

# Fusion of Building Information Modeling and Blockchain for Metaverse: A Survey

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**ABSTRACT** Metaverse and blockchain, as the latest buzzwords, have attracted great attention from industry and academia. They will inevitably promote technological innovation in the field of building information modeling (BIM) in the future. BIM organizes various building information into a whole by establishing a virtual three-dimensional model of architectural engineering using digital technology. The metaverse seamlessly integrates the real world and the virtual world, and conducts rich activities such as creation, display, and trading. Therefore, through the exploration of the metaverse, it will be possible to build an exciting digital world and transform the physical world better. Meanwhile, introducing the blockchain technology could ensure the fairness and security of resource transactions, data storage, and other activities. In this survey, we delve into the metaverse and blockchain empowerment by studying BIM components, metaverse applications in virtual world construction, and the latest research on blockchain. We also discuss how BIM technology and blockchain can be integrated with metaverse. The collaborations between academia and industry would be certainly required for further development and interdisciplinary research on the metaverse and the integration of blockchain into BIM. We hope to see our survey help researchers, engineers and educators build an open, fair and rational future BIM ecosystem.

**INDEX TERMS** Blockchain, building information modeling (BIM), city information modeling (CIM), device-free localization, metaverse.

## I. INTRODUCTION

The metaverse is loosely defined as an extensive online world in which people interact via digital avatars. Companies like Meta Platforms [1], formerly known as Facebook Inc., have touted plans to develop metaverse experiences, services, and hardware. The metaverse concept is rooted in the science-fiction novels named “Snow Crash” by Neal Stephenson [2] and “Ready Player One” [3]. In the latter, the world has been ravaged by climate change and a fossil-fuel crisis, and the metaverse is an escape. The metaverse is aimed at providing

an open, shared and persistent virtual world that offers accesses to the three-dimensional (3D) virtual spaces, solutions, and environments created by users. On the other hand, various virtual technologies create the ways to access metaverse. For example, virtual reality (VR) is one of technologies to create 3D virtual environments with specifically functionalities.

In the metaverse that tech companies are aspiring to create, people are enabled to watch a UFC fight from any angle including from the perspective of the fighter. Some metaverse-esque experiences have already exist. Roblox Corp. [5] and

Epic Games Inc.'s "Fortnite" [6] have hosted virtual concerts with stars like Ariana Grande and other immersive experiences. Eventually, the idea evolved that people would be able to do almost anything via their avatars in the metaverse: construct architectural structures, attend school, attend concerts, participate in work meetings, etc. For instance, Decentraland [7] is a diverse 3D virtual reality platform living on the Ethereum blockchain in which users can construct architectural structures, such as casinos, art galleries, and concert halls, by using the ERC-20 token standard for its cryptocurrency (MANA). While people can enter the metaverse via an internet browser and a crypto wallet, and provide a more immersive experience through virtual reality headsets, users can only see the online world. In contrast, augmented reality superimposes virtual objects on the user's perspective of the physical world.

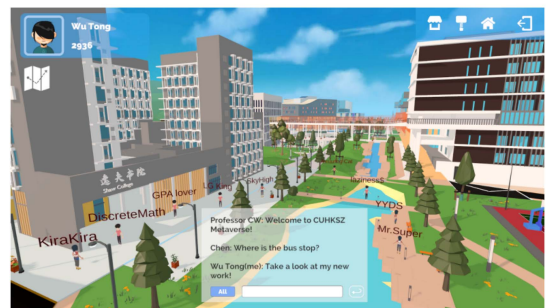
With breakthroughs in digital transformation, the latest trend in every industry is to build digital twins (DTs), using real-time data throughout the asset life-cycle [8]. Digital twins play an important role not only in the conceptualization, prototyping, testing and design optimization phases, but also in the operational phase. The virtual world of the metaverse generates the volume, variety and velocity of data, such as structured and unstructured data, making deep learning-based digital twins essential [9].

From a macro perspective, Duan et al. [4] emphasize the representative applications for social goods and design a three-layer metaverse architecture, including infrastructure (campus, as shown in Fig. 1), interaction, and ecosystem. From the perspective of users, the requirements of freedom of the virtual world, the content and interaction methods of the Internet, etc. are constantly increasing [10]. Braud et al. [11] exploit the feasibility of a large-scale and persistent experience shared among all visitors on the first AR campus metaverse by considering the nature of the various environments and the available sensing platforms. Yang et al. [12] highlight the fusion of artificial intelligence technologies and blockchain to construct an intelligent, open, and promising metaverse by the description of the economic system in the metaverse. Gadekallu et al. [13] investigate key-enabling technologies in the metaverse based on blockchain, including digital twins, Internet-of-Things, immersive applications, Big Data and so on.

All physical space design—interiors, buildings, campuses, and cities—is born as metaverse spaces. We can find that building and space design are the fundamental components of metaverse that enable players or participants to engage in long-term, coordinated conjoined action. As illustrated in Fig. 2, the Building Information Modeling (BIM) [14], [15] is regarded as the collective process of creating and using building information that forms the basis for all decisions during the life cycle of a facility (from planning to design, the release of design documents, construction, operation, and demolition). For example, Sampaio [16] find that BIM solutions can solve the problem of retrieving and presenting information, thereby improving the efficiency of



(a) Campus billboard in metaverse.



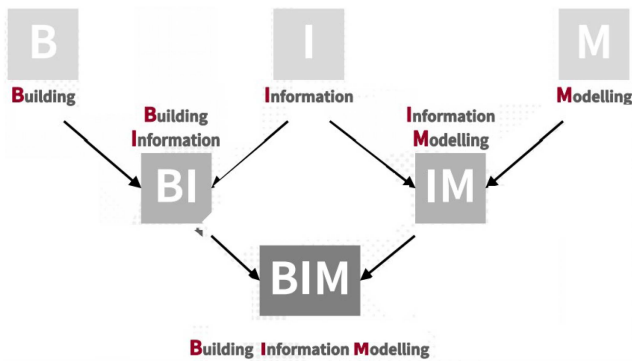
(b) The demonstration of campus navigation in metaverse.

**FIGURE 1. The immersive experience for users in metaverse with an university campus prototype. Figures are from Ref. [4].**

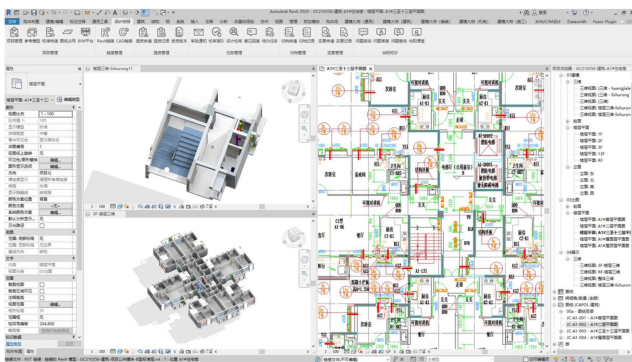
Communication in interactive and collaborative projects by adding VR. The integration of BIM with augmented reality (AR) is believed to highly increase BIM's applicability to fieldwork. Chai et al. [17] examine the credibility of BIM integration into AR (AR-BIM) in the construction industry and provide a simple case to demonstrate that BIM is compatible with integration with the AR platform.

Furthermore, a novel concept of city information modeling (CIM) [18], [19] is proposed to bring great benefits to the urban construction and city management by fusing BIM, digital twin, Geographic Information System [20](GIS), and other technical foundations (See Fig. 3(a)). The CIM has the following characteristics: (a) Digital governance applied to urban modernization. (b) Building a digital virtual city to map, monitor, analyze, and simulate the physical city. (c) Realizing the full digitization, and spatialization of physical cities and forming digital twin cities. To accommodate datasets relevant to different aspects of city planning, Hamilton et al. [21] present how to develop an  $nD$  urban information model.

In the future, BIM is promising to build exciting 3D virtual environments, which help developers of this virtual world to transform a better physical world through the exploration of



(a) Components of BIM



(b) Architectural design process with 3D visualization using BIM

**FIGURE 2. Illustration of building information model.**

the metaverse. In this paper, different from the existing works, we exploit the fusion of BIM technologies and blockchain with metaverse to exploit the construction of basic components. The main contributions of this paper are summarized as follows,

- 1) We investigate the preliminaries of the BIM in the metaverse.
- 2) We then discuss how BIM technologies and blockchain fuse with the metaverse, and review the state-of-the-art studies.
- 3) Finally, we envision promising directions, typical challenges and open issues to shape the future metaverse in the next decades.

The organization of this paper is shown as follows. Section II provides the preliminaries of BIM; Section III discusses the applications of BIM in metaverse; Section IV shows the combination of blockchain in BIM; In Section V, challenges and open issues of the fusion of BIM and blockchain with metaverse are discussed. Finally, Section VI concludes this paper.

## II. PRELIMINARIES OF BIM

The core requirement of BIM is to organize various building information into a whole by establishing a virtual three-dimensional model of construction engineering using digital technology. BIM technology can be applied to specific

application scenarios according to the following three characteristics: (a) Applied to the whole life cycle of construction projects (design-build-use-demolition), (b) BIM software for digital design, (c) The database of BIM is dynamic and constantly updated and supplemented during the application process.

### A. VISUALIZATION

In BIM, the design and construction processes are all carried out in the interface of 3D visualization [24]. Through the 3D visualization, it is convenient for users to make optimization design of electromechanical details and building space, as demonstrated in Fig. 4. The traditional engineering design process is only expressed in the form of plane, table and information target. BIM is the most intuitive visual information model for the design effect and complex modeling. It can help the communication in the process of project design and construction, and improve the efficiency of decision-making.

For example, full-scale 3D rendering from 2D plans and drawings can be used to develop 3D designs of building models, to provide immersive experience of space and interior visualizations for AEC industry professionals [25]. In addition, the 3D BIM models are compatible with VR technology, which making it possible for the construction companies to experience the architecture and engineering of the designs and take informed decisions. Also, it enables users to experience 3D visualizations with walkthrough and interactivity by VR Head Mounted Devices (HMD).

Hence, the 3D Virtual Reality construction BIM models can be applied into several fields, such as the design communication and construction progress plans for healthcare, hospitality, roads and highways [26], campus (Fig. 5(b)) and bridges, tunnels, railways, or even residential, commercial or industrial buildings.

### B. DIGITIZATION

Using BIM technology, the design process can transform the design elements into variables of a certain function by means of programming, parameterization, etc. [27]. The design results could be obtained by changing the form of parameters, especially for complex forms or repetitive shapes that are difficult to achieve manually. For the higher design work, through integrating and invoking the geometric information of the building (dimension, positioning, spatial topology relationship, etc.) and non-geometric information (such as materials and physical characteristics, system types, specifications, models, manufacturers, functions and performance technical parameters, construction methods, engineering logic relationships, etc.) to achieve effective storage, rapid preparation, calculation and analysis of project management process data [28].

It is mainly used in the management of project information, rapid calculation of project quantity, earned value analysis of construction progress, project procurement plan, project payment progress and other management work.



(a) Components of CIM software platform which integrates BIM technology, Geo-Spatial Data and the Internet-of-Things technologies [22].



(b) A 3D city model of Berlin created by virtualcitySYSTEMS. It is currently the world's largest urban spatial database [23].

**FIGURE 3.** Illustration of city information modeling.

**C. SIMULATION**

Using the above engineering information, simulation work or experiments that cannot be carried out in reality can be simulated during the design and construction process through the system setting of the database structure and interactive mode, such as: building wind environment simulation, acoustic environment simulation, sunshine simulation, Simulation of emergency evacuation, simulation of building energy consumption, simulation of building seismic performance, simulation of building carbon emissions, simulation of construction progress, simulation of key and difficult construction plans, simulation of people flow during operation, etc. Based on the simulation results, optimization suggestions could be put forward for design, construction and operation based on data analysis and prediction.

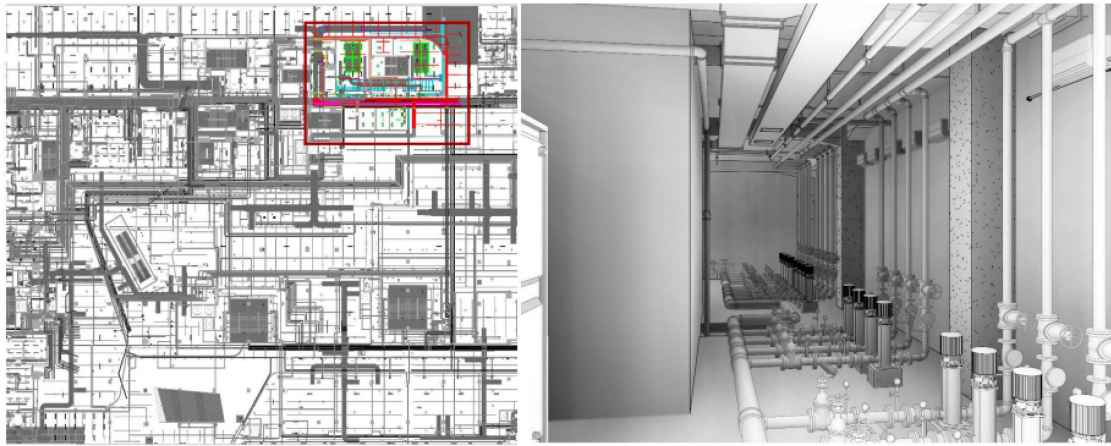
Currently, virtual buildings are mostly in read-only environments that only be changed when their owners release updates.

There is no technology to reproduce 3D space with fidelity that can capture more than just static elements with data links for now. There is not even a way to simulate simple dynamic scenes, such as a person walking through a door [29].

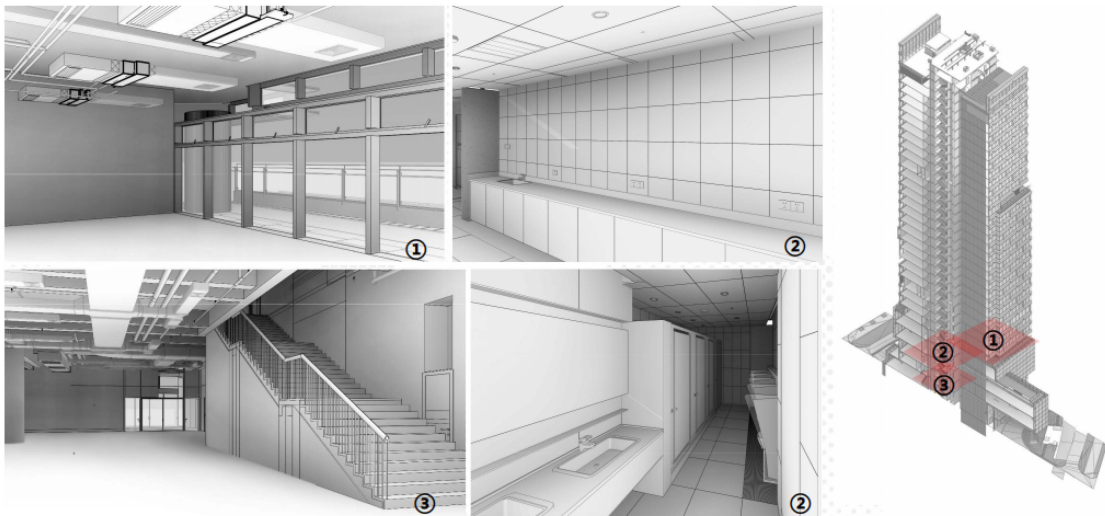
**D. CITY INFORMATION MODELING**

CIM is an application based on the concept of BIM [18]. It is an information system that integrates urban macro scenario information, playing important roles in the whole life cycle management of design, construction and operation in the construction field to the city.

technology is empowered by the BIM, digital twin, geographic information system (GIS), Internet of Things (IoT) [30], [31] and other technical foundations [32]. It integrates the urban ground and underground, indoor and outdoor, historical status, future multi-dimensional and multi-scale information model data and urban perception data, to build an



(a) Optimization design of electromechanical details



(b) Optimization design of building space

**FIGURE 4.** Characteristics of BIM in architecture design.



(a) Floor plan of the campus of Guangzhou University



(b) 3D visualization of a building complex in the metaverse [33].

**FIGURE 5.** Comparison of the conventional 2D plan scheme and 3D visualization of a building.

organic complex of urban information in three-dimensional digital space.

The main application scenarios of CIM technology are summarized as “CIM+” applications [34]. The CIM+ applications include urban construction, urban management, urban renewal, urban industrialization, urban physical examination, urban safety, urban transportation, urban water, urban power, urban monitoring, urban carbon emissions, urban epidemic prevention, emergency command and special application in other fields.

By comprehensively describing various elements such as urban land, buildings, and infrastructure, it reflects the digital governance capability of urban space of the CIM basic platform. Moreover, it shows the CIM basic platform has the ability to realize the construction and analysis of business data for various business information, such as urban planning and building management. Through assisting in setting indicators for business management of various majors, the CIM platform is possible to calculate and analyze indicators for various businesses and behaviors in the city, and interpret the operation status of the city.

### III. BIM IN METAVERSE

#### A. OVERVIEW OF JUNCTION POINTS

The metaverse is a virtual world that is linked and created by means of technology, maps and interacts with the real world [35]. The underlying data source of CIM technology is supposed to be one of the basic building blocks of the digital twin city in metaverse. At this stage, the economic system built by metaverse based on blockchain technology mainly integrates the virtual world and the real world in the economic system, social system, and identity system.

In the existing concept of the metaverse, the creation, update, and maintenance of urban information systems and building information systems are biased towards re-creating virtual land, virtual buildings, and virtual cities. Therefore, how to create a metaverse that records the development, changes, and iterations of cities and buildings based on real-world information data, using BIM, CIM, blockchain technology, etc., is a promising research direction in future.

For example, with the increasing application of BIM for asset management within architecture, engineering, and construction, the issues related to the development and production of a facility are related to differences between the as-built design and the facility or complex technical systems [36]. An analysis of existing information technology shows that it is possible to reduce the production and operating costs of an asset by concentrating the main costs in the design phase, which would be realized by BIM technology.

#### B. ARCHITECTURAL DESIGN

Tim et al. [37] design a navigation framework that includes the factory's buildings, their related environment and the interior equipment for digital twins of factories, which offers the major data structures for obstacles, navigable spaces and avatars

that are to use pathfinding and path following functionality. Lu et al. [38] propose a framework for future development of smart asset management integrating digital twins. Digital twins fuse artificial intelligence, machine learning and data analytic to create dynamic digital models that enables to learn and update the status of the physical counterpart from multiple information sources. And BIM technology is the application of digital twins in the field of construction. Through comparing Fig. 5(a) and Fig. 5(b), it is obvious that users will get better experience with 3D visualization with metaverse technology to illustrate the campus scenario. Furthermore, fusing BIM technologies into constructing the metaverse world could enhance the experience by introducing more details.

### IV. BLOCKCHAIN IN BIM

Generally, in a BIM project, there are multiple distributed parties to collaboratively complete project files. This needs a system to record revision events, share some near real-time information, and engineering files. This system is in crucial need because it should also integrate the BIM resources of multiple cloud services, which meets the needs of various clients for global, diversity, storage and communication. Fortunately, blockchain as an emerging technology for realizing distributed hyper-ledger [39], [40], it has attracted extensive research attention in recent years [41], [42]. All transactions in the blockchain network are stored in blocks, which are linked like a chain and organized in chronological order. Additionally, transactions written into blocks are immutable and transparent to all peers [43]. And the blockchain can avoid the single point of failure problem that is easy to occur in the security mechanism of the centralized trust entity. The single point of failure means that once the centralized trust entity component is damaged, the entire system will stop running [44]. The blockchain can avoid such situations, while no trusted third party required.

With all these attractive features, blockchain is distinct from traditional centralized trust entities and becomes an important enabler of the future financial system. Blockchain has grown rapidly in recent years, from the first decentralized cryptocurrency Bitcoin [39] to Ethereum with smart contracts [45], followed by emerging permission-editable blockchain such as Hyperledger Fabric [46]. With its decentralized nature, blockchain has penetrated into multiple applications that are closely related to all aspects of our daily life, such as cryptocurrencies, business applications, smart cities, IoT applications, and so on. In [47], Lv et al. proposed a secure multidimensional data storage solution called BlockNet with the immutable characteristics of Blockchain, which can ensure the security of the digital mapping process of the IoT, thereby the improvement of the data reliability of digital twins. They also proposed a nonmutagenic multidimensional Hash Geocoding method to address the challenges face by multiscale spatial data processing, allowing unique indexing of multidimensional information and avoiding information loss.

### **A. DISTRIBUTED STORAGE IN BIM**

The combination of blockchain and distributed file systems is emerging as a promising solution, with blockchain expected to provide incentives and security for files stored in the system. Currently, popular blockchain-based distributed file systems include IPFS [48], Swarm [49], Storj [50], and PPIO [51]. Among these file systems, IPFS is a peer-to-peer distributed file system for storing and accessing files, websites, applications and data; Swarm is an Ethereum-based distributed storage platform and content distribution service; Storj is another peer-to-peer A decentralized cloud storage platform that allows users to share data without relying on third-party data providers, the PPIO is a decentralized programmable storage network that allows users to store and retrieve any data from anywhere on the network. The combination of blockchain, IPFS, Swarm and Storj file systems respectively use Filecoin [52], Ethereum [45] and Metadisk [53] as their incentive mechanisms. PPIO utilizes up to 4 proof algorithms for its incentive layer.

### **B. SECURITY COLLABORATION IN BIM DESIGN**

The purpose of the blockchain is to achieve decentralized transaction management, that means any node of the network can join the ledger and initiate transactions equally according to the rules, the transactions do not require any third-party management. Transactions could add information to achieve save the data in the blockchain network [54]. The node of the blockchain network could save all the data in themselves' server. The data of this network will be sliced to keep the security.

To address the security issues brought by the openness and high decentralization of BIM and IoT services of smart buildings, Siountri et al. [55] exploit the integration of BIM, IoT, Blockchain and advanced digital technologies for a museum. The proposal satisfies multiple administrative requirements, such as the security and the convenience of the visitors, the laboratories and the storage areas.

The network of the blockchain could be private network, which means the data of BIM could save to the block to keep privacy [56]. Blockchain is a decentralized technology that can accelerate the shift of workflow dynamics from the current hierarchical structure to a decentralized, collaborative chain of command, and influence cultural and social change by encouraging trust and transparency [57]. Currently, the construction industry mostly relies on the "Security through obscurity" approach as a security technique to protect data [58], which emphasizes the confidentiality of the implementation and mechanisms of cybersecurity systems. Therefore, a small amount of information leakage can have a significant impact on the entire security network [59]. Eliminating third-party oversight of network transactions would require providing several improvements over existing systems in terms of network security levels. No single node in a blockchain network has full access to all information, as multi-signature protection can add another layer of security by accepting multiple

keys to authorize transactions. Hackers can gain full access in the network only when more than 50% of the nodes are compromised [60].

### **V. CHALLENGES AND OPEN ISSUES**

The metaverse is a virtual world that is linked and created by means of technology, and maps and interacts with the real world. The underlying data source of CIM technology will be one of the basic building blocks of the digital twin city in the metaverse. At this stage, the economic system built by metaverse based on blockchain technology mainly integrates the virtual world and the real world in the economic system, social system, and identity system. The application scenarios and relationships of metaverse, blockchain and BIM are summarized in Table 1 through the dimensions of object and time period.

According to our observation, in the concept of the existing metaverse, the creation, update and maintenance of urban information systems and building information systems are currently biased towards re-creating virtual land, virtual buildings, and virtual cities. Thus, how to create a metaverse that records the development, changes and iterations of cities and buildings based on the existing real-world information data, using BIM, CIM, blockchain technology, etc., will without a doubt to be a promising research direction. Some important open issues will be discussed in this paper.

### **A. KEY FACTORS OF ARCHITECTURAL DESIGN PROCESS IN METAVERSE**

#### **1) PHYSICAL PROPERTIES OF ARCHITECTURE**

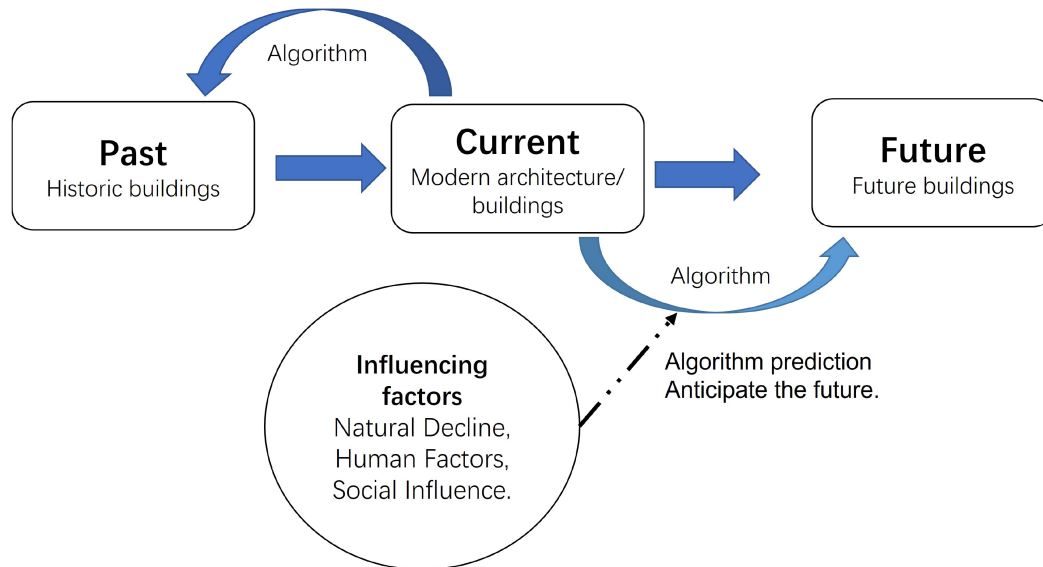
The material and technical conditions of the building are the material basis and technical means to realize the function of the building. The material basis includes building materials and products, construction equipment and construction equipment, etc. Among them, building materials and structures are the skeleton that constitutes the building space environment, and building equipment is the technical conditions to ensure that the building meets certain requirements for use, and building materials, such as concrete. Rebar, aluminum alloy, glass, metal and other materials; construction equipment, such as elevators, fans, pumps, pipes, etc.; the building itself exists in material form.

#### **2) NON-PHYSICAL NATURE OF ARCHITECTURE**

It refers to the interactive emotions related to human, i.e., urban feelings. Although the building itself exists in material form, it also needs to meet our various material activity needs and spiritual activity needs, including basic psychological activities and advanced psychological activities. The building itself is static, and the main body in the human environment is an active factor that includes both explicit and implicit active activities. Therefore, the building itself and the behavior of building users work together to complete the entire life cycle of the building.

**TABLE 1.** Application Scenarios and Relationships of Metaverse, BIM, and Blockchain

Object & Period	Past	Current	Future
People (i.e. Metaverse users)	Historical users	Retained users	Potential users
Events (i.e. Blockchain storage)	Historical activity records	Real-time interaction information	Interaction activity prediction
Property (i.e. Building information)	Historical building information	Existing building information and real-time architectural design	Future urban development



**FIGURE 6.** Considering the gap between the existing building information and the historical building information in the past, combined with the international situation, geographical environment, policy guidance, economic development, humanities and other factors, the algorithm for the natural decline of historical buildings from the development of existing buildings is deduced. By using deep learning algorithms and combining the influence of multiple data sources, a decision-making model for future urban development is derived.

**B. IMMERSIVE EXPERIENCE IN ARCHITECTURAL DESIGN STAGE: REALITY AND FANTASY**

**1) ARCHITECTURAL DESIGN BASED ON EXISTING PHYSICAL LAWS**

In reality, architectural design is a particularly comprehensive thing. First of all, it must be feasible economically and socially, and the construction cost of a certain functional building must be within a reasonable range; secondly, the technology and the existing construction technology are feasible, and the technology of realizing the building construction process cannot be separated from the restrictions of physical laws; thirdly, it is necessary to consider the impact of its presentation on the entire city, the environment and life, or on the historical form and life form; finally, the architectural design must meet the design specifications of various professions or the approval of relevant administrative departments, such as the land department, planning Departments, construction departments, transportation departments, greening departments, etc.

**2) ARCHITECTURAL DESIGN OUT OF THE PHYSICAL LAWS (I.E., FANTASY ARCHITECTURAL DESIGN OR VIRTUAL ARCHITECTURAL DESIGN)**

In the virtual world (metaverse), there are no rules and regulations of the construction industry in the real world, and the design of virtual buildings is simpler than traditional drawings, and the design is not restricted by physical laws, so there is no need to consider construction costs and environmental impacts; so The style creation can be more exaggerated and requires more creativity. Based on the design of the virtual world, each independent space can be another infinite space, which brings creative space to architects and puts forward higher comprehensive ability requirements for architects.

**C. TEMPORAL IMPACT OF ARCHITECTURAL DESIGN**

As depicted in Fig. 6, considering the gap between the existing building information and the historical building information in the past, combined with the international situation, geographical environment, policy guidance, economic development,



humanities and other factors, the algorithm for the natural decline of historical buildings from the development of existing buildings is deduced. By using deep learning algorithms and combining the influence of multiple data sources, a decision-making model for future urban development is derived.

### 1) RELATIONSHIP BETWEEN REAL ARCHITECTURE AND TIME SHIFT

Famous architects once put forward that “Architecture must be a unique product of that place and that era. Its purpose is to connect the time of the city and create the soil where the culture of the city can be cultivated. From the past to the present, and then to the future, Therefore, there is a city’s scenery, and architecture plays a part in it.” Architecture is the carrier of human history and culture, and a witness to the trajectory of historical moments. Each historical period has its own specific architectural form and style; in reality The existence of time is irreversible; when reviewing historical buildings, historical buildings can only be described through photos, images, language, etc. Existing buildings are also historic buildings at some point in the future.

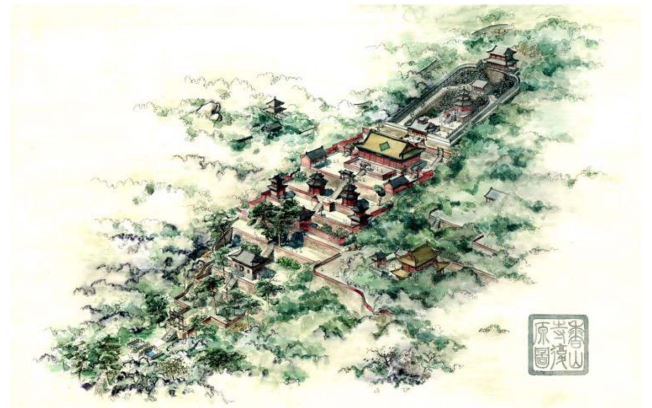
### 2) RELATIONSHIP BETWEEN VIRTUAL ARCHITECTURE AND TIME SHIFT

In the metaverse, the time attribute is retroactive, and the past, present, and future can be spanned. At the same time, time can also be discontinuous, and it can show restart, fault, and nonlinear characteristics. Information is freely extended in natural time, preserved, and used by different people in different times and spaces. Similar to the static space that has special meaning for people, it can be expanded more. For example, you can go back to your childhood home in the past, or other places of great significance, and be in a virtual house to recall the past. Or for historical buildings that no longer exist in reality, the whole process from construction to demolition can be reproduced.

### D. BLOCKCHAIN-BASED BIM

As aforementioned, a centralized transaction system is vulnerable and multiple parties in the system are mutual distrust. Fig. 9 demonstrates a blockchain-based BIM data transaction system which would solve these problems. This system could also integrate the BIM resources of multiple cloud services, which meets the needs of various clients for global, diversity, storage and communication.

The blockchain-based BIM data transaction system is consisted with information server, off-chain data layer, smart contract layer and blockchain layer. It realize the encrypted storage of BIM data resources utilizing the data encryption, non-tampering, and decentralized storage features of blockchain technology. The smart contracts would be utilized to automatically execute the transactions of BIM data. Though this system, it could realize the whole procedure of 1) user information storage, 2) on-chain BIM data release and 3) transactions of BIM data. In detail, the step 1) includes



**FIGURE 7.** Restoration of ancient architecture and scenario reproduction [61].

ID registration, login and ID encrypted storage through smart contracts; step 2) release the BIM data and encrypted storage it through smart contracts; step 3) realize BIM data transaction based on token, where the uses who have token could get the BIM data list and then purchase the one he prefers. Note that the transaction results are credible and cannot be tampered with.

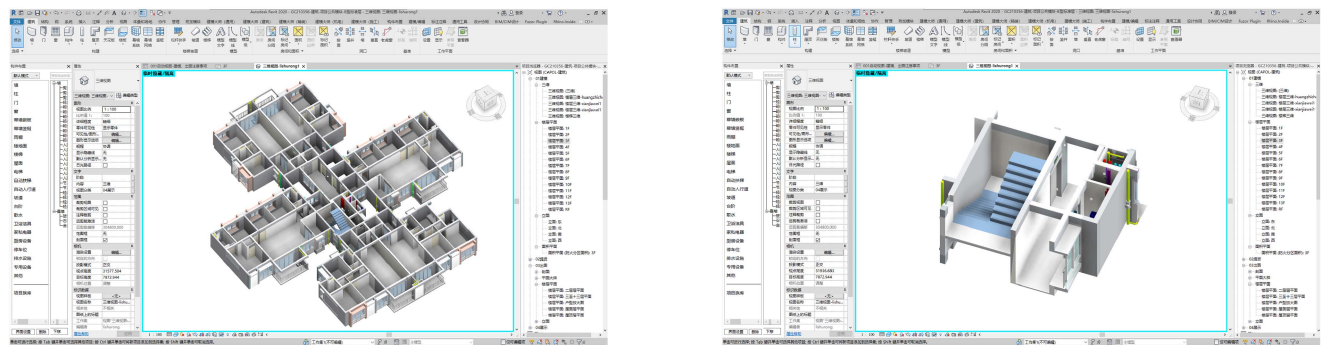
### E. TECHNICAL APPLICATION SCENARIOS

#### 1) RESTORATION OF CULTURAL RELICS

The restoration work is actually to restore the appearance and structure of the cultural relics. However, this work is extremely challenging because cultural relic restorers have to structure the whole from the fragment. Here, we take Xiangshan Temple as an example. As depicted in Fig. 7, it is a royal temple that can be called the best in Chinese classical gardening art. In the past 150 years, this royal temple has been damaged many times for various reasons. Although the overall building complex has disappeared, some fragments still remain. Thus, these fragments have become important clues for restoration. Moreover, how to use metaverse technologies for restoring the cultural relics to the world through time travel will be a promising topic in future.

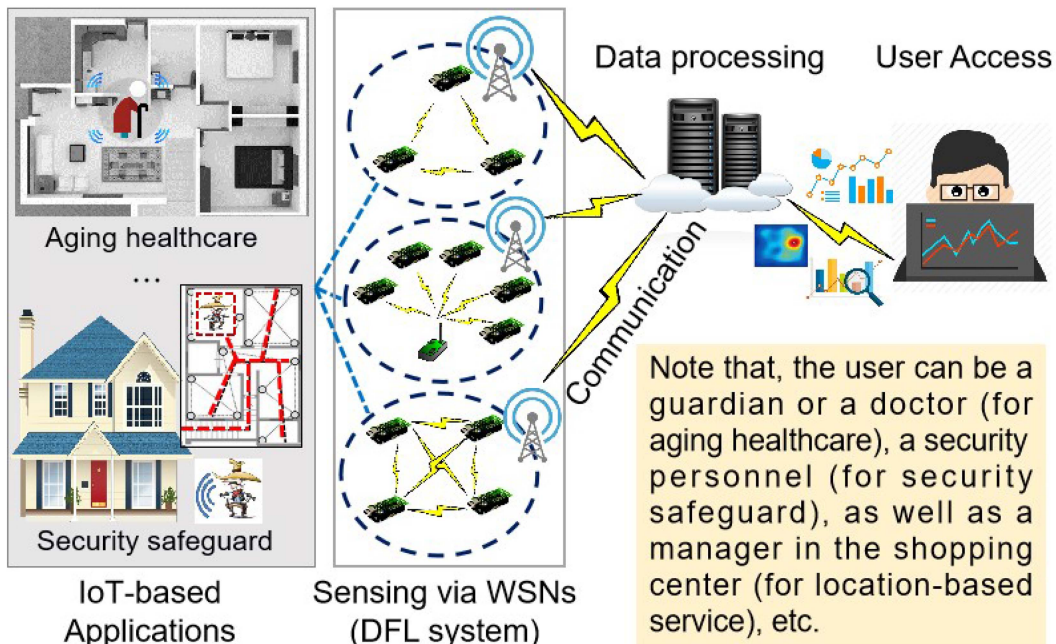
#### 2) IOT-BASED WIRELESS SENSING TECHNOLOGY FOR FUNCTIONAL DESIGN IN METAVERSE

IoT-based wireless sensing technologies [64] will be important for human-machine interaction of metaverse users and hereby enrich the basic constructions of metaverse world. Especially, as demonstrated in Fig. 8(c), wireless sensing technologies, e.g., device-free localization (DFL) [65], [66], gesture or action recognition, real-time target tracking, etc., will provide various accesses to metaverse. Compared with computer version technology, wireless sensing methods using RSS or CSI signals to recognize targets, which has potential merits in preserving privacy of metaverse users. Therefore, the intelligent wireless sensing technologies will definitely be



(a) Functional design in a building

(b) Structure design of a building



(c) Indoor device-free localization for functional requirements, e.g., aging healthcare, intruder detection [62], [63] in buildings

**FIGURE 8.** Technical application scenarios for functional requirements based on IoT applications.

promising trends to empower the interaction of real world and virtual world.

In addition, to fuse of various applications in metaverse, BIM will be a perfect tool before build the virtual world. As illustrated in Fig. 8(a) and Fig. 8(b), leveraging the design software of BIM, metaverse engineer could make various simulations of functional requirements in virtual buildings. This framework is also applicable to CIM, i.e., building-complex design of a city scale.

### 3) FUSION OF BIM, BLOCKCHAIN AND METAVERSE FOR BUILDING ENERGY EFFICIENCY AND LOW CARBON

As aforementioned, the BIM allows users to record a full-life-cycle information of buildings. The metaverse technologies provide accesses to future perspective. Therefore, the fusion of BIM and metaverse make it more flexible to conduct the construction design, building functional design and simulation for energy efficiency. Especially, it does not need to

consider the pollution caused by the construction process, and allows to consider many influencing factors, such as climate [67], personnel activities [68], [69], building material [70], equipment [71], etc. Thus, the entire process is green and low-carbon. In addition, due to power surplus and shortage of individual users in local grids, the renewable-energy electricity will be frequently traded among distributed users. Blockchain will be a promising technology to support such a secure decentralized transaction ecosystem.

### F. OTHER ISSUES

Based on the merits of BIM, blockchain and metaverse, there are many interesting issues could be investigated in future. For instance, immersive design experience based on the metaverse, evolution, preservation and reproduction of architectural scenarios, time museum, criminal investigation review and rehearsal, recording the development and evolution of cities, etc. Leveraging the blockchain technology, it

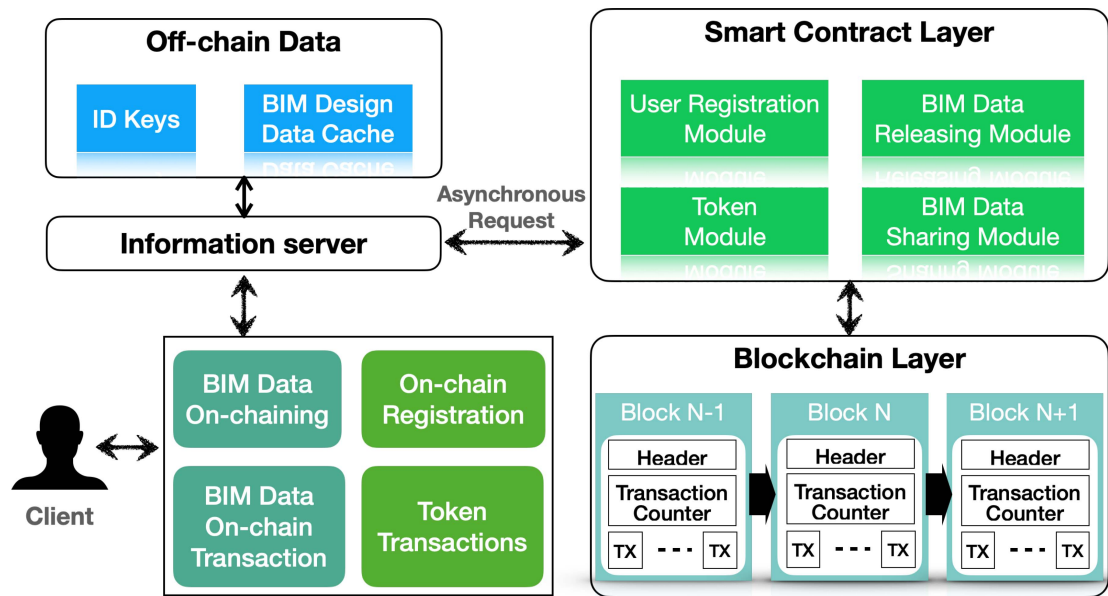


FIGURE 9. Blockchain-based BIM data transaction system framework.

may be possible to achieve distributed storage of data in a large BIM design engineering. However, how to protect the privacy of metaverse users and BIM engineering data will be crucially challenging in future.

## VI. CONCLUSION

BIM technologies and blockchain are regarded as significant roles in the ever-expanding metaverse. For example, metaverse applies BIM technologies to create and design the fundamental components of virtual world, such as buildings, cities and even plants, in which anyone can safely and freely engage in social activities that transcend the limits of the physical world. By reviewing the most related works on digital twins, BIM technologies and applications in the virtual world, and blockchain-empowered applications, we expect to provide a thoughtful review to the researchers from both academia and industries. Finally, we envisioned critical challenges and open issues in designing the fundamental components of metaverse with the fusion of BIM and blockchain.

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