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FRAMEWORK FOR BLOCKCHAIN-ENABLED BUILDING INFORMATION MODELING (BIM) DATA SHARING IN CONSTRUCTION SUPPLY CHAIN

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ABSTRACT

Sharing construction project data among the construction supply chain (CSC) stakeholders (e.g., Architects, General Contractors, Subcontractors, and Suppliers) is critical for the successful delivery of construction projects within time, budget, and expected quality. Building Information Modeling (BIM) is an advanced technology for the stakeholders to create and share the construction data. However, BIM data is not effectively shared among the stakeholders because of the difficulty in determining BIM data ownership and the ambiguity in clarifying who will be responsible for BIM data inaccuracies. Consequently, the stakeholders cannot trust that their data are safe from data ownership and liability issues, hesitating to share their data. This study examines the potential of blockchain to address the limitations of BIM by analyzing blockchain use cases in construction and other industries. Furthermore, based on the findings, this paper proposes a novel framework for a blockchain-enabled BIM data sharing application to improve the quality assurance process in the CSC. This study contributes to the body of knowledge by 1) enabling the construction industry to understand the potential of blockchain through construction and other industries' blockchain use cases and 2) providing a practical framework for blockchain-enabled BIM data sharing to improve the quality assurance process in the CSC.

KEYWORDS

BIM, Blockchain, Construction Supply Chain, Data Sharing, Trust

INTRODUCTION

Sharing construction project data among the construction supply chain (CSC) stakeholders (e.g., Architects, General Contractors, Subcontractors, and Suppliers) is critical for the successful delivery of construction projects within time, budget, and expected quality (Titus & Bröchner, 2005). Building Information Modeling (BIM) is an

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advanced technology for the stakeholders to create and share the construction data (Liu et al., 2015). The technology provides a digital data platform that enables the stakeholders to transfer construction data across the supply chain with virtual 3D objects, including robust information at different stages, and deploy several collaborative instruments to drive project goals (Huang et al., 2009).

Despite the benefits, its legal and contractual systems are yet to be standardized (Arshad et al., 2019), thus leading to the difficulties in determining BIM data ownership and the ambiguity in clarifying who will be responsible for BIM data inaccuracies (Alnaqbi et al., 2022; Azhar, 2011; Enshassi et al., 2019; Oraee et al., 2019; Sun et al., 2017; Thompson & Miner, 2006).

Blockchain has the potential to address the aforementioned limitations of BIM to provide a secured platform for sharing construction data. Blockchain is a technology that can make data traceable and immutable (Hughes et al., 2019; Wickboldt & Kliewer, 2019). If we can make the data stored and shared in a BIM-based data sharing platform traceable and immutable, the CSC stakeholders can determine the data ownership and clarify who is responsible for any data inaccuracies. Consequently, the enhanced security and trust enforced through Blockchain can facilitate and promote BIM data sharing across all the CSC stakeholders in construction projects.

The purpose of this paper is to examine the potential of blockchain to address the limitations of BIM as a trusted tool for sharing data across the CSC. This research analyzes the blockchain use cases in construction and other industries, thus examining the potential of blockchain to address the BIM data ownership and liability issues. Furthermore, based on the findings, this paper proposes a novel framework for a blockchain-enabled BIM data sharing application to improve the quality assurance process in the CSC.

BLOCKCHAIN AND POTENTIAL OF BLOCKCHAIN-ENABLED BIM DATA SHARING

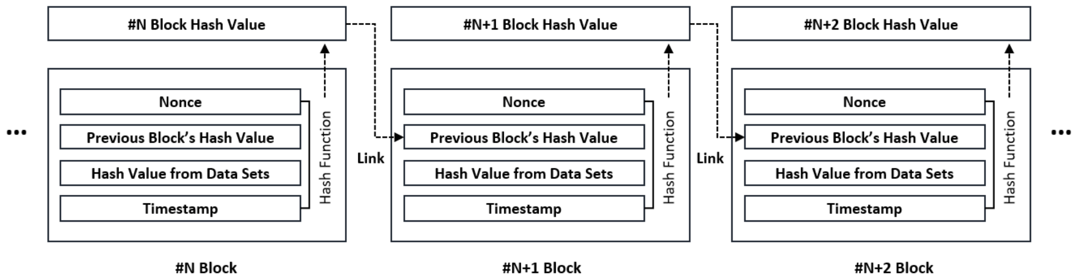

Figure1: Blockchain Components

Blockchain is a technology that can provide a digital ledger consisting of linked blocks containing data sets. The data in each block are encrypted by a hash function and changed into a unique hash value. This hash value creates a chain between blocks because each block contains the previous block's hash value (Figure 1). When a new block is added to this chain, the block must satisfy the criteria of the consensus protocol (e.g., Proof-of-Work). After data are stored in the chain through the process as mentioned above, the data are replicated and distributed to all the nodes in the blockchain, thus creating a decentralized ledger. These capabilities make the falsification of data in blockchain technically impossible. For example, for the falsification to be validated as an official modification, the entire data across the blockchain should be modified corresponding to the falsification because of the chains created by hash values. Furthermore, the process of creating the new blocks within the falsified data should be verified with the consensus protocol, which requires sufficient time and computing power. This process makes the falsified blockchain shorter than the original one, which continuously adds a new block. Accordingly, the falsified chain is discarded because the longest blockchain is determined as a valid blockchain. In summary, blockchain enables the users to have a decentralized ledger in which the stored data are immutable and traceable. This advantage has the potential to address the limitation of BIM in providing a secured and trusted platform sharing construction data.

The exploration of blockchain as a tool to enable immutable and traceable BIM data exchange among project participants is ongoing. Different scholars have identified and listed potential application scenarios. Turk & Klinc (2017) investigated the potential of blockchain to provide a trustworthy infrastructure for BIM data management during all building life-cycle stages. Mathews et al. (2017) revealed that the combination of BIM and blockchain can enhance trust among the construction stakeholders because blockchain can immutably and traceably record the BIM data-based transactions in the CSC. Erri Pradeep et al. (2019) also found that blockchain can enhance the trust among the construction stakeholders using BIM by enabling change tracking and establishing clear liabilities, which facilitates collaboration and information sharing. In addition to the trust enhancement, Nawari and Ravindran (2019) investigated how blockchain applications could be advantageous in the BIM workflow by emphasizing network security, providing more reliable data storage and management of permissions, and ensuring change tracing and data ownership.

Even though the above studies provided theoretical evidence that blockchain can facilitate BIM data sharing by making the data immutable and traceable and thus enhance trust among the construction stakeholders, the practical framework of the blockchain-enabled BIM data sharing across the CSC is in its early stages. Filling this research gap, Dounas et al. (2021) developed a framework of decentralized architectural design using BIM agents connected over blockchain. In addition, they developed a software based on the framework that enables recording all design attempts with BIM, including ones that have failed, and all positive steps towards design optimization. However, this framework is limited to the BIM data sharing in the design phase, not considering the BIM data transactions across the CSC.

RESEARCH METHODS

To develop a practical framework for the blockchain-enabled BIM data sharing across the CSC, we analyze the blockchain use cases in various industries, including healthcare, food, finance, and construction. The use case analysis reveals the practical advantages of blockchain in diverse types of supply chains and the limitation of blockchain applications in the construction industry. The identified advantages demonstrate the potential of blockchain to address the BIM data ownership and liability issues. Based on the findings from the analysis, we design a novel framework of a blockchain-enabled BIM data sharing application to practically improve the quality assurance process in the CSC.

BLOCKCHAIN USE CASES IN DIVERSE INDUSTRIES

HEALTHCARE INDUSTRY

There are a number of healthcare industry companies investing in blockchain technology (Castillo, 2019). One specific example of blockchain being used in the healthcare industry is its use in combating prescription drug fraud. A considerable portion of drug abuse in the United States of America is prescription drug abuse (Peterson, 2000). Common approaches utilized to acquire prescription drugs illicitly are doctor shopping (visiting multiple providers to unlawfully obtain prescriptions), altering prescriptions, forging prescriptions, and photocopying prescriptions (Blumenschein, 1997; Peterson, 2000).

The software company, Nuco, recognized a solution to combating prescription drug fraud using blockchain technology (Engelhardt, 2017). In their framework, the prescriber first creates the prescription on the blockchain platform. The information for the prescription (i.e., drug name, quantity, anonymized patient identity, time and date, etc.) is linked to a unique identifier in the form of machine-readable code (Engelhardt, 2017). Next, the pharmacist uses the unique identifier to fulfill the prescription on the blockchain platform. The blockchain platform documents the fulfillment effort, analyzes the blockchain for warning signals (i.e., whether the prescription has been filled previously or if the patient has multiple prescriptions from separate providers), and notifies the pharmacist if that prescription is qualified to be filled (Engelhardt, 2017). This system could drastically reduce prescription drug fraud as the blockchain would eliminate the ability to photocopy prescriptions, immediately identify any alterations, crosscheck for doctor shopping, and the patient would have to have access to prescriber's blockchain account in order to forge prescriptions. Through blockchain technology's encryption, patient privacy would be maintained while stakeholders could trust the information due to blockchain's immutability.

Another specific example of blockchain being used in the healthcare industry is in medical records. Currently, a patient's medical records are commonly disintegrated across various healthcare providers (Virginio Jr & Ricarte, 2015). Research has shown that improvements in the accuracy, availability, accessibility, and legibility of medical records improves healthcare quality and outcomes (Hong et al., 2015). One type medical record is the hospital discharge summary. Hospital discharge summaries communicate, "a patient's care plan to the post-hospital care team," and are believed essential in benefiting patient health and wellbeing when transitioning care settings (Kind & Smith, 2008). The company Medicalchain deployed a digital solution to improve the accuracy of hospital discharge summaries and worked on implementing that system on a blockchain technology platform (Engelhardt, 2017). Their current platform focuses on using blockchain technology to provide a secure, single source for patients' medical records that allows practitioners to update patient medical records in real time in a transparent, auditable, and secure way (Medicalchain, 2018).

FOOD SUPPLY INDUSTRY

As mentioned, blockchain enables supply chain stakeholders to safely store data into tamper-proof environment and share the data only with the people who are permitted to obtain the data through the peer-to-peer transaction. Food industry applies those benefits to their supply chain. As the food trade becomes globalized, verifying the safety and quality of food in the supply chain has become challenging (Aung & Chang, 2014). To solve this problem, IBM has developed an information-sharing system by using the benefits from Blockchain technology, which is called IBM *Food Trust*. This system allows authorized users to verify the freshness of food and trace records of food provenance, transaction data, and processing details.

For example, the system provides users with information about product quantity and quality at every point of the supply chain (e.g., farms, packing houses, manufacturing of goods, warehouses, distribution centers, and stores). The users can check the location of supply chain facilities with map view as well as current at-risk inventory at each facility. This helps the users examine inefficiencies in the supply chain and assess the freshness of the products in real time. In addition, the authorized users can trace every product throughout the supply chain within this system. They can verify the provenance of the products and be aware of their real-time location and condition, which helps the users identify contaminated food and respond immediately. These benefits increase customer trust in products. In addition to tracking freshness and traceability, the system facilitates holistic management of critical documents, such as authorizations, licenses, and inspection results, in a secure data storage. Traditionally, the documents have been scattered along the fragmented supply chain and are difficult to manage because of their quantity, complexity, and variety. However, the novel system allows users to gather them into the distributed database by Blockchain, which simplifies the tracing of information such as issuers and issue dates in a tamper-proof environment. A more detailed explanation of the system can be found at IBM (2019).

FINANCIAL SERVICES AND BUSINESS INDUSTRY

After the emergence of Bitcoin in 2009, the blockchain applications for financial services have been extended in a prominent way. Among the Finance use cases addressed by the book Blockchain: A Practical Guide to Developing Business, Law, and Technology Solutions (Bambara et al., 2018), two categories can be identified: customer-related and Smart Property approaches.

Within the first group, the Know Your Customer (KYC) scenario provides an automated customer identification and transaction history validation before enrolling him/her with a financial institution. To perform this, "the customer's personal information is encrypted and added as a block in the blockchain" (Bambara et al., 2018). After that, the financial institution refers the customer to its block, so that the customer allows access to his/her KYC data. Later on, the financial institution validates the provided information and decides to approve or not the customer's admission. The customer's block remains intact and in the blockchain, available for other financial institutions by the time a potential customer provides them with access. This approach was tested in the ASEAN (Association of Southeast Asian Nations) region on spring 2017 by a consortium between a Singapore government body and various banks that include HSBC and Mitsubishi UFJ Financial Group, Inc. (Sharma, 2019). Meanwhile, different financial institutions such as Santander, PNC, and SABB applied blockchain to improve the global payment process through the Ripple protocol. This pact allows the use of blockchain technology for cross-border payments, currency exchanges and the access to a broad exchange network. Ripple relies on a distributed ledger technology, or a database shared and updated within multiple entities (regardless of their geographic information) and whose transactions besides being public, require the use of a native currency called ripples. It enables cross-border payments between multiple participants of the network and direct customers. A common transfer requires the Global Payment hand over from the first Financial Institution to the Ripple's digital asset XPR, where a bilateral clearing or risk arrangement between the exchange parties takes place under the light of fee across (FX) traders, followed by the fund's relocation at the Targeted Institution in the required currency. This approach shortens the payment cycle, enhances currency conversions, offers global affordable money transfers and allows the incorporation of alternative payment options for customers (Bambara et al., 2018).

For the Smart Property approach, the most outstanding use cases include the creation of Smart Property (to trace and control physical assets) and Transferring the Ownership of Smart Property (as a new method for procuring Smart Property and transferring the information attached with it). Different Real Estate companies are currently applying blockchain to enhance the search, procurement and sale of properties (Harbor, Managego, Property Club).

CONSTRUCTION INDUSTRY

The construction industry has investigated the potential of blockchain applications to various sectors across the construction value chain, such as property management, information sharing management, supply chain management, construction management, and payment management (Dakhli et al., 2019; Perera et al., 2020).

The use cases show two prominent trends. First, blockchain is applied for data immutability and traceability in the CSC. For example, blockchain can help trace the supply chain of precast construction projects, improving the prompt delivery of precast components and enabling stakeholders to track the reasons for disputes in the supply chain (Wang et al., 2020). Second, blockchain is used to embody smart contracts that can expedite construction payment across the CSC by automatically processing the payment. For example, the digital data of construction performance can be collected by BIM or other data capture systems and used to process the interim payment based on the predefined algorithm written in a blockchain-enabled smart contract (Hamledari & Fischer, 2021). Despite the valuable trends, integrating BIM with blockchain to facilitate data sharing and developing a framework of blockchain-enabled BIM data sharing to improve the CSC is still in its exploration stages.

DISCUSSION

The above analysis of the blockchain use cases reveals that blockchain can generate cryptographically secured, tamper-proof and traceable data sharing platforms across the supply chain, thus creating a trustworthy environment for information sharing. It shows the potential of the blockchain-based platforms to address the BIM data ownership and liability issues. Despite this potential, integrating BIM with blockchain to facilitate data sharing and developing a framework of blockchain-enabled BIM data sharing to improve the CSC are still in their exploration stages. Addressing this research gap, this study proposes a novel framework for a blockchain-enabled BIM data sharing application to practically improve the quality assurance process in the CSC, which will not only reduce the time and cost of the quality assurance process but also increase the accuracy of the assurance through the integration of BIM and Blockchain.

FRAMEWORK FOR BLOCKCHAIN-ENABLED BIM DATA SHARING IN CONSTRUCTION SUPPLY CHAIN

The proposed framework (Figure 2) improves the quality assurance process of the CSC by leveraging blockchain-enabled BIM data sharing. In the current process, a general contractor manually compares the information in the quality documents provided by subcontractors or suppliers with the predefined quality standard in the specification from architects. However, in the proposed framework, the detailed information of products or construction work and the quality standard will be stored into a BIM model and can be compared digitally and automatically. This will not only reduce the time and cost of the quality assurance process but also increase the accuracy of the assurance, thus preventing mistakes or defects in construction phase. Blockchain platform in the framework is a key element to enable this digital and automatic quality assurance system using BIM data. Because it can provide a cryptographically secured, tamper-proof and traceable data sharing platform, the stakeholders including architects, general contractor, subcontractors, and suppliers can input their data into the BIM model without any concerns about the BIM data ownership or liability issues. Consequently, instead of the document-based manual quality assurance process, the system enables the digital and automatic quality assurance process using a BIM model. This will not only reduce the time and cost of the quality assurance process but also increase the accuracy of the assurance by using the BIM data, which can store very sophisticated and detailed construction information into a 3D model.

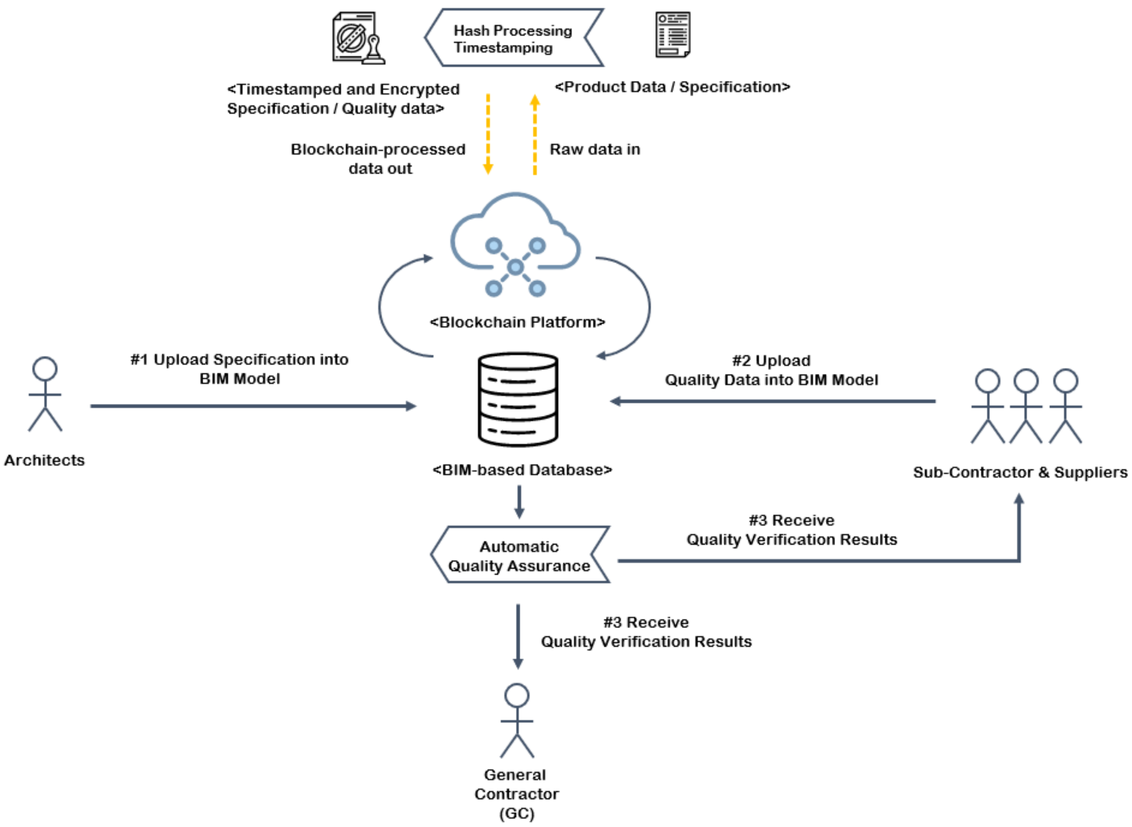

Figure 2: Automatic Quality Assurance using Blockchain-enabled BIM data Sharing

LIMITATION AND FUTURE STUDIES

This study involves development of a conceptual framework for blockchain-enabled BIM data sharing to improve the quality assurance process in the CSC. Accordingly, future studies will focus on developing a pilot system based on the framework and validating its effectiveness by conducting a few pilot tests in the real-world construction projects. Moreover, future studies are needed to investigate the potential of the proposed framework in expediting and facilitating cash flow across the CSC. The existing studies on blockchain applications in cash flow of construction projects (Ahmadisheykhsarmast

& Sonmez, 2020; Das et al., 2020; Elghaish et al., 2020; Hamledari & Fischer, 2021) can be integrated with the proposed framework to create new insight into the cash flow management of the CSC.

CONCLUSIONS

This paper has examined the potential of Blockchain to facilitate sharing of BIM data across the CSC by analyzing blockchain use cases in construction and other industries. The analysis shows that Blockchain can generate cryptographically secured, tamper-proof and traceable data sharing platforms across the supply chain, thus creating a trustworthy environment for information sharing. These advantages can effectively address the critical limitations of BIM data sharing, which are the BIM data ownership and liability issues in the CSC. Based on the findings, this paper also proposed a novel framework for Blockchain-enabled BIM data sharing to improve the quality assurance process in the CSC. The framework enables the CSC stakeholders to leverage their BIM-based data for quality assurance process because the framework employs blockchain to enable BIM data sharing by removing the BIM data ownership and liability issues. Subsequently, the BIM-based digital data in the framework allows the stakeholders to leverage the automatic quality assurance system, which can reduce the time and cost of the quality assurance process and also increase the accuracy of the assurance. As a result, this study contributes to the body of knowledge by 1) enabling the construction industry to understand the potential of Blockchain through construction and other industries' blockchain use cases and 2) providing a practical framework for blockchain-enabled BIM data sharing to improve the quality assurance process in the CSC.

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