A blockchain-based framework for supporting BIM-based building code compliance checking workflow

H Gao and B Zhong

1 School of Civil and Hydraulic Engineering, Huazhong University of Science and Technology, Wuhan 430074, Hubei, China.

E-mail: dadizhong@hust.edu.cn

Abstract. Code compliance checking of building designs is an essential task during the design and construction process, this process is time-consuming and laborious, and there is a risk of human manipulation, collusion and tampering with the results during the process. Existing BIM automated compliance checking technologies can reduce human errors and automatically output drawing review reports in some domains. But there are still few provisions that can be automatically reviewed, and most of the provisions still require human intervention. This research proposes a blockchain-based framework for managing both automated and manual compliance review processes in a BIM environment. The framework is developed to help improve the traceability and transparency of the compliance review process in the BIM environment. The framework includes on-chain and off-chain solutions for addressing the management issues in the code checking process. The prospects of the solution, challenges in implementation and future research directions were discussed.

1. Introduction

Design review is to identify defects and shortcomings of the design before construction takes place[1]. The aim of the design review is to ensure the design quality and detect design issues before construction. With the development of BIM technology, the data is presented in a machine-readable format and supports model checking applications in different disciplines[2–6]. In current design review practice, there are limited provisions that can be automatically reviewed, and many tasks still require human intervention. It leads to the risk of human manipulation, collusion and tampering with the results during the design review process.

Blockchain is an emerging technology that can improve data security, transparency, and traceability, it has attracted attention from different industries such as healthcare, logistics, finance, and agriculture[7–11]. The concept of blockchain was invented by Satoshi Nakamoto in 2008 to solve the security and privacy issues of digital currency transactions (Bitcoin)[12]. Blockchain is a distributed ledger that chronologically and securely records all data shared among all participants in a Peer-to-Peer network[13]. Data is uploaded to the distributed ledger through the consensus mechanism of different nodes in the network and updated in real time[14]. The peer-to-peer propagation mechanism makes records that cannot be tampered with. At present, various types of blockchains have been developed, these blockchains are divided into three types, public blockchain, private blockchain and consortium blockchain. They are different in the degree of openness, transaction speed, consensus mechanism, and scalability. Due to the requirements of limited participants, high transaction speed, privacy protection
and scalability, consortium blockchain is widely studied in the research of the construction industry[8,15,16].

The study is to explore the potential of consortium blockchain in design review by developing a blockchain-based framework for managing compliance review processes in a BIM environment. It aims to provide a new solution for overcoming management issues in the design review practice, such as tracing the source of design errors and reducing the risk of collusion and human manipulation.

2. Statement of the problem in the design review process

Through the analysis of the workflow of existing government design review agencies in China, there are some common management issues in the current practice of design review: 1) The design review process is not transparent, and there is a risk of collusion between the owner and the reviewer. 2) The review comments and revision process of the design drawings were not recorded, and quality problems occurred during delivery, and it was difficult to determine the legal liability. 3) The data is stored on a centralized database, and the data is at risk of tampering, manipulation, unauthorized access. In order to solve these problems, this study proposes a design review management framework based on blockchain, and discusses the role of blockchain in design review process management.

3. Creation of a blockchain-based BIM design review framework

The main goals of developing the framework are to i) integrate the blockchain into the BIM design review workflow, ii) strengthen the liability control and data security in the BIM review process through the blockchain. This framework is based on the following technologies.

3.1. Related technologies

3.1.1. Automatic Code Checking(ACC). In some advanced countries, the governments require the delivery of the BIM files in the design stage. Manually performing code reviews for BIM data is not only time-consuming and labor-intensive but also prone to errors. Some of the countries are promoting automatic code checking applications. At present, BIM-based automatic code checking technology is being extensively studied[17–19], which can improve the accuracy and speed of compliance review in some areas. Most studies use the Industry Foundation Classes (IFC) to extract building object information as the source information to perform design compliance checking. The limitation of automatic code checking is that many parameters required by design rules are not defined in IFC format[19]. Hence, this study proposes a blockchain-based design review environment which both considering the process of automatic code checking and design review by human expert.

3.1.2. Hyperledger Fabric. Hyperledger Fabric is one of the leading open-source consortium blockchain systems, it was associated with Linux Foundation[20]. Different to public blockchain such as Ethereum, Bitcoin, Fabric focuses on developing private blockchain solutions in B2B applications. In Fabric, all participants on the blockchain network should get valid identities through MSP (Membership Service Provider). MSP is a mechanism that enables participants to convert their identities into digital certificates that can be recognized by a permissioned blockchain network. In this way, it can guarantee that only the permitted participants can access the design review process record. Fabric provides channel mechanism to put different participant nodes (such as designer, owner, reviewer, and government regulator) on the same blockchain, each node on the chain will hold the same copy of the design review process record which is known as a ledger in blockchain, the ledger records the transaction details (such as model modifications, the digital signature of nodes, time stamps, etc.) of each operation in the activities, it has the characteristic that once the ledger is established, it cannot be changed. The mentioned features of Fabric make that the data in the design review process is secure and can be traced.

3.1.3. IPFS. In a BIM-based design review environment, large files submitted by designers such as BIM files, design simulation and calculation reports need to be stored off-chain because it will increase the
transaction speed and storage cost in a P2P network. Many blockchain solutions use cloud storage or local databases to record the transaction information off-chain, but the lack of a decentralized storage structure will also bring side effects on the management of design files. Interplanetary File System (IPFS) is a decentralized P2P file system to share unchangeable information in the blockchain network[21]. IPFS eliminates the role of centralized storage server and replaces it with a P2P file transfer protocol, files are distributed in different storage nodes which avoids a single point of failure. In the BIM-based design review environment, IPFS chooses to provide secure off-chain storage for large design files or documents.

3.2. System architecture

This paper proposes a system architecture based on the consortium blockchain. In this architecture, Hyperledger Fabric is selected to implement the blockchain network due to the requirement of data privacy and permission mechanism. As is shown in figure 1, the architecture is composed of four key components which are the application layer, consensus layer, network layer, storage layer.

Application layer: The application layer involves the key applications in the design review activities, such as design review process management, record storage, version management of BIM models, personnel identity management, etc.

Consensus layer: The consensus layer enables highly dispersed nodes to reach a consensus on the block data. It is a multi-party collaboration way to coordinate the multi-participants to reach an agreement about the process data in the design review activities and to ensure the record is difficult to be deceived.

Network layer: The blockchain network layer is to realize the information exchange between different participants and to make the data of the design review process transparent and traceable.

Storage layer: The layer is about the storage of the process data, it can be divided into on-chain data storage and off-chain data storage. Considering that storing large files on-chain will cause delays and increase storage costs. This study uses a combination of on-chain and off-chain storage. In the design review process, the BIM models and unstructured large design documents are stored off-chain with the help of IPFS, the hash value of these files is stored on-chain.
3.3. Information flow during the design review process

The design review system based on the blockchain can be developed into a DApp (Decentralized Application), as is shown in Figure 2, the designed workflow of the DApp is as follows:

The owner obtains a digital identity through Fabric CA (Certification Authority), then logs in and uploads the design files to the DApp. DApp uploads the design files to the IPFS database and generates the hash value corresponding to the files, and uploads the hash value and transaction information (timestamp, file type, digital signature, etc.) to the Fabric blockchain network. When each node on the blockchain reaches a consensus, a block is formed and stored on the chain.

The reviewer accesses the DApp through a digital entity, then starts the design review process. Design review is divided into review by human expert and automatic code checking by computer program. Some provisions can be automatically reviewed by computer programs, others can be reviewed manually. First, the BIM-based code checking algorithm will automatically check and output unqualified building elements and the corresponding violations. The records will be directly upload to the blockchain network through the peer node directly, it can prevent the possibility of tampering. After the reviewer has completed the design review, the reviewer needs to upload the design review report and add comments with digital signatures and time stamps. Regardless of whether the design review is passed or not, the review report and original design files will be uploaded to the blockchain network as immutable proof.
The designer logs in to the client through the digital identity granted by the Fabric CA, and downloads the review report of the unqualified design file, and makes changes. Then the designer uploads the modified files into the DApp, the transaction information will be broadcast after each node reaches a consensus, then the reviewer can download the modified design file in the IFPS database and repeat the design review process. In this process, each modification of the design file will be stored as transaction information to the blockchain network as an unchangeable record.

During the review process, the regulation authority does not participate in the actual activities. As a node on the blockchain, the node’s ledger records all the review processes.

![Information flow of blockchain-based design review process](image)

**Figure 2.** Information flow of blockchain-based design review process

### 3.4. Off-chain data management

This study uses IPFS as off-chain data storage, the participant in the blockchain network can share files through IPFS, the files are stored distributed in the P2P network, the peer-to-peer protocol of IPFS makes that the files cannot be modified. Combine asymmetric encryption with IPFS, design files can be shared among specific participants. For example, in **figure 3**, the designer is sharing BIM model with the reviewer, the following steps describe the process:

1. The designer desires to share the BIM file to IPFS and solely provide access to the design reviewer.
2. The designer encrypts the BIM file with the public key of the reviewer.
3. The designer uploads the encrypted BIM file to IPFS, and IPFS generates a hash value for the file.
4. The designer uploads the hash value and transaction information (time-stamp, file name, etc.) to the blockchain network.
5. The reviewer downloads the encrypted BIM file on IFPS through the hash value.
6. The review decrypts the BIM file with his or her private key.

IPFS a peer-to-peer network that allows data to be served based on its content, not its location. The address of the file is represented by a hash, once the content of the BIM file is changed, the hash value of the file will also change, and the historical version of the BIM file will still exist and cannot be modified. At the same time, during the file transfer process, the malicious third party does not have the private key of the reviewer, and cannot obtain the BIM file.
4. Discussion

The design review panel is required to be independent of the local authority and the developer. But due to the funding relationship, sometimes, the design review process may not be completely objective. There exists a risk of collusion between the reviewer and other related parties. This section discusses the potential benefits that the proposed framework can bring to the design review process.

- Provide transparency in the design review process. In the traditional design review system, the system usually records the final qualified design documents without the process information. The content-based addressing mechanism of IPFS provides version management function for design files. It can provide a transparent environment to record the design review reports and model modifications in the process. Thereby reducing the possibility of collusion between the designer and government supervisor.

- Improve the design liability control. In the blockchain-based process, immutable proofs contribute to supporting accountability and traceability of design problems. If there occur quality issues, the designer and the reviewer's electronic signature and time stamp can be used to trace the cause of the problem in the design stage and help improve design liability control.

- Ensure system security. The blockchain-based solution integrated with IPFS makes that the data is stored on a P2P network, it is independent of any third-party storage. The sharing of the design files is securely transmitted through asymmetric encryption. It can ensure that the original design files and design review process records will not be tampered with.

At the same time, some challenges may hinder the deployment of the proposed blockchain-based system architecture in the practice. From a technical perspective, the distributed storage mechanism of the blockchain will make each node to store a copy of the transaction information. As the number of projects increases, it may cause transaction delays and reduce the efficiency of data queries on the blockchain. From a management perspective, the construction industry is considered a traditional industry that is unwilling to accept new technological changes. It is a challenge to persuade government agencies to transform a centralized database into a distributed storage database.

5. Conclusion and future work

This study explores how blockchain technology can improve traceability and transparency in BIM-based design review workflow. The study analyzes the existing problem in the design review process and provides a framework integrated consortium blockchain with IPFS to strengthen the liability control and data security in the design review process. In the presented framework, the blockchain technology is used for tracking data exchange in the design review workflows and different versions of BIM model are unchangeably stored on the IPFS network. Blockchain technology will help create an environment of trust and improve design responsibility control and reduce collusion among stakeholders and ultimately contribute to achieving better design quality. The DApp related to the proposed framework is under development, future work will integrate the IFC-based automatic BIM version difference detection algorithm into the blockchain solution to improve the process tracking ability.
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