Protecting BIM Design Intellectual Property with Blockchain: Review and Framework

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Abstract
Building Information Modelling (BIM) makes construction workflows more agile and allows for easier data reuse. This change has been largely beneficial for designers to save time and resources during the design phase or introduce changes during the construction phase. However, during a construction project lifecycle, designs files change hands frequently, which increases the chances for design leaks and copyright infringement. Several studies have introduced Blockchain as a tool to improve digital ownership and Intellectual Property management. This study reviews the literature where Blockchain was used for developing Intellectual Property management tools. The study also provides a framework for protecting the Intellectual Property of BIM design using Blockchain technology. The framework used a combination of distributed ledger and distributed storage in the Hyperledger environment to achieve improved secured data exchange, which would reduce data leaks and unauthorised use of BIM assets.

Keywords: BIM, Intellectual Property, Blockchain, Construction Design

1 Introduction

Since the advent of BIM, synergies with other technologies have emerged to provide further utility. Technologies like the Internet of Things (IoT), Virtual Reality (VR), Augmented (AR), Big Data and recently Blockchain have been used along with BIM to provide additional features for different stakeholders.

Blockchain was introduced as a tool to protect Intellectual Property in several fields due to its ability to preserve digital value. Recent studies from fields such as digital literature publishing (Chi et al., 2020, Gipp et al., 2017), Digital art and photography (O'Dwyer, 2020, Bhowmik et al., 2018, Dong and Ieee, 2018), 3D printing (Engelmann et al., 2018, Holland et al., 2017, Holland et al., 2018, Klockner et al., 2020, Kurpjuweit et al., 2019), GMO (Stazi, 2020), Intellectual Property management (Modic et al., 2019, Chen et al., 2020) and architectural design (Adibfar et al., 2020, Dounas et al., 2020) have discussed Blockchain as a solution to protect owner's rights in digital environments.

This study proposes a Blockchain-based framework to allow architecture design owner entities or individuals to register their designs on a distributed ledger to preserve their designs' ownership.

The study objectives are (1) present the concept of intellectual protection for BIM assets; (2) present the scenarios for adoption based on the goal of adopting Blockchain; (3) presentation of a framework for BIM design Intellectual Property protection using Blockchain technology. The article aims to shed light on intellectual property in the BIM environment and explore the possibility and cases where Blockchain can improve BIM content management.

2 Literature review

2.1 Overview

Blockchain uses the distributed ledger technology to store data in the form of blocks, which makes records immutable and distributes them across the nodes of a network providing secure, permanent references for interested parties (Puthal et al., 2018). Bitcoin is the first running example of public Blockchains, which uses a distributed ledger to mint and exchange its own digital currency (Nakamoto, 2008). Ethereum is the first smart contracts platform that utilises Blockchain to execute smart contracts and store them on a Blockchain. The Ethereum project allowed businesses and individuals to realise the potential of Blockchain in business logic applications (Buterin, 2013). Indeed, multiple projects have since built business logic for specific purposes to take advantage of the technology.

This section is divided into two parts: (1) Blockchain studies in the construction industry; (2) studies where Blockchain was introduced as an Intellectual Property management tool beyond the construction industry.

2.2 Blockchain and BIM

A study by Darabseh and Martins (2020) recognises the growing interest in Blockchain and its applications in construction. Only two publications were found in 2017, and forty existed by the end of 2019. Blockchain deals mainly with data, and the construction industry is a data-intensive industry; better control over construction project data will improve projects overall performance. A summary of the recent development in the field is provided in this section.

Blockchain and AECO (Architecture, Engineering, Construction, and Operation) industry related studies cover a wide range of use-cases. A notable synergy in the industry has been identified between BIM and Blockchain, as Blockchain is presented as a BIM data governance layer (Liu et al., 2019). Safa et al. (2019) claim that BIM with Blockchain will make assets ownership unambiguous. Nawari and Ravindran (2019) find that Blockchain can improve construction claims, information requesting, versioning, and tracking processes. Also, Liu et al. (2019) argue that Blockchain can improve the construction design process by improving team's collaboration and reducing cyber threats in the BIM environment.

A digital twin system was developed by Lee et al. (2021) to trace and support information during construction project development. The system used sensors to acquire data from reality and compare it with BIM models in order to generate a compliance statement. The system is composed of two parts: (1) Blockchain, where the system uses Azure cloud platform to run a Hyperledger Blockchain; (2) Unity platform to run a compliance analysis based on the information retrieved from the Blockchain to verify that reality matches the project BIM models. Below, Figure 1 shows the developed system architecture.

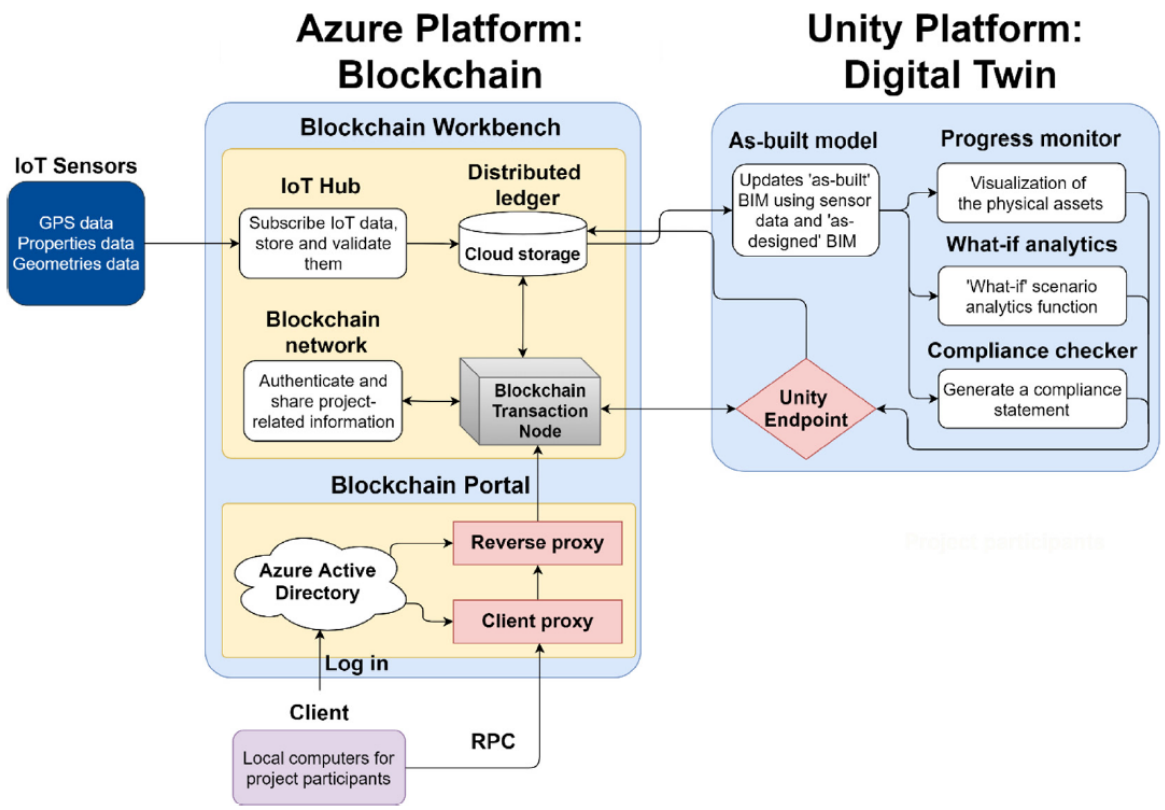

Figure 1 Digital twin using Blockchain system architecture (Lee et al., 2021)

Blockchain and BIM synergy is an organisation level system that requires an advanced infrastructure. Bitcoin Blockchain was designed to serve as a ledger for peer-to-peer cash transactions (Turk and Klinc, 2017). However, construction data requires advanced features and tools to function properly within the construction environment. Zheng et al. (2020) claim that currently, public Blockchains are not organisation friendly. The claim was based on the fact that identities and transactions privacy is solely protected using pseudonyms. Pseudonyms in Blockchain refer to the use of hashes instead of real names of users and processes. In case pseudonyms were used alone in organisation applications, Blockchain can result in exposing sensitive information in case a hash gets linked to a user or process (Sun Yin et al., 2019).

2.3 Blockchain and Intellectual Property management

Producing Intellectual work requires resources to create, and businesses around the globe are trying to improve the available tools to increase their control over the intellectual properties they own in order to ensure fair use and protect it from copyrights infringements. One of the prominent applications for Blockchain is Intellectual Property management. This section includes a rundown of the studies where Blockchain was used as a solution for Intellectual Property management.

2.3.1 3D Printing

3D printing, also known as additive manufacturing, is a distributive technology and one of the industry 4.0 pillars (Dilberoglu et al., 2017). The additive manufacturing process's main asset is the design, where leaking the design file will allow anyone with a 3D printer to reprint it. In order to avoid this issue and create a robust system to manage these designs, several studies presented Blockchain technology as a solution.

Holland et al. (2017) presented the traditional methods used in protecting 3D printing designs, which include: (1) internal security; (2) external security; (3) product labelling; and (4) legal safeguards. In addition to that, they propose a Blockchain-based licensing for 3D printing designs. The system uses a closed chain of trust where the components of the system are

Blockchain friendly, which mean they can send and receive information through a Blockchain. The printing licenses are issued through a smart contract. A Delphi study by Kurpjuweit et al. (2019) concluded that Blockchain would improve additive manufacturing supply chains and act as a secure inter-organisational Intellectual Property management layer. A system with traceability and copyright protection capabilities was developed by Alkhader et al. (2020). The system integrates all the involved elements of the additive manufacturing process, including people involved like manufacturers and designers, in addition to components used in the printing process such as 3D printers and IoT sensors. The system uses three Blockchain products to achieve systems governance: (1) ledger to store transactions data; (2) Ethereum smart contract to regulate the relationship between people involved in addition to decide which data get stored in the ledger and which get rejected; (3) IPFS storage nodes which is a distributed storage system. Ragot et al. (2020) discussed the Intellectual Property of 3D printing designs using Blockchain and machine learning, where Blockchain was used to protect the design data, and machine learning were used to detect similarities between designs.

2.3.2 Literature and publishing

The Intellectual Property of literature allows authors to gain royalties of their intellectual production, which encourages them to keep producing and discourages copyright infringement. However, e-book and digital publications are an easier target to piracy; therefore, Blockchain was introduced as a solution to tackle this problem as a replacement for traditional digital right management systems.

Chi et al. (2020) presented a self-publishing eBooks system using Blockchain. The system removes the need for a publisher by replacing it with a smart contract. The system deploys multiple Blockchain system to reach this goal. The books metadata are stored on a public Blockchain. Authors only can update the book record using the private key generated when the book record created. The books are stored in a separate depository in a sharded form. The person interested in buying the book can verify its content by requesting a random piece of the book. The interaction between the authors and buyers are stored in a separate Blockchain where activities like book buying or renting are stored. This multiple chain system allows for better governance where the data and metadata are stored in separate depositories. This also keeps the transactions size smaller, which is sustainable for system performance.

CryptSubmit is a Blockchain-based system proposed by Gipp et al. (2017) as an automated scholars' publications submission and review and publishing platform. This system aims to fight ideas and literature plagiarism by creating a timestamp-based system where the Blockchain serves as the data repository for manuscripts with their author's information. The system was integrated into the OJS submission system as proof of concept. The system allows for improved communication in academia and introduced incentives for the reviewer, which will act as an accelerator to increasing academic production.

3 Framework for BIM design authenticity verification and controlled access using Blockchain technology

3.1 Background

The cost of a data breach report by IBM security (2020) stated that during the period between August 2019 and April 2020, 525 organisations from 17 countries and 17 industry reported data breaches. The average cost of each breach was 3.86 million USD, with an average time to identify and recover of 280 days. The Intellectual Property data share of the total breached data is 32%. Root causes for data breaches are (1) human error 23%; (2) system glitches 25; (3) malicious attacks 52%. Malicious attacks target digital infrastructures to forcefully control them in order to take valuable information or reduce the efficiency of the digital systems. During the period between 2014 and 2020, the data breaches due to malicious attacks increased from 42% to 52%. The main threat vectors for malicious attacks are: (1) compromised credentials 19%; (2) cloud misconfiguration 19%; (3) vulnerability in third-party software 16%. Fifty-three per cent of the malicious attacks were caused by financially motivated attackers (IBM-Security, 2020).

This section presents the recent developments in construction information management such as ISO19650-5:2020 and proposes a framework for using Blockchain technology to improve construction data management.

3.2 Building Information Modeling (BIM)

BIM integrated practices require data authors (appointed parties according to ISO 19650) to share the results of their works frequently (ISO, 2018). Shared data becomes vulnerable to misuse or data leaks. There is currently no way to protect or control BIM data after sharing it other than trusting all parties to respect the data protection policies. However, several measures can be implemented to improve control over BIM data, such as following the recent ISO 19650-5 standards for information management using building information modelling (ISO, 2020), general standards such as ISO/IEC 27001 for information security management or adopting data protection technologies such as Blockchain (ISO/IEC, 2018, ISO, 2018).

3.3 ISO19650-5:2020

The recently released standard ISO19650-5:2020 aims to address the security concerns for managing BIM data. The standard defines an asset as: "item, thing or entity that has a potential or actual value to an organisation". The standard differentiates between the data and the metadata, defined as "data about data". ISO19650-5:2020 presents a data control system by creating special procedures to exchange sensitive data. The data is considered sensitive if it fits under one of these categories: (1) data that can affect privacy, security, or safety of individuals; (2) Intellectual Property and trade secrets data; (3) data that can cause harm to an organisation or a nation or threaten nations local or foreign affairs. This can happen in several forms: data loss, misuse, modification, and unauthorised access (ISO, 2020).

The standard approach requires each organisation to assign an individual from the top management to make decisions on their behalf regarding their data. These individuals are required to provide information such as (1) risk appetite, which measures their entity's risk tolerance; (2) organisation sensitivities. The results of the collected information are assessed to establish governance, accountability, and responsibility for each entity. The governance structure assesses data security for assets, develops security mitigation measures, documents tolerated security risks, reviews the security strategy, develops a security management plan, monitors and audits the security plan, and develops a security breach management procedure. It also oversees the execution of these procedures in case a breach happens (ISO, 2020).

3.4 Blockchain Technology

According to access type, Blockchains can be public, permissioned, or hybrid. Also, according to the type of service, Blockchains can be (1) Cryptocurrency Blockchains for currency exchange, such as Bitcoin. (2) Cryptocurrency and Business Logic, where Blockchain executes business logic smart contracts and exchanges cryptocurrencies, such as Ethereum Blockchain. (3) Business logic Blockchains is an umbrella term for inter-organisations Blockchains developed to serve a business need by utilising the smart contract concept (Ramamurthy, 2019). The smart contract is a self-executing code when defined conditions are met (Di Francesco Maesa et al., 2019).

3.4.1 Infrastructure inversion

When a new major technology emerges, it uses the legacy infrastructure until it has its own fully compatible infrastructure. The set of difficulties faced during this process is called infrastructure inversion (Bitforx, 2018). This happened during the early phases of cars adoption, when motor vehicles used paths made for horses, causing a decrease in their efficiency due to incompatibility with the available infrastructure. Blockchain technology is in a similar situation where the companies' cultures, regulations, people perspectives, and digital services are not yet Blockchain-friendly.

In order to accelerate Blockchain adoption and reduce the friction with the current infrastructure, several alliances were formed to create open-source business logic Blockchain codes. These projects allow businesses to deploy their own Blockchains with minimal costs where

they modify the project codes to serve their needs. Hyperledger (Hyperledger, 2020), R3 Corda (Corda, 2020) and Multichain (MultiChain, 2021) are examples of Blockchain business infrastructure projects. Table 1 shows a comparison between them.

Table 1 A comparison between Hyperledger, Corda and Multichain

Project	Developer	Smart contracts languages	Identities management service	Supported databases
Hyperledger	Linux Foundation	JavaScript Java Go	Membership Service Providers (MSP) certificates	LevelDB CouchDB
Corda	R3	Java Kotlin	Identity Manager certificates	Azure SQL SQL Server Oracle Postgres
Multichain	Coin Sciences	JavaScript	Doorman certificates	Postgres MySQL MongoDB

The three platforms mentioned above several other provide a platform to bridge traditional cloud systems in order to facilitate the adoption process. The platforms allow programmers to write smart contracts in common programming languages and support various types of databases. Identities management services in such systems are access control systems to regulate users' access to permissioned Blockchains. The certificate-based identities are the dominant model because they provide a context-based identity instead of role-based identities.

The Hyperledger fabric is a sub-project of the Hyperledger project that provide businesses with a Blockchain backend required to use Blockchain within their businesses. Hyperledger's fully open-source nature allowed major IT companies to participate in the project development, which created a whole ecosystem with business-oriented tools and solutions. Hyperledger features include modular architecture; flexible consensus models and types; multiple data storing modules; data channels for minimised data channels; query support including JSON on-chain queries; provide even hook for data analytics or databases connections; support smart contracts versioning; upgradable Blockchain code. The previously mentioned features make it a suitable choice for Intellectual Property management using Blockchain technology (Hyperledger, 2020).

3.4.2 IPwe as an example

An example of a commercial Intellectual Property (IP) protection system has been announced recently by the company IPwe (Casper, 2021). The company plans to use a hybrid Blockchain system where the data is stored on both a Hyperledger permissioned Blockchain and the Casper public Blockchain. However, the data stored on the Casper public Blockchain is just an abstraction for the full data stored on the Hyperledger Blockchain (Casper, 2021). Figure 2 shows the IPwe IP management system.

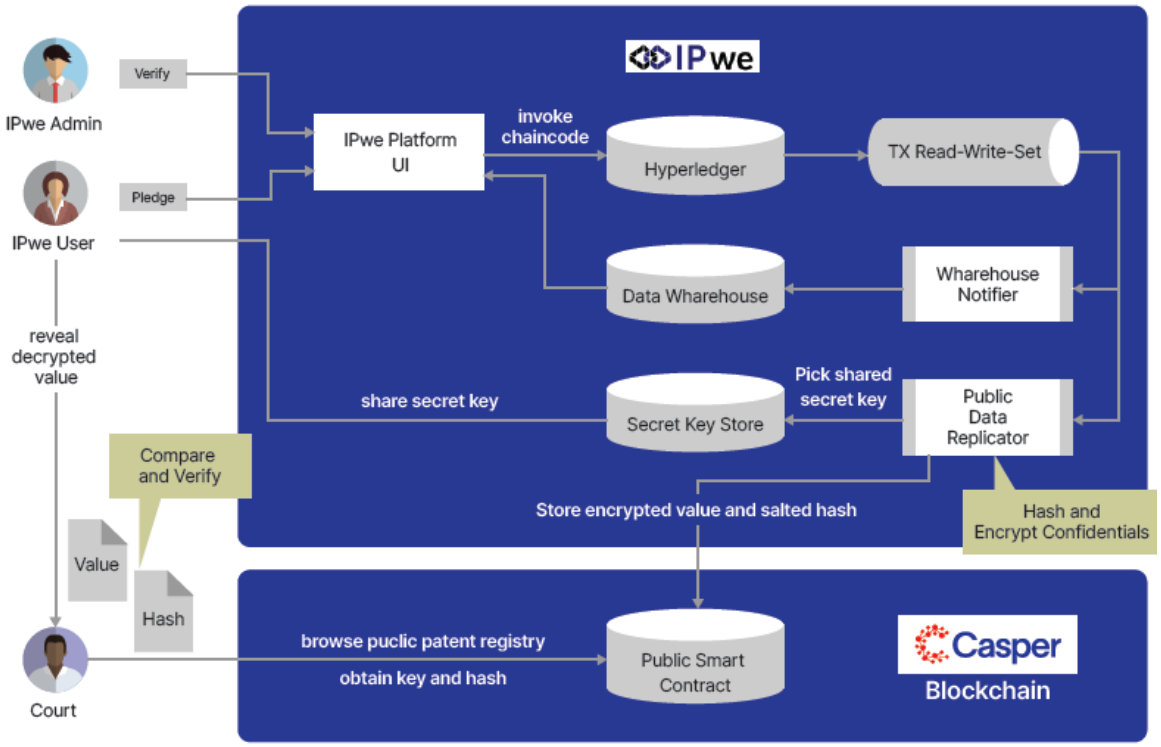

Figure 2 IPwe IP management system (Casper, 2021)

Blockchains provide users with trustless solutions where intermediaries are replaced with a smart contract. However, in public Blockchains, the smart contract code is published and accessible for any network participant. Transparency here has a negative side because Blockchain is an emerging technology, which is largely unproven in the AECO sector. The public access for smart contracts may provide opportunities for third parties to exploit bugs in contracts.

3.5 BIM-IP Decentralised Application

Blockchain technology can be utilised in protecting the intellectual property of digital construction assets. However, implementing a Blockchain-based solution depends on the goal of the solution and the type of the asset. There are three types of Blockchain proofs Blockchain can provide for intellectual property protection:

(1) Proof of authenticity, which is one of the growing fields in Blockchain applications. Non-fungible token (NFT) is the output of executing a standardised smart contract on a Public Blockchain that serves as a permanent record of the metadata of the asset with a connection to the asset stored in a decentralised IPFS storage (Chevet, 2018). The token is used to authenticate originality and ownership, where whoever has it in their web3 wallet owns it. When an asset is presented as NFT, it allows creating digital scarcity where the metadata can prove if the content is original or replica. BIM assets such as BIM design files and families can be wrapped into an NFT smart contract, which can be used as proof of design authenticity, proof of design version, or proof of design or family file ownership.

(2) Proof of contribution: Blockchain ledger serve as a record of events. Contributions in collaborative work environments can be recorded in a Blockchain ledger which is immutable and permanent. Recording contributions in Blockchain allow for a trustless collaboration environment with enhanced traceability and reliability where the contribution ledger allows to evaluate performance, compliance with contractual clauses (Song et al., 2021).

(3) Proof of use: digital construction assets require resources and time to be developed. The BIM-based design allows certain components to be used on multiple projects, such as families

files in the BIM authoring software. A Blockchain-based system can present a secure data exchange and use-right management. Designs and assets can be exchanged and managed using a use-right certificate (Naz et al., 2019).
The Decentralised Application (DApp) is an application that stores data on a Blockchain (Wu, 2019). DApps has two main components (1) the front end, which is the user interface (UI) which code be a Command Line Interface (CLI) or Graphical User Interface (GUI). (2) backend where a Blockchain runs the operations according to its defined smart contract.

BIM design files are composed of parametric elements. However, authoring tools store it in a proprietary file format. The construction industry solved that by creating the Industry Foundation Classes (IFC), which is a standardised data exchange format used to enable interoperability between different software vendors. IFC is an independent application neutral format developed by the BuildingSMART alliance. IFC schema has several formats such as SPF, XML and JSON, which make it suitable for Web applications. In addition to that, there are several open-source BIM web management tools that support IFC standards (Afsari et al., 2017). Open source is the main licence type used in Blockchain projects to give the users the opportunity to audit the code, which in turn reduces users' concerns from leaking their data through hidden backdoors embedded in the code (Laurent, 2004).

Figure 3 shows the system components diagram for BIM-IP Management DApp using Hyperledger, IPFS, and IFC technologies. The framework uses Hyperledger and IPFS as Blockchain infrastructure, and IFC is proposed as a medium for data exchange.
The proposed framework consists of three main parts Front-End, Back-End and the data

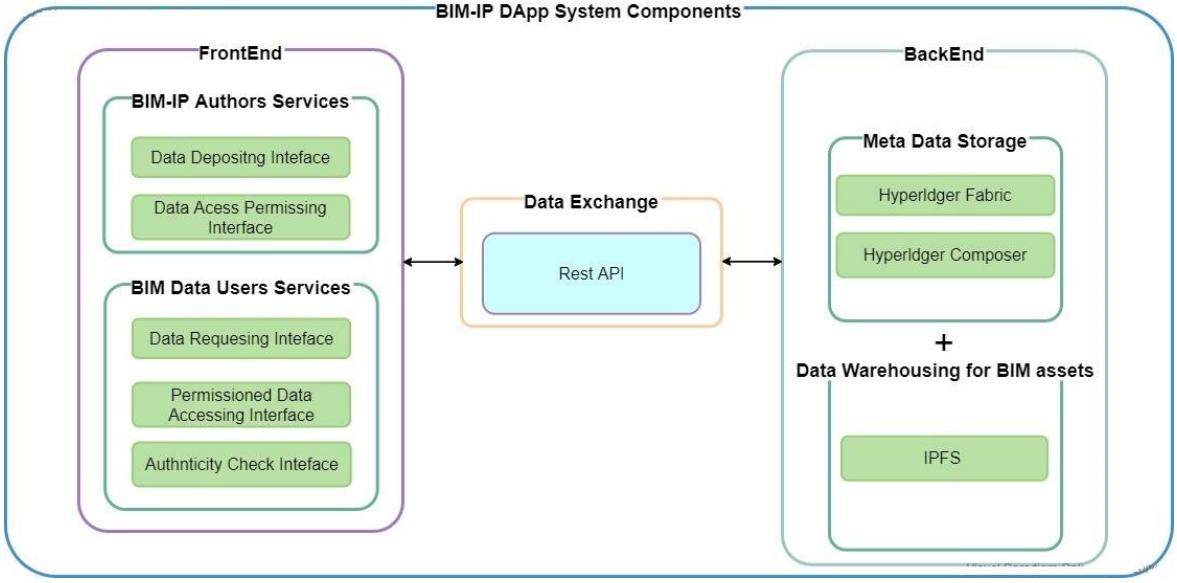

Figure 3 Proposed BIM-IP DApp system components.

connection between them. The Back end consists of three parts (1) Hyperledger fabric is the ledger that serves as a permanent record for the design files identification cards. (2) Hyperledger Composer is a friendly user interface management for the Hyperledger fabric; (3) IPFS which is a distributed peer to peer file storage system where the original design files are stored, and the hash code generated when the file added to the system is added to the Fabric records which verify the authenticity of the file used (Darabseh and Martins, 2021). The front end is separated into two sections: (1) authors services where a data depositing interface allows authors to deposit their files and include the ownership information and the IFC file, in addition, to define who has access to the record; (2) BIM data users interface which allows users to request access for models or check what models they already have access to use. The interface also checks the authenticity of designs by querying the Blockchain so similarities in the metadata or using an external tool to check similarities between two IFC file.

The front end and the backend communicate through a Rest API, which is an application programming interface built for Hyperledger fabric with respect to Representational state transfer (REST) guidelines (Rodriguez, 2008). This Rest API allows applications front ends to communicate with the back ends in a standardised way, overcoming the programming languages difference used when developing a Blockchain solution.

The framework utilises Hyperledger project tools to achieve low maintenance, effective BIM Intellectual Property in accordance with the ISO19650-5:2020. If the BIM design is deemed as sensitive data, then the files exchange process is moved to the proposed Blockchain-based system. The channels feature in Hyperledger based Blockchain allows for the "need-to-know" ISO19650-5:2020 principle, which is defined as the "legitimate requirement of a prospective recipient of information to know, to access, or to possess sensitive information" (ISO, 2020). The Hyperledger Fabric channel is a private communication tunnel shared between two or more network participants. The transactions in the channels are private and confidential, and only the channel members can view its content. Also, the Hyperledger Membership Service Providers (MSP) feature uses the X.509 certificates standard, which allows for advanced capabilities such as time-limited access or revoking the certificate if a security incident happens as a part of the security management plan developed in accordance with ISO19650-5:2020 (Kinkelin et al., 2020).

4 Conclusion

The ISO19650 is an important step toward more digitalised construction activities, and it provides a guideline to counterattack malicious cyber activities that target digital construction information. In order to convert the ISO19650-5:2020 guidelines into a working solution, this article proposes a framework to protect the Intellectual Property of BIM designs which is considered sensitive information by the ISO19650-5:2020 standard using Blockchain technology. The proposed framework uses Hyperledger project products such as Fabric and Composer to create the Blockchain and the IPFS system as storage for the BIM files. The proposed framework considers IFC for representing the BIM design file. IFC is widely accepted and has web tools that allow users to perform similarity checks to identify Intellectual Property infringement.

Blockchain can be used in a BIM environment to provide a ledger for intellectual property related events such as assets ownership, contributions in developing an asset, and controlling the use of digital assets.

The study contributes to the Blockchain and BIM synergy by presenting a Blockchain ISO19650-5:2020 compatible framework to fight copyright infringement and ensure secured BIM data exchange; however, further work is required to check the framework and verify its validity.

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