A BLOCKCHAIN-BASED SECURE SUBMISSION MANAGEMENT FRAMEWORK FOR DESIGN AND CONSTRUCTION PHASES

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ABSTRACT: *AEC projects generate numerous versions of BIM models during the design and construction phases. This process is complicated by the sheer number of domains in large projects and the interlinkage of BIM deliverables (for example the structural BIM model follows the corresponding architectural BIM model). However, due to the generation of multiple versions and parallel design progress in different domains (especially in large projects), multi-domain delivery teams often fail to access and comply with the latest/required/approved design requirements during the progression of the design phase and complete issue addressing during the construction phase, which creates confusion, may lead to disputes. Moreover, due to the contractual nature of the parties involved data and process security is also very important. Therefore, this research presents blockchain-based secure coordination workflows for effective collaboration, parallel design progress, and issue management among BIM developers from multiple domains. Smart contract logic for facilitating dynamic dependency logic for coordinating linked multi-domain submission over the project timeline is presented. A method to ensure that issues are completely, and timely addressed, and related parties are held accountable for their actions or non-response is presented by integrating a BIM change identifier and blockchain in typical issue management workflows. The method considers collaborative design and issue management workflows for the secure, efficient, and complete design of BIM models. The method is validated using an ongoing large construction project in Hong Kong.*

KEYWORDS: *Version Management, Issue Management, Security, Blockchain.*

1. INTRODUCTION

Construction projects generate huge amounts of digital information that requires sharing among stakeholders from different construction domains during the design, construction, and operation phases. It is well established that effective building data management strategies (including rules, programs, and practices) integrated with a Common Data Environment (CDE) is recommended to streamline coordination among project partners to ensure project success. However, the existing CDEs are faced with several error-inducing methods/gaps that cannot prevent incomplete BIM model delivery during the design and construction phases or hold the responsible stakeholders accountable for their actions. In particular, the first problem in existing CDEs is the lack of secure (in terms of accountability) and automated coordination methods in multi-domain delivery teams – Construction projects especially during the design phase generate a large number of BIM model versions. This process is complicated by a large number of domains in large projects and their interlinkage in submission management. For example, it is a regular practice to design structural models (the dependent model in this case) based on the latest or approved architectural model (the leading model in this case). Similarly, MEP (Mechanical, Electrical, and Plumbing) models are designed based on both architectural and structural models. However, due to parallel design progress that creates multiple versions in each domain, multi-domain delivery teams often fail to access and comply with the latest/required/approved design requirements during the progression of the design phase which creates confusion, causing incomplete deliveries and resulting in disputes between the delivery teams. Therefore, methods to facilitate automated coordination of multi-domain submission management and ensure accountability of delivery teams are necessary. The second problem in existing CDEs is the lack of methods to automatically check the completeness of BIM deliverables and to ensure accountability of stakeholder actions during the construction phase. The construction phase is more complex in comparison to the design phase due to the involvement of real-time data, time-bound tasks, and the addition of new stakeholders such as sub-contractors from multiple domains. In big projects, a large number of issues may be generated for reviewing, resolution, and approval by multiple stakeholders. Hence integrating automatic delivery completeness checker and stakeholder accountability in the traditional issue management workflow is desirable. Some existing CDEs facilitate issue resolution workflows with options for manual coordination. However, this may not be efficient in large projects involving hundreds of issues and stakeholders. In addition, the existing CDEs lack robust and secure methods to ensure stakeholder accountability.

A BIM-based issue management approach that incorporates the integration of issue management with other BIM processes such as design coordination was proposed (Wang & Wang, 2020). Jaly-Zada et al. (2015) extended the IFC schema to record a history of changes. A graph-based approach (Moayeri et al., 2017) was investigated to

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capture the ripple effects of BIM version change. Jiao et al. (2013) developed a version update identifier at a BIM-object level to track changes and assign accountability for version change. Commercial and open-source applications such as Autodesk BIM 360 (Autodesk), Newforma BIM Track (Newforma, 2021), and Kubus IFC viewer (Kubus, 2022) have also deployed version and issue management for BIM deliverables. However, the existing approaches lack methods to accommodate submission dependency and completeness-related requirements in the traditional version management and issue management workflows.

Therefore, a "Blockchain-based Secure Submission Management Framework" is presented that captures information from Open BIM models using the IFC format, documents, stakeholder actions, and automated methods and integrates them with blockchain to facilitate stakeholder accountability. The framework includes – (1) a Blockchain-based Dynamic Dependency Workflow to facilitate coordination and stakeholder accountability in large projects with dynamic interlinkage among submissions from different domains and (2) a Blockchain-based Completeness Checking Issue Management Workflow to facilitate automatic checking for faster/efficient issue resolution. To realize this framework, the existing IFC schema was extended to include version and issue-related information. An entity to store blockchain transactions was also created in the extended IFC schema to integrate IFC models with block-chained information. Blockchain smart contracts and ledger data models were developed to irreversibly record stakeholder actions during the version management and issue management phases. An efficient BIM change identifier method was developed using the BIM-segmentation and hashing method to efficiently parse and identify changes between two BIM models. This method was integrated into the traditional issue management workflow to automatically check whether all the issues related to a BIM deliverable were addressed or not. A prototype for the proposed framework was developed using the Hyperledger Blockchain Platform (Hyperledger, 2020) and was tested in an ongoing project in Hong Kong.

The remainder of this paper is organized as follows: Section 2 presents the methodology of the proposed framework. The framework validation scenario and results are discussed in Section 3. The paper is concluded in Section 4.

2. METHODOLOGY

This section describes the methodology used to facilitate secure versioning and issue management in construction projects. As shown in Figure 1, the framework consists of three modules – (1) version management module and (2) issue management module that connects to a blockchain layer. These modules are discussed as follows:

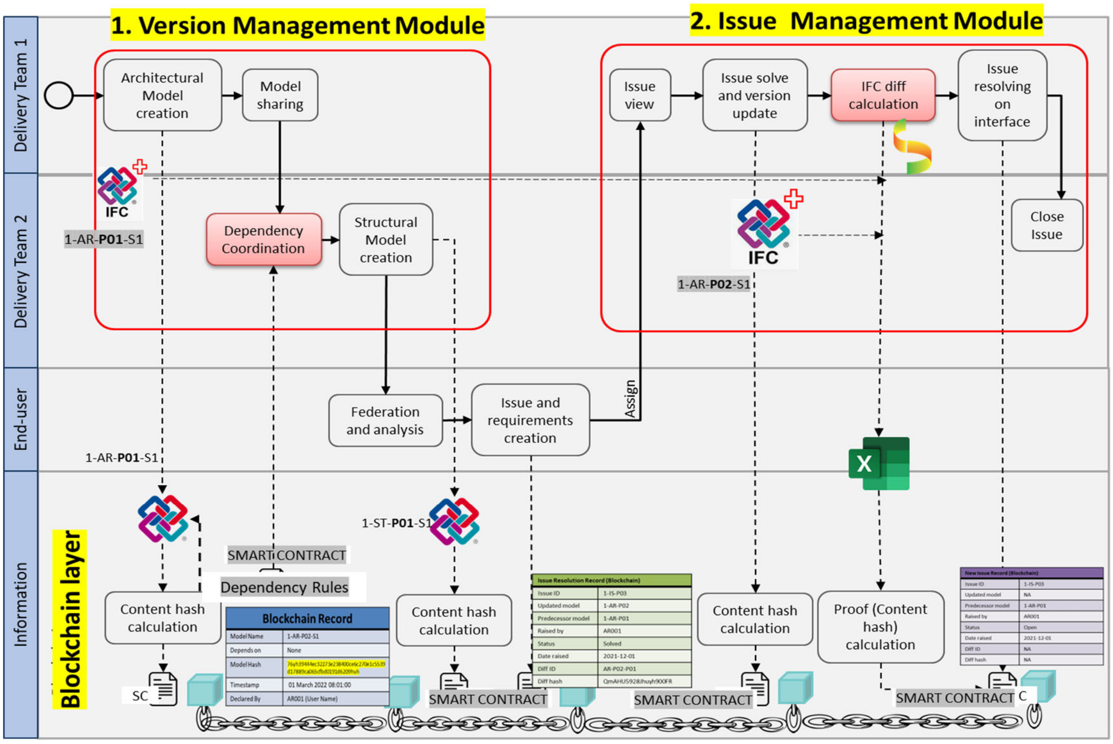


Figure 1 Methodology using Open BIM (IFC) for secure, complete, and coordinated Submission Management

2.1 Blockchain-based Version Management Module

This module manages and coordinates submission management considering versions and dependencies from different domains in an AEC project. AEC project submissions have dependencies on each other. For example, the submissions from the MEP (Mechanical, Electrical, and Plumbing) domain are dependent on the structural and architectural model of a building in general. This means the delivery team of the MEP model should ensure that they are using the latest/approved version of the architectural and structural models. Figure 2 shows some examples of dependency rules identified from a large ongoing project in Hong Kong. However, due to many versions generated during the design phase in each domain, the project stakeholders often fail to follow the latest/approved/assigned versions of the leading models. In this case, a dispute may happen between the leading and the dependent delivery teams causing a delay to the entire project schedule. Therefore, a method including IFC extension and smart contract logic was created to ensure that the dependent parties download the latest/approved/assigned leading model before they can submit their own models. Along with this checking, this action is also recorded in the blockchain to facilitate accountability of the leading and dependent parties at a later stage. Figure 3 shows the extended IFC schema which stores information such as Model name (includes domain name) and version number. An entity to store a blockchain transaction is also added in the extended IFC, called "TnxID" as shown in Figure 3, to link IFC models with blockchain ledgers.

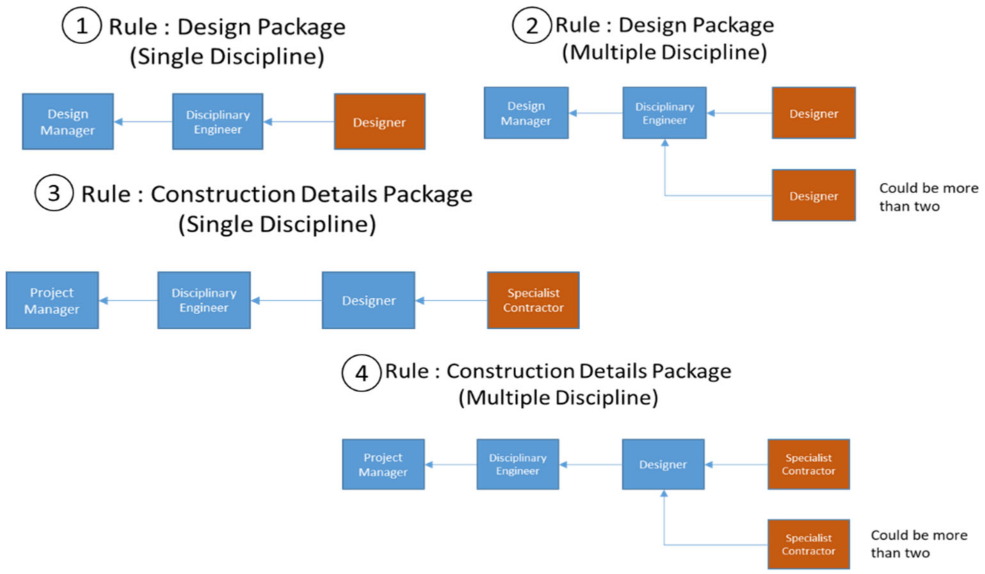


Figure 2 Example of submission dependency rules in AEC projects

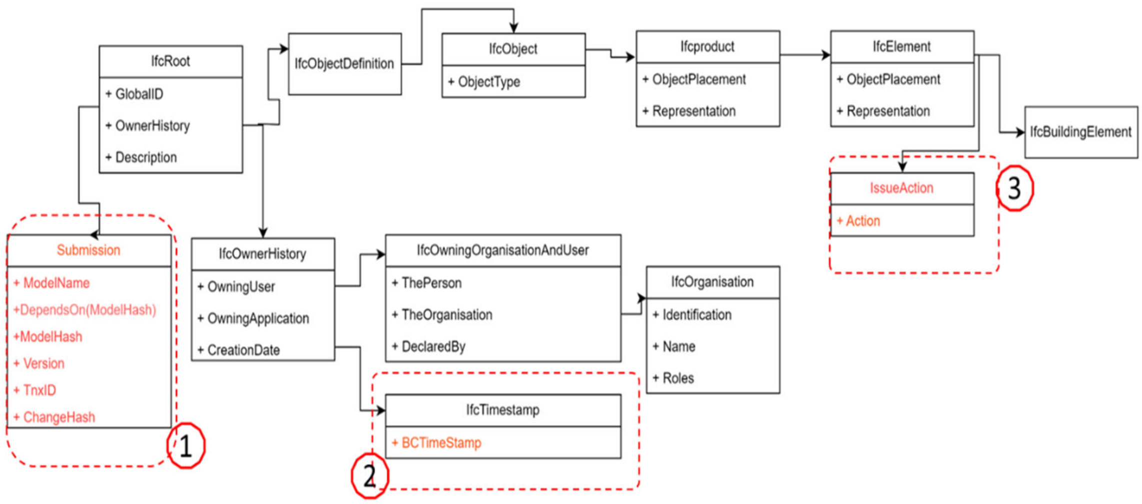


Figure 3 Extended IFC Schema for submission Management

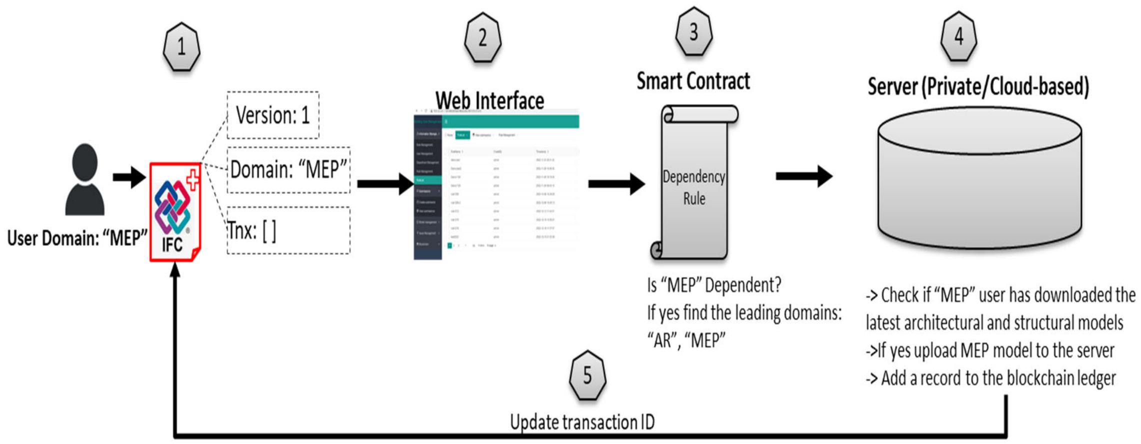


Figure 4 Methodology for Dependency Checking by the Version Management Module

As shown in Figure 4, dependency checking is performed by the version management module in four steps – (1) populating the IFC to be submitted with information such as version number and domain name, (2) submitting via a web interface, (3) invoking blockchain smart contract containing the dependency rule, (4) checking if the corresponding leading models were downloaded, (5) adding a record to blockchain ledger (Figure 5 (a)) and updating the uploaded model with a transaction ID.

Version Record	
Model Name	1-MEP-P02-S1
Depends on	1-AR-P02-S1
Model Hash	76yh39444ec32273e238400ce6c270e1c5539d17889ca065cfbd0191d6209huh
Timestamp	01 March 2022 08:01:00
Declared By	MEP001 (User Name)

(a)

Issue Resolution Record	
Issue ID	1-IS-P03
Updated model	1-AR-P02
Predecessor model	1-AR-P01
Raised by	AR001
Status	Solved
Date raised	2021-12-01
Diff ID	AR-P02-P01
Diff hash	QmAHU5928Jhuyh900FR

(b)

New Issue Record	
Issue ID	1-IS-P03
Updated model	NA
Predecessor model	1-AR-P01
Raised by	AR001
Status	Open
Date raised	2021-12-01
Diff ID	NA
Diff hash	NA

(c)

Figure 5 Blockchain Data Models for Version Management and Issue Management

2.2 Blockchain-based Issue Management Module

As shown in Figure 1, a workflow was developed to integrate issue management logic with OpenBIM and Blockchain to ensure issue resolution completeness and accountability. This workflow links project issues, stakeholders (Responsible, Accountable, Consulted, and Informed Parties), IFC-based change identifiers in BIM models, and blockchain.

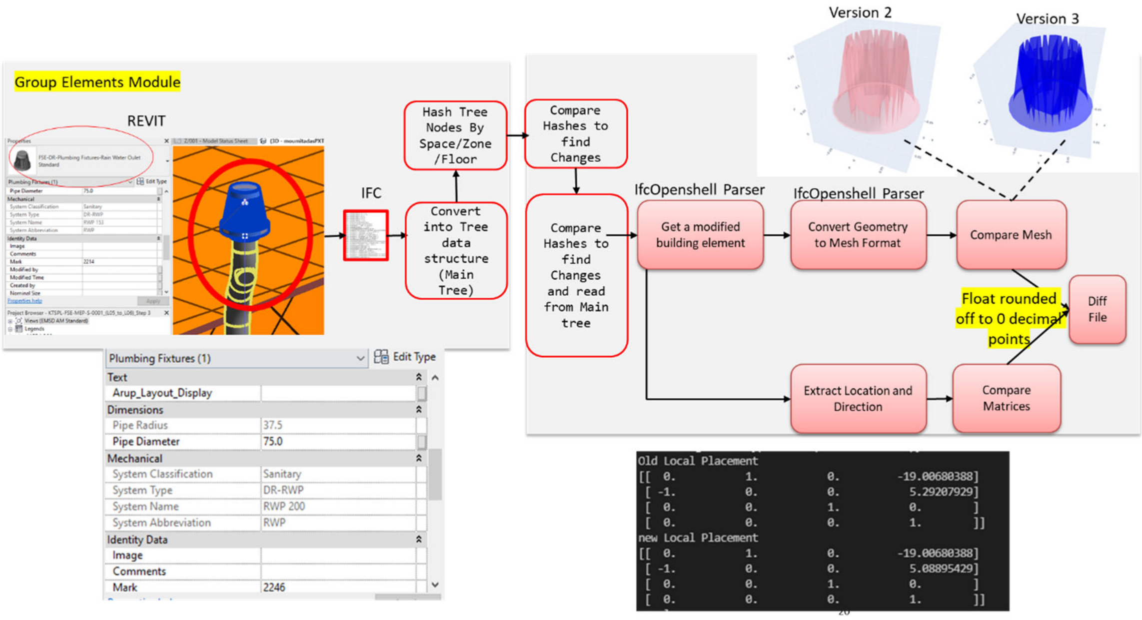


Figure 6 Methodology of the BIM Change Identifier (Diff) Module using OpenBIM and Hash-based Segmenting.

As shown in Figure 1, a BIM change identifier (called Ifcdiff module) is developed and integrated in the issue management workflow, OpenBIM has been used to integrate (interoperability properties) a BIM model change identifier (Diff) and blockchain with a traditional issue management workflow. Figure 4 shows the methodology of the diff which involves – (a) parsing the IFC models, (b) converting it into a tree-like data structure (using OpenShell)-called the main tree, (c) compressing the tree element-wise, space-wise, and zone-wise (as per user input) into a hash-based tree data structure, (d) comparing between BIM versions using the hash-based tree and identifying differences between hashes, (e) extracting the details of the changed elements for fine-grained comparison for geometry, location, and properties, (f) converting element shapes into a mesh data structure and perform mesh comparison to identify the change in geometry, (g) compare location and direction matrices to identify changes in the position of elements, (h) excel-based report generation recording the changes (addition, deletion, and modification based on IFC guides) for manual and automated review, and (i) recording of proof the diff file and issue status on the blockchain (as shown in Figure 5(b)).

The workflow facilitates automated checking of issue resolution using the openBIM-based Diff logic. End users such as issue creators can mark the building elements (using IFC *Global IDs*) (using the IFC extension as shown in Figure 3), which are to be added/modified/deleted as per the issue resolution process. The workflow automatically updates the issue status as incomplete if all the issues are not resolved and send a notification to the issue creator for manual review and override if desired. As shown in Figure 1, the issue creation and resolution are recorded on the blockchain for accountability.

3. VALIDATION

For validation a prototype was A prototype was developed and tested. Python and Openshell (IfcOpenShell, 2022) are used to develop the diff algorithm, which is used to detect model changes that should be tracked and blockchained. Hyperledger Fabric serves as the blockchain platform to immutably and traceably record BIM coordination, delivery, and operation actions. This platform provides a secure and scalable way to manage BIM data, enabling efficient collaboration between different stakeholders. It also provides a transparent and secure way to manage BIM data, ensuring that project progress is monitored and tracked effectively.

The dynamic dependency logic and the blockchain interface and tested for versioning in the Kai Tak Sports Park (KTSP) Project. The project has over 40 domains up to March 2023 which created at an average of 200-300 versions per fortnight from the entire project. This required complex dynamic rule generation for linking submissions and managing their versioning. The prototype was tested and found to be effective in the management of multi-domain submission management for the KTSP project. The end users found the platform to have the following value additions – (a) team members are sure about the model status (because of blockchained single source of truth), (b) team members are sure if the submissions have followed the correct dependency and version for model delivery for a milestone/review, (c) accountability of delivery teams to prepare deliverable with the correct information is added.

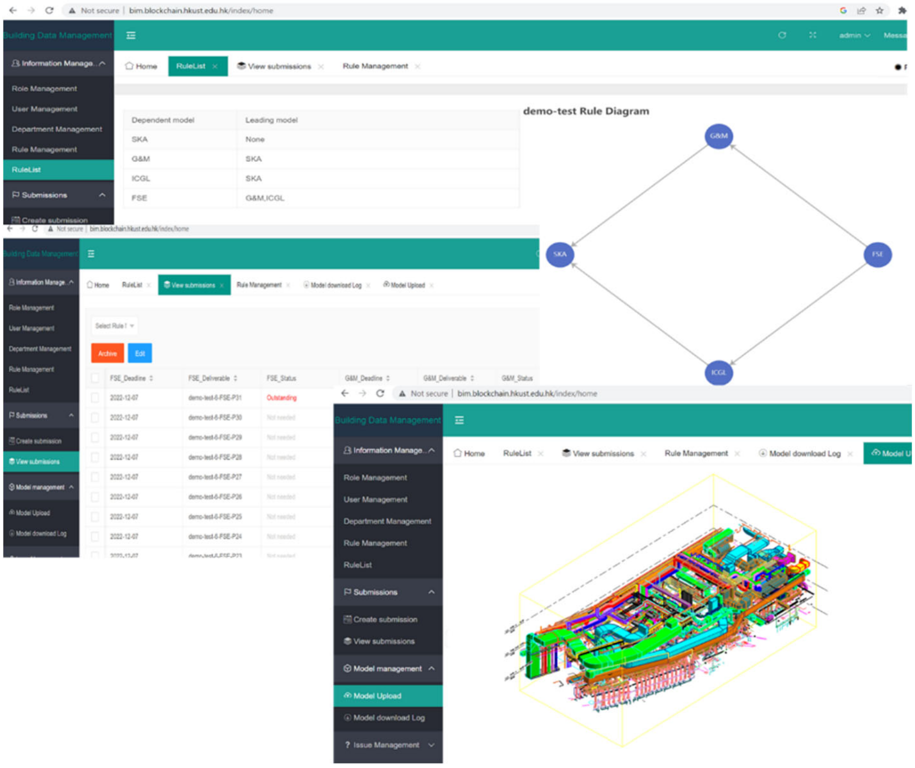
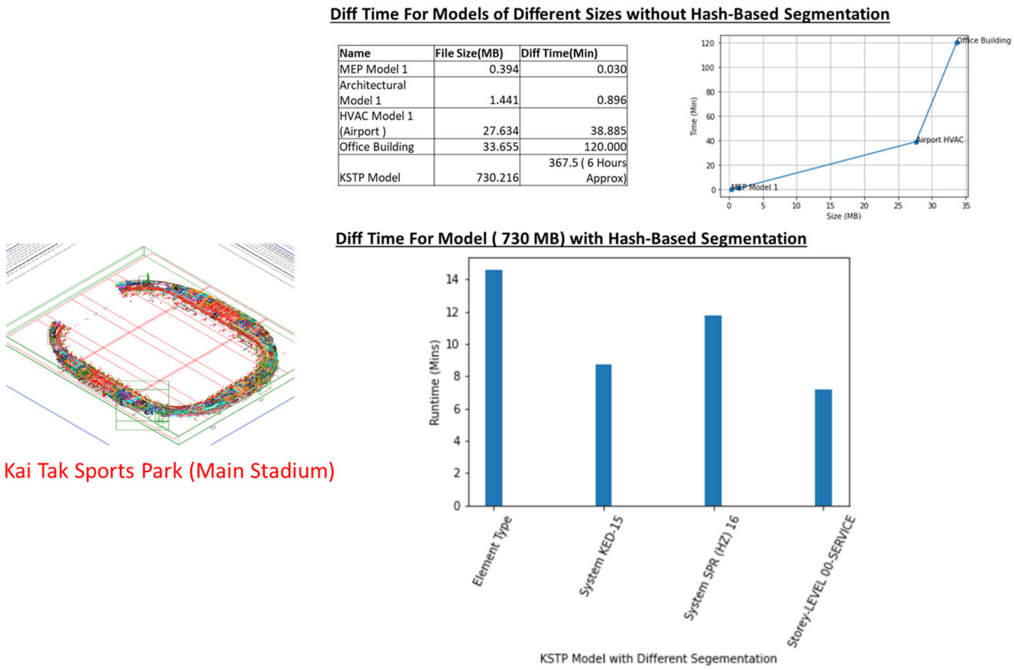


Figure 7 Prototype Web-interface Showing Dynamic Rule Creation and BIM Visualisation

Figure 8 shows that the BIM change identifier was evaluated on models ranging from sizes 0.3 MB to 730 MB. It can be seen that there is a linear rise in the computation time of the diff program with increasing file size. As described in the methodology section, the diff logic uses a hash-tree-based data structure that segments the BIM model and facilitates comparison for a faster computation time. Figure 8 shows the results of hash-tree based segmentation on a model sized 730 GB. This method is particularly efficient in identifying small changes (such as a few modifications on a particular element type or floor) in large BIM models. The prototype is also being tested on the ongoing KTSP project. The end users have so far evaluated the platform as – the actions of all parties are blockchained which will be useful to hold parties accountable if the need arises. They have also stated that a confident audit trail record will be created, that will help resolution of future disputes or remeasurement of works upon quantifying and monetizing additional works variations.



Name	File Size(MB)	Diff Time(Min)
MEP Model 1	0.394	0.030
Architectural Model 1	1.441	0.896
HVAC Model 1 (Airport)	27.634	38.885
Office Building	33.655	120.000
KSTP Model	730.216	367.5 (6 Hours Approx)

Figure 8 Validation of the Diff Module of the Issue Management Workflow

4. CONCLUSION

A blockchain-based framework for version and issue management was presented in this paper. With the advent of digitization and the inherent contractual organizational structure in the construction industry, data security, integration, and stakeholder accountability has become very important. This is more important, especially in BIM projects which contain sensitive information and are difficult to manage in a multi-data owner environment. Therefore, the proposed framework includes - (1) Blockchain-based Dynamic Dependency Workflow and (2) Blockchain-based Completeness Checking Issue Management Workflow to facilitate integration and accountability in large-scale construction projects. For validation, a prototype was developed and implemented on an ongoing Hong Kong based project with real end users. The framework was found useful in terms of security and functionality by the end users including representing a single source of truth, maintaining version dependency, and completing outstanding issues.

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