FAST AND SECURE BIM DESIGN USING BLOCKCHAIN: AN EXAMPLE OF MAKESHIFT HOSPITAL PROJECT FOR COVID-19 TREATMENT IN HONG KONG

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ABSTRACT: *A crucial action of COVID-19 combat is the quick design and building of makeshift hospitals (MHs). Although adopting building information modeling (BIM) promotes the digitalization and communication of design collaboration, data security vulnerabilities (e.g., lacking traceability and transparency) are detected and have inevitably impeded the efficiency and productivity of the MH project. Such problems often lead to rework and unnecessary disputes, wasting valuable time on projects requiring ultra-fast construction speed. The emerging blockchain technology offers an immutable and traceable collaboration environment. However, limited studies have integrated blockchain in the BIM design process, especially design in emergency projects like MH. Therefore, this paper proposes a blockchain-enabled collaboration (BEC) framework for fast and secure BIM design. The framework is illustrated in an actual MH project in Hong Kong, and results show that: (1) it supports secure and automated BIM data exchange and (2) it saves 23 % of the time in a design coordination case.*

KEYWORDS: *Covid-19, BIM, Blockchain, Makeshift Hospital, Smart Contract.*

1. INTRODUCTION

The COVID-19 pandemic seriously threatens the global public medical and health system. By January 2023, there had been over 750 million confirmed illnesses and over 6 million documented fatalities (WHO, 2023). Governments launched many emergency construction projects to meet the enormous demand for patient quarantine facilities, establishing multiple makeshift hospitals (MHs) (Luo et al., 2020). A makeshift hospital, also referred to as Fangcang hospital or mobile cabin hospital, is a type of emergency service that assembles modular medical units to form a temporary hospital to address the ongoing scarcity of medical supplies. Two examples in China, Huoshenshan hospital and Leishenshan hospitals, built and delivered in 10 days and 18 days, respectively, have proved that the suppression of epidemic outbreaks is made possible by establishing temporary MHs, which are crucial for lifesaving and improving recovery rates (Zhou et al., 2022).

MHs have challenging tasks, intricate specifications, and condensed design and build times. Therefore, building information modeling (BIM) technology is introduced because these criteria present additional difficulties for design work (Tan ey al., 2021). BIM is essential in streamlining coordination by combining organizational and procedural data into a shared repository. According to (Luo et al., 2020), BIM benefits the MH design in three aspects. First, MH design needs significant optimization work by reducing changes during the building phase by visualizing all conflicts. Additionally, designers can use integrated BIM data to speed up construction for parallel scheduling, improving design simulation, like predicting the transmission of viruses in negative pressure wards. Finally, BIM is a platform everyone can use to easily create, exchange, and collect digital data to promote collaboration.

However, some data security concerns still exist in the MH BIM process, causing reworks and time waste, hindering efficiency and productivity. For example, in contrast to general construction projects in which BIM models from various disciplines are created sequentially, models in MHs are made independently and concurrently. When BIM information is synchronized amongst teams, there is a danger of data omission and inconsistency, which eventually leads to design errors because there are no referenced models for the untransparent collaborative environment. Besides, there are no routine meetings for BIM coordination due to time constraints. Instead, a "peer-to-peer (P2P)" communication model is used, wherein project members contact accountable designers directly and personally through virtual meetings or phone calls. However, because it lacks verifiable and traceable records, this method can occasionally be disorganized and ineffectual, making collaboration time-consuming.

Blockchain is a distributed database technology that leverages peer-to-peer networks, cryptographic hash algorithms, and consensus mechanisms to secure data integrity (Tao et al., 2020). The blockchain prevents a single

administrator from controlling the entire network because each peer keeps an identical and append-only data copy (also known as the blockchain ledger). The benefits of blockchain in construction payment (Das et al., 2020), supply chain management (Tezel et al., 2021), and design collaboration (Pradeep et al., 2021) have been preliminarily investigated. However, incorporating blockchain into MHs is still in its infancy for two barriers: (1) The mechanism of embedding blockchain in an MH BIM process is unclear. Problems like which activities need blockchain and what data should be transferred are still awaiting solutions. (2) Key technical elements, like smart contracts supporting blockchain data interaction, have not been developed.

Therefore, this paper proposes a blockchain-enabled collaboration (BEC) framework for fast and secure BIM design. The primary scientific contributions of this paper are: (1) identified three main security risks in the MH BIM design process, (2) proposed a BEC framework to alleviate harms brought by the security issue, thus improving design efficiency, and (3) developed three smart contracts to automate the data exchange in a blockchain. Finally, the framework is demonstrated and evaluated in an actual MH project in Hong Kong.

2. METHODOLOGY

2.1 Identification of BIM security vulnerabilities in MH

Locating the risks is the fundamental step in developing the BEC framework. In this study, one BIM manager and two BIM designers who had a direct hand in an MH project and were familiar with the intricate steps of BIM-based design were interviewed four times each. Data collection took place over one month in 2022, from March to April. A BIM collaborative design workflow is in Figure 1.
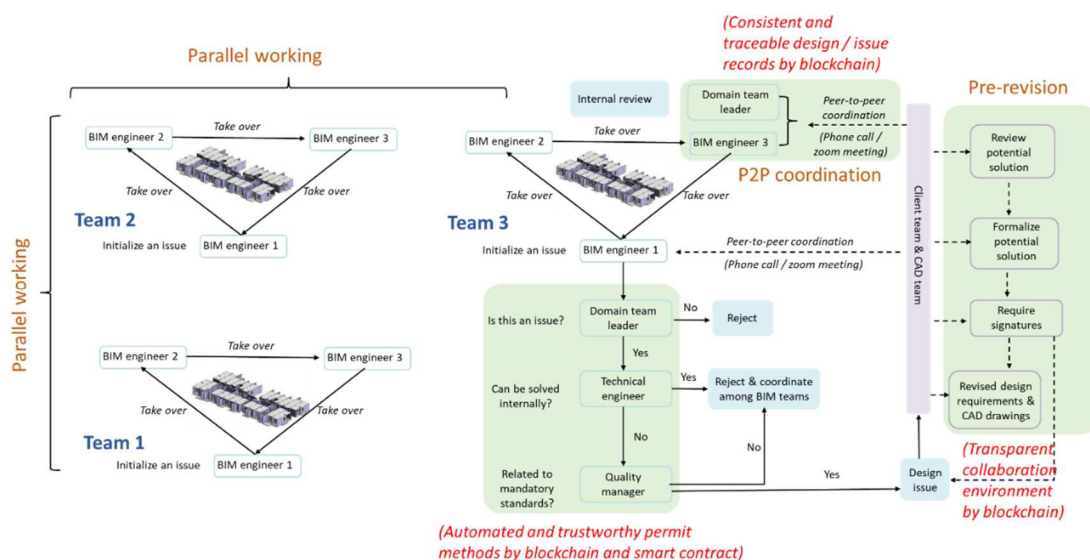

Fig. 1: BIM-based design workflow in MH

Three factors account for how the workflow quickens the BIM design process. The parallel design is the first benefit. Several models are produced simultaneously in this MCH project, reducing time compared to normal construction projects in which BIM models from several disciplines are developed sequentially. P2P communication is the second advantage. There are no scheduled meetings for BIM coordination because of scheduling constraints. Instead, a P2P communication model is used, in which accountable designers are contacted directly and personally by project members during virtual meetings or phone calls when design issues arise. This is an effective method for facilitating communication since it prevents pointless meetings and enables responsible individuals to identify design concerns promptly. Pre-revision refers to addressing design or BIM model issues before the client issues formally amended drawings or documentation, saving waiting time. Content marked green in Figure 1 indicates the steps that can be improved by blockchain.

However, security flaws are also caused by such unique collaboration methods. The risks and merits provided by blockchain are presented in Figure 2. For parallel work, the absence of a visible path for updating information causes differences across models, mistakes in design, and even delays. Blockchain guarantees data transparency and consistency thanks to its distributed architecture. In the course of the discussion, the BIM manager bemoaned

the fact that they frequently wasted time looking up design records to identify problems because ECPs lacked adequate logging facilities, leaving out certain previous data. Additionally, several designers collaborate to develop a model in a "relay race" fashion, with each team member finishing a section of the model in turn. The designer contacted during the P2P collaboration may not be aware of the specifics of the issue if they recently took over the contract from another designer (the issue proposer). All design logs and actions can be immutably recorded using blockchain to improve collaboration traceability.
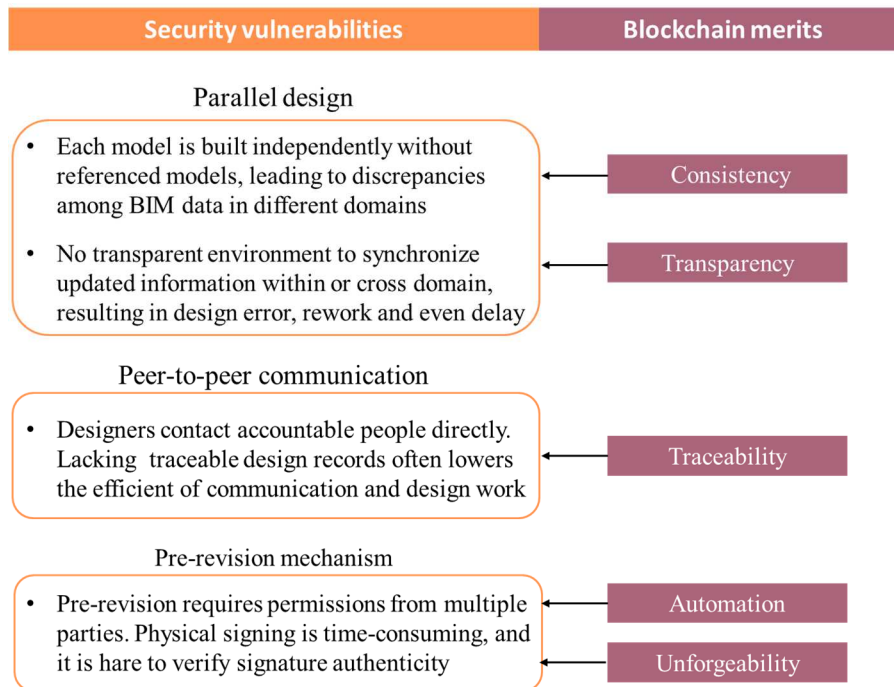

Fig. 2: Blockchain merits in MH

2.2 Blockchain-enabled collaboration (BEC) framework

The BEC framework in Figure 3 shows the logic of implementing blockchain in an MH BIM design and offers a technical stack for data flow. The seven-layer architecture serves as an example of the technical stack used to create a BEC framework. Through the application layer, which provides an interface for user management, users in the user layer can sign up for the blockchain. User operations may be documented in the blockchain in this manner. These "one-stop" registration processes make it easier for consumers to use blockchains because they simply need to complete standard registration processes. The interaction between the front-end inputs and the blockchain databases on the backend is carried out through smart contracts at the smart contract layer. Blockchain smart contracts, machine-readable pieces of code, can self-execute business logic (e.g., payment) on blockchain ledgers, thus empowering automatic and unforgeable collaboration actions (Li et al., 2022). Event transactions will represent collaboration actions, such as permission transactions (metadata of permission execution), issue event transactions, and model event transactions (metadata of events pertaining to BIM models). Large-sized data like BIM models and non-graphic documents are also stored in off-chain databases, which can be local servers or cloud servers like Autodesk BIM 360. This is in addition to on-chain data (transactions). This layer has a digital signature generator that generates digital signatures using the 256-bit secure hash technique (SHA-256). These fingerprints are spread across the blockchain network. The infrastructure layer serves as the foundation and provides necessary services, including cloud data storage, operating systems, and hardware (e.g., GPU and CPU).
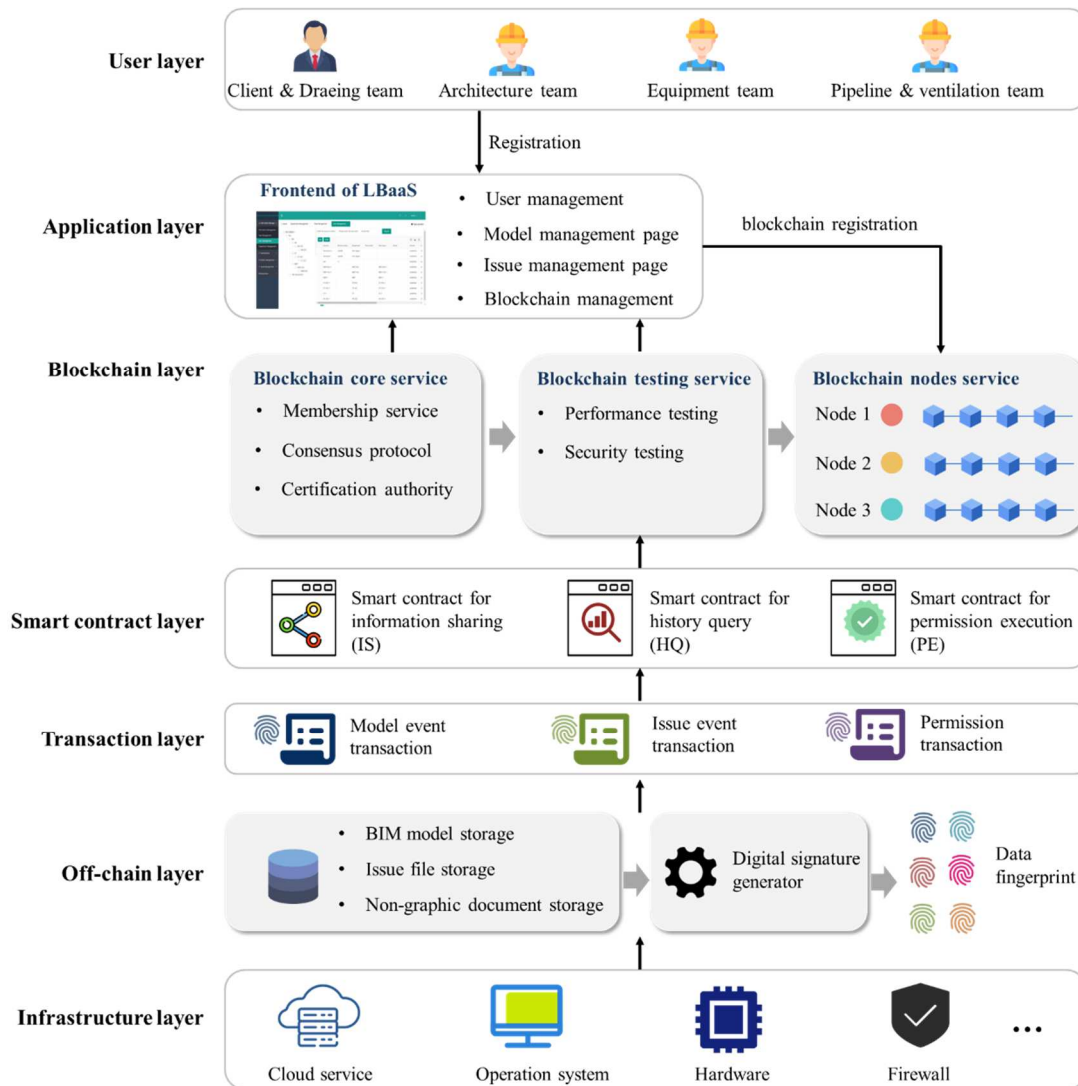
Fig. 3: Architecture of BEC framework

2.3 Smart contracts for BIM data interaction

In the BEC framework, three smart contracts have been coded. The pseudocodes are shown in Figure 4. A transaction comprising the model ID, fingerprint, user ID, and timestamp will be transmitted to the IS (information sharing) smart contract whenever a user uploads a new model (or issue). An endorsing node will verify this transaction by examining the legality of the transaction (Step 1). Illegal transactions will be denied, or they can go through and be sent back to the smart contract with endorsing signatures. An example of an illegal transaction would be one where the transaction data model is not required to follow a key-value structure (Step 2). In Step 3, the smart contract hands the transaction off to an ordering service that will chronologically group the transactions that occurred within the specified time into a new block. All blockchain nodes will receive it through the smart contract, and upon obtaining it, they will verify the block (Steps 4 and 5). The ledger will be updated with confirmed blocks as immutable records.

The rationale behind PE (permission execution) smart contracts is similar. One distinction is the smart contract input, and the other is the status results. After reviewing an issue, a project member (such as a domain manager) can decide. An endorsing peer will receive a new transaction from the PE smart contract along with all essential metadata (such as issue ID, issue decision, reviewer comments, etc.) so they can verify that the input complies with the regulated data model. Then, the project member will update the blockchain world state, a database that displays the most current status of various files and is built on top of the blockchain ledger. Besides, the PE smart contract creates and stores the digital signatures of the user to ensure the integrity of outcomes, saving time by doing away with the laborious physical permit process. The HQ (history query) smart contract will retrieve previous transactions (e.g., file ID) based on the provided key.

	Pseudocode of information sharing (IS) smart contract
1	**Input:** IS transaction data, IS function
2	**Output:** New block in blockchain
3	**Step 1:** IS function proposes the transaction for legality checking
4	*if input data model = pre-defined IS data model*
5	*Function name = IS*
6	*generate endorser signatures*
7	*else*
8	*validation fails*
9	**Step 2:** Get back endorsing signature
10	*return pre-execution results ← transaction data‖read-set‖write-set‖signatures*
11	**Step 3:** Sent to ordering service for new block packing
12	*new block ← pre-execution results‖block hashes‖Merkle tree‖timestamp*
13	**Step 4:** Broadcast the new block to all nodes
14	**Step 5:** Verify and add to ledger
15	*if validation results = true*
16	*return new block ← block number "N+1"*
17	*notification message ← "Transaction has been successfully shared"*
18	*else*
19	*IS transaction sharing fails*
20	**Step 6:** Notification
21	**End**

	Pseudocode of permission execution (PE) smart contract
1	**Input:** PE transaction data, decision, PE function
2	**Output:** New block in blockchain, issue status change
3	**Step 1:** PE function proposes the transaction for legality checking
4	*if input data model = pre-defined PE data model*
5	*Function name = PE*
6	*generate endorser signatures*
7	*else*
8	*validation fails*
9	**Step 2:** Get back endorsing signature
10	*return pre-execution results ← transaction data‖read-set‖write-set‖signatures*
11	**Step 3:** Sent to ordering service for new block packing
12	*new block ← pre-execution results‖block hashes‖Merkle tree‖timestamp*
13	**Step 4:** Broadcast the new block to all nodes
14	**Step 5:** Verify and add to ledger
15	*if validation results = true*
16	*return new block ← block number "N+1"*
17	*notification message ← "Transaction has been successfully shared"*
18	*New issue status ← reviewer ID‖decision*
19	*else*
20	*PE transaction sharing fails*
21	**Step 6:** Notification
22	**End**

	Pseudocode of history query (HQ) smart contract
1	**Input:** Target file ID, HQ function
2	**Output:** Transactions details of a given ID
3	**Step 1:** HQ function checks if the given ID exists in blockchain
4	*if ID exists*
5	*query results ← transaction value of this given ID*
6	*else*
7	*reject the query*
8	**End**

Fig. 3: Architecture of BEC framework

3. VALIDATION AND EVALUATION

3.1 Validation scenario

The roadmap for the validation scenario, which aims to confirm the viability of the smart contract and the authorization workflow, is shown in Figure 5. The AR-01 presents a concern regarding the current window size of a medical block, which is 600*1200mm, although the standard suggests a 900*1200mm window. The problem is then generated, along with a design document, for review. The domain team leader AR-0 reviews the issue detail and approves it with the remark that "this is an issue." The technical engineer (TE-1) notes that this problem cannot be resolved internally and requires the client's additional input. The quality manager (QM-1) approves this issue because it relates to requirements that should be accepted by the client and drawing team. All these permissions are carried out by calling the PE smart contract. Results indicate that every authorization action was carried out

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automatically and stored in the blockchain. Each transaction records the following information: (1) the user ID executing the action, (2) the judgments (in this case, "approved") made by various users, and (3) the precise remarks made by various parties.
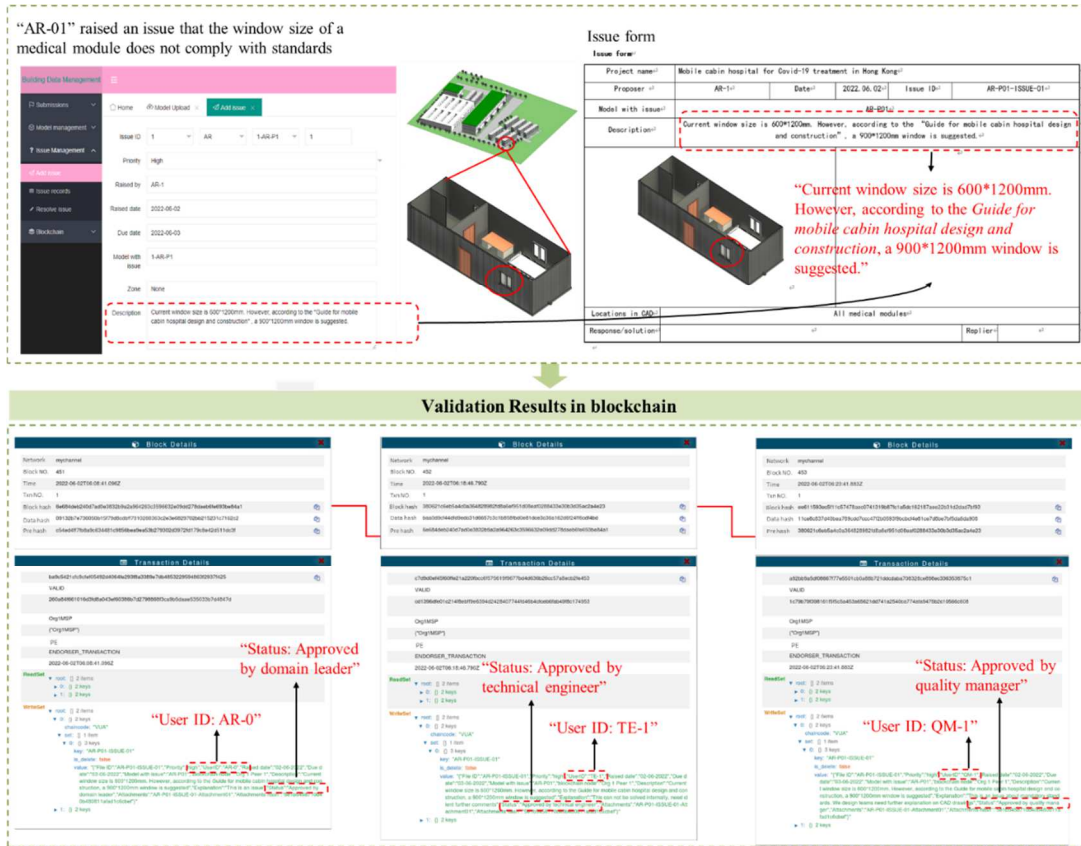

Fig. 5: Framework validation in a BIM permission execution scenario

3.2   Framework evaluation

The evaluation includes two parts. The first is BEC computing performance testing, aiming to see if the proposed framework meets the basic data processing requirements. High latency, like what is in the Bitcoin blockchain, is not acceptable in construction design. The second is a comparison evaluation to test if the BEC framework advances existing BIM solutions regarding design efficiency.

Blockchain latency measures the time required for a smart contract to register a transaction in the blockchain (Ciotta et al., 2021). To determine whether a blockchain's "speed" meets business needs, latency is a crucial statistic in the evaluation process. In MHs where rapid information sharing is required, high latency is problematic. The latency of three smart contracts is measured in this research. To prevent abnormal findings, the repeated test is run ten times. The results in Figure 6 demonstrate that all latency is millisecond-level. No latency standard has been established in construction, because the blockchain is currently being built. Consumers won't notice the delay if the blockchain application's maximum reaction time is less than 1 second, according to Fatokun (2021). Recommendations and best practices from studies (Sheng et al., 2020; Tao et al., 2021) state that millisecond-level blockchain latency is acceptable for design and construction procedures. The BEC framework latency is, therefore, permissible.

The quantitative analysis of how automated smart contracts in the BEC framework could promote efficiency is shown in Figure 7. Three project participants from the MH project—one BIM manager and two designers—were requested to conduct a BIM design coordination case in both the current BIM 360 platform and the prototype based on the BEC framework. Because the BEC framework employs a workflow like current practice, the time investment in the initial model change is the same (30 mins). The model adjustment required the design team to review previous data. The retrieval of a CAD drawing's change history took 11 minutes due to inadequate traceability in traditional solutions. The BIM team only spent 3 minutes identifying all BEC framework traceable blockchain ledger records thanks to the HQ smart contract. Both solutions required P2P collaboration and took 8

minutes. The team leader had to sign a design sheet before it could be pre-revised. The current method required 10 minutes to obtain a physical signature (including the waiting time). In contrast, calling the PE smart contract in BEC took 6 minutes. The BIM team also had to do extra work since they missed a supplier update because they were working on a different system; as a result, they had to spend an additional 10 minutes using existing solutions to fix the problem. Finally, by utilizing BEC and smart contracts (72 min in total), 23% of the time was reduced compared to the current solution (94 mins in total)
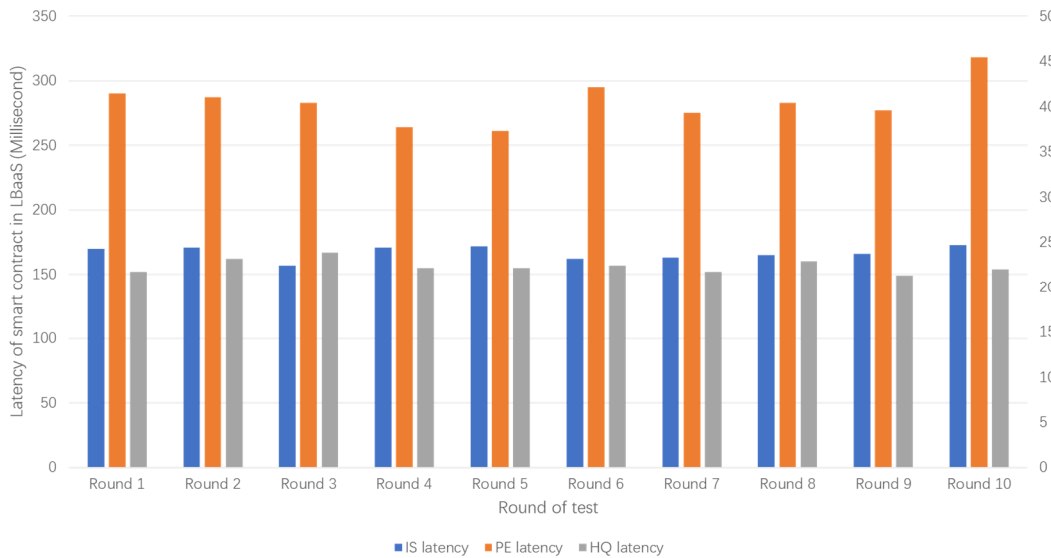
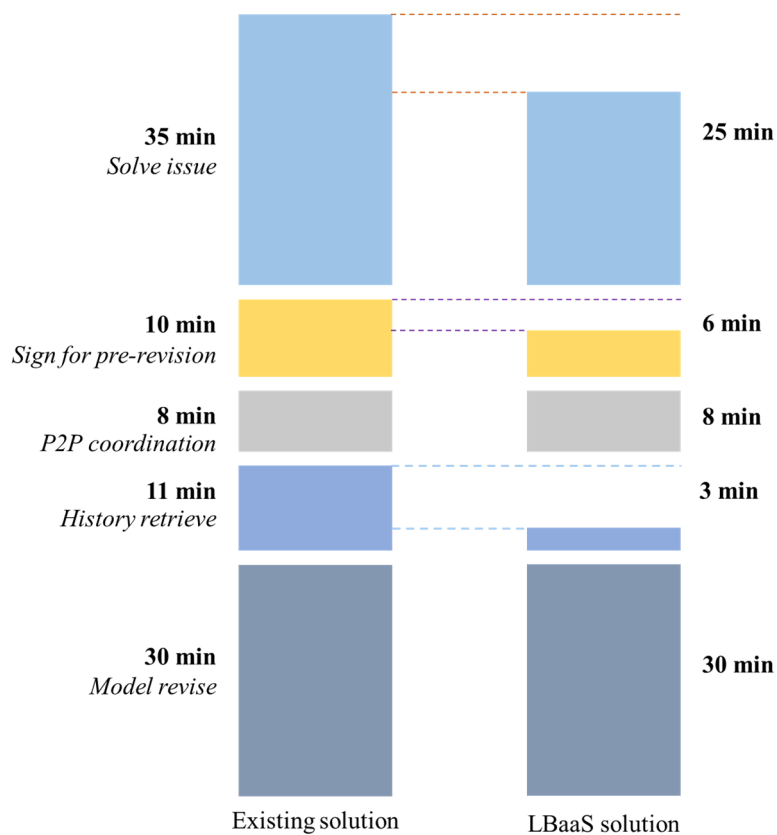

Fig. 6: Latency of BEC framework

Fig. 7: Comparison results of a BIM coordination scenario

4. CONCLUSION

BIM-based design in MHs risks data security issues that will impair job productivity due to stringent time constraints and complex design processes. Therefore, this study proposes a BEC framework to increase the design efficiency of ECPs while lowering the obstacles to accessing blockchain benefits. Three objectives have been achieved. Firstly, through interviewing BIM participants from an MH project, three risks, namely, lacking transparency, lacking traceability, and lacking permission automation, that will harm the design process are identified. Secondly, a BEC framework is presented to show the technical architecture to guide the data exchange and BEC prototype development. Third, three smart contracts are developed for secure information sharing, permission execution, and historical data query. Due to time and technological limits, there are still restrictions on this early exploration. Non-automatic data verification comes first. The blockchain ledger generates and records data fingerprints. The verification procedure is still manual, though. Further research is still required on automatically comparing a file with its fingerprint.

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