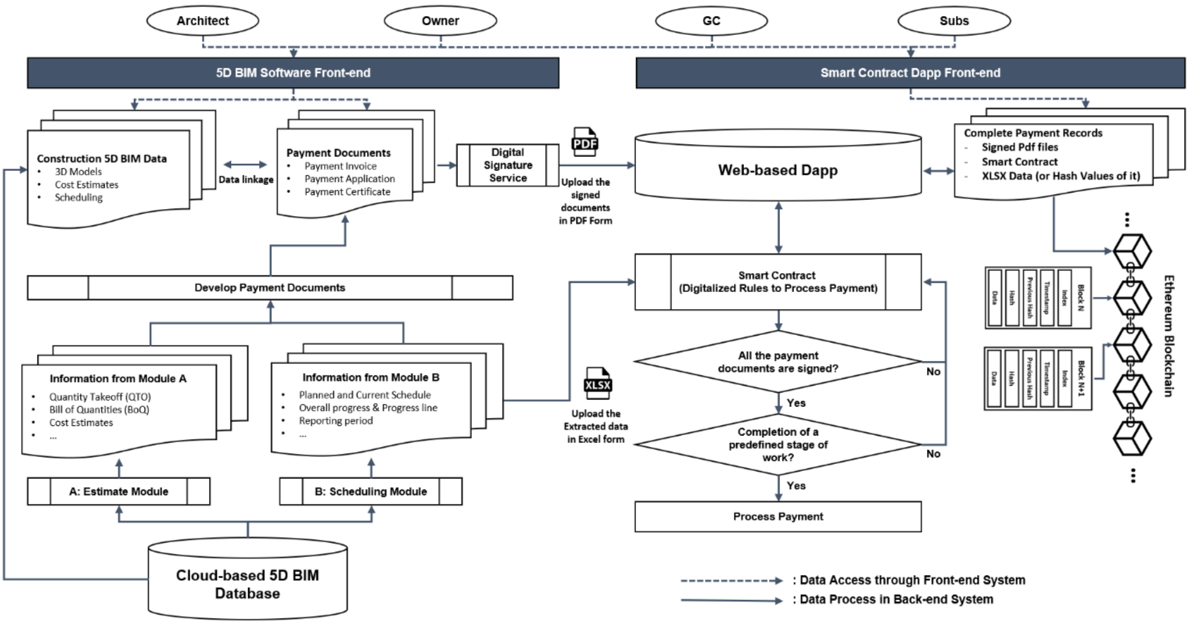

Figure 6. System Architecture of Smart Contract-enabled 5DBIM for Expediting Cash Flow

operated, it uses Gas, which is computing power to create blocks for a smart contract in Ethereum. The used Gas should be calculated because the operating costs can be estimated based on the used Gas. In addition, the pilot system should address the price volatility issue of cryptocurrency. For example, the price of Ether, the cryptocurrency used in the proposed system, varies based on the time in which it is used. To address this issue, future studies can refer to the solutions provided by Hamledari and Fischer [34]. The solutions include employing stable cryptocurrencies introduced by [35, 36], cryptocurrencies pegged against fiat currencies/commodities, asset-backed crypto tokens defined on public or private chains, etc [34].

5 Conclusion

This study contributes to the body of knowledge by proposing an improved workflow for digitalizing and automating the payment process using emerging technologies. The proposed workflow enables the construction stakeholders to access a cloud-based 5D BIM platform to review real-time construction progress data. By having access to both as-planned, as-built 5D BIM progress data, and by linking pay application documents to the supporting 5D BIM data, the stakeholders could visually and easily understand and verify the scope of the work completed, and compare the invoices with the initial estimate, and total contract sum charged so far. The payment documents confirmed by each responsible stakeholder are automatically processed with a blockchain-enabled smart contract, thus expediting the payment process by reducing the paper works and eliminating the intervention of financial institutions. As a result, the proposed workflow enables the integration of construction professionals' insight on construction progress with the automatic payment process using blockchain and smart contract. It also facilitates the industry's adoption of 5D BIM and blockchain technologies by providing a practical and specific application framework in solving a critical issue, late- and non-payment in the CSC.

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