A review of BIM data exchange method in BIM collaboration

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Abstract: Nowadays, building information modeling (BIM) plays a crucial role in project collaboration. BIM information should be freely exchanged among different stakeholders for the purpose of collaboration. With the development of Information and Communication Technology (ICT), there are many novel data exchange methods for BIM information exchange. However, little literature has attempted to review the current status of BIM data exchange methods. This study aims to provide a comprehensive summary of the status quo of BIM data exchange methods, including file-based method, cloud-based method, and three local data exchange methods. The advantages and disadvantages of each method are identified. This paper reveals that more efforts should be paid for enhancing the capability to deal with large Industry Foundation Class (IFC) files; a more stable, consistent identifier that can uniquely and easily identify an object should be developed; more opportunity in integrating BIM with some emerging technologies, like blockchain, should be seized to solve the problems in BIM data exchange. This study presents an in-depth analysis of the current BIM data exchange method and helps the industry and academia to identify the existing gaps

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and future directions.

Keywords: Building information modeling (BIM); Data exchange; Collaboration.

1 Introduction

Since building information modeling (BIM) first appeared in journal articles[1], BIM has aroused widespread interest in academia and industry in many countries. BIM serves as a digital representation of physical and functional characteristics of a facility, which can be shared among various stakeholders[2]. The richness of data in BIM provides a brand new way that people design, construct, and operate a building. From this point of view, BIM has led to great transformation in Architecture, Engineering, Construction, and Operation (AECO). BIM is not only a tool for representing facilities but also a project and process management technique, covering almost all the information related to the project[3].

Recent years have witnessed a surge of leveraging BIM technology in a variety of applications. It is reported that BIM increased labor productivity from 75% to 240% within a small contractor[4]. With the help of BIM, Lee et al. proposed an ontological method to automate the inference process and gain a more precise cost estimation, reducing the amount of manual work[5]. Liu et al. also developed a framework for integrating change management with BIM and created an automated model updating workflow[6]. Besides, BIM has been regarded as a powerful and disruptive tool for education and training to boost education design and students' learning outcomes[7]. Grilo and Jardim-Goncalves proved that BIM has effectively promoted electronic procurement in the AECO sector[8]. In these cases, BIM can benefit project management a lot.

Another significant advantage of BIM lies in project collaboration. BIM has the ability to improve the collaboration between stakeholders, including owners, architects, engineers, contractors, and suppliers, by conveying accurate information efficiently[9]. The concept of “collaboration” refers to a process during which participants collectively evaluate their differences and seek cooperative solutions that are beyond the vision and capacity of any single individual participant[10]. From a project management perspective, collaboration means an agreement that some experts share and exchange their expertise, information, and experience to fulfill a specific task and reach the project aim[11][12]. The lack of collaboration in construction projects has been heavily criticized in the literature[12]. The advent of BIM technology provides a digital information platform for the collaboration of construction projects. Information exchange, corresponding to data exchange in BIM, is a crucial basis for participant collaboration. BIM, as a pool of digital data, can convey the proper information to proper participants with the assistance of modern Information and Communication Technology (ICT).

However, BIM-enabled data exchange is also faced with several problems from both social and technical aspects. For the social issues, Gielingh identified the lack of motivation, legal concerns, and industrial unreadiness when integrating BIM into collaboration[13]. In 2004, Kam and Fischer summarized some of the technical problems, such as geometric misrepresentation, loss of object information, application-specific input/output, time-consuming one-way conversion processes, and so on[14]. With the rapid development of BIM and ICT technology, many aforementioned problems have already been solved, and many new ones have emerged. Nevertheless, there is very little literature regarding the current BIM data exchange methods.

This study aims to provide a comprehensive elaboration of the status quo of the prevailing BIM data exchange approach from a technical perspective. Section 2 reviews the file-based data exchange method. The cloud-based approach is reviewed in Section 3. Moreover, three local data exchange method is summarized in Section 4. Conclusions and future directions are given in Section 5.

2 File-based data exchange

File-based BIM data exchange is to directly transfer a specific file to the receiver manually. In the early stages of BIM development, different software vendors had their own file formats, which can not be recognized by other software. It caused much trouble in project collaboration when the stakeholders used different software. Therefore, as expected, Industry Foundation Class (IFC) format, as a neutral data format, has been widely accepted by existing BIM collaboration standards and various software vendors[15]. Many recently developed applications and studies are based on IFC format[16][17].

Exchanging IFC-based files is the most simple and straightforward way of communicating BIM information. In IFC schema, one can easily extract a subset of data from the overall model via Model View Definition (MVD), a pre-defined subset of the IFC schema in light of the receiver's need[18].

However, file-based exchange transfers information in a one-way manner, leading to the results that designers should transfer files repeatedly in each design iteration to ensure all the design changes are considered[19]. The request for BIM information and file transfer is manually made often through emails or other correspondence. And current file-based exchange technologies are incapable of managing data inconsistencies and redundancy, with network resources occupied by excessive files[20]. Moreover, the file-based exchange is unlikely to provide object-level data management without auxiliary tools. For example, different participants may have different access privileges. For a file-based system, the accessibility of data can only be regulated on a file-level instead of an object-level[21].

3 Cloud-based data exchange

Cloud computing has long been regarded as transforming information technology. The most widely accepted definition of cloud computing stated that "Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction"[22]. The benefits of cloud computing come in many aspects, such as low cost, scalability, independence of hardware, and venue[23]. Three common cloud service architectures are identified: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). By deployment model, cloud service can also be categorized into four types: Private cloud, Community cloud, Public cloud, and Hybrid cloud. The advent of cloud BIM is considered to realize the function of real-time data exchange[24]. There are already a number of vendors developing their own cloud services, such as Graphisoft's BIM Explorer (BIMx) and BIMcloud, Autodesk's A360, and BIM360, BIMServer, ONUMA System, and Trimble QuadriDCM and Trimble Connect[19].

By combining cloud computing and BIM technology, cloud BIM promises to solve some of the problems, such as lack of computing power and high cost[20]. Cloud BIM also allows real-time access to data, on-demand access to computing resources and applications, which potentially provides a high level of collaboration in a consolidated model[19].

However, the collaboration between various cloud BIM software provided by different vendors is difficult[25]. The open standards for cloud BIM collaboration, like IFC schema, are expected to be developed to tackle this issue[19]. More importantly, organizational and legal problems are regarded as the major obstacles to implementing cloud BIM[24]. For example, shared common platforms, like cloud BIM, create significant vulnerability and uncertainties towards privacy and information security due to its nature of openness and decentralization[26]. Redmond et al. maintained that the current contract does not cover information about the ownership clarity of the BIM model[27]. The lack of a clear statement about responsibility and liability can hinder the adoption of cloud BIM. Moreover, the promotion of cloud BIM is in urgent need of a large number of technicians and professionals to adapt to this new technology[24][27].

4 Local data exchange method

The above two methods are general methods for BIM data exchange. Recently researchers have developed some other approaches to deal with local data exchange for partial models, including the serialization method, transaction-based method, and blockchain-based method.

4.1 Serialization method

Some researchers attempted to serialize the contents of IFC files in order to store, transfer, identify, trace objects. Data serialization refers to encoding IFC objects into a format or data structure that can be stored or sent to other applications[28]. The data structure is critical for exchanging data and other applications at an object level.

One of the serialization methods is the "flattening" method. Data exchange relies on an identifier (e.g., the reference number of each line in IFC files and Globally Unique Identifier (GUID)) to trace objects. The line reference number serves as a local reference of an object, but only valid within one file[29]. With the help of these reference numbers, IFC files are organized into an object-based inheritance hierarchy[30]. GUID is a unique and reproductive 128-bit number for identifying objects[31][32]. Different software has different internal data structures and editing operations, which results in the inconsistency and inadequacy of both the reference number and GUID to be an identifier during the IFC roundtripping process[33][34]. Some techniques have been developed to avoid using the reference number or GUID as an identifier. The "flattening" method, proposed by Lee et al.[35], is to replace the reference numbers with the actual values by a recursive strategy and decode nested relationships between various instances to form a full and unique description string for an IFC instance itself[36]. In this case, each line of IFC files does not include any reference, and the hierarchical structure is "flattened". Each object can be identified by this unique string directly, not affected by the unstable reference number or GUID. However, such a flattening process may be sensitive to redundant instances[34] and produce an overly long string, which costs a lot of computing resources and time[33].

Some other studies seek to convert an IFC file into a graph. Arthaud and Lombardo developed a method to transform IFC files into oriented graphs[37]. Oraskari and Törmä derived an RDF graph from IFC files and used a Short Paths Crossings Algorithm (SPCA) to assign an identifier to those instances that do not have a GUID[29]. However, these graph-based methods depend more or less on the GUID and can be very time-consuming when IFC files are too large. Additionally, these methods can not cope with duplicate instances[34].

4.2 Transaction-based method

Froese pointed out that collecting common data in a centralized server allows various flexible data management services and enables a series of transaction-based IFC exchange with proper data exchange protocols between distributed parties[38]. Jørgensen et al. developed an IFC model server, supporting functions such as working on partial models, granting different access rights to different users, and versioning on an object level[39]. Du et al. realized the real-time information interaction between BIM and VR via transactional data exchanges[32].

These transaction-based data exchange applications benefit from GUID, which could be used to index an object for each transaction. Nevertheless, its disadvantages also lie here. GUID has been criticized for its inconsistency and instability[33].

4.3 Blockchain-based method

Since Nakamoto proposed the prototype of Bitcoin in 2008, blockchain, as its core technology, has been a buzzword around the world[40]. Nowadays, blockchain has evolved from version 1.0 to 4.0[41]. Blockchain technology has permeated into all walks of life, including the AECO industry. It can be used to facilitate the BIM collaboration process.

Xue and Lu developed a semantic differential transaction (SDT) approach to capture model changes as SDT records and chronologically collect them into a BIM change contract (BCC)[36]. All the stakeholders can submit their BIM changes to the blockchain, and all history changes of the project are stored in one blockchain, unchangeable. This method addresses the challenge of information redundancy in integrating BIM and blockchain, and turns out to be light and lean, suitable for performing heavy computation[36].

However, the conflict-resolving mechanisms need to be improved by some other sophisticated models[36]. And only two pilot case studies were conducted to prove the feasibility of the SDT approach. More tests considering extensibility and compatibility problems should be carried out within real blockchain shells in the context of practical construction projects[36].

5 Conclusions

BIM data exchange plays a crucial role in BIM project collaboration. With the development of Information and Communication Technology, some previous problems are already solved while some new issues emerge. In this study, the current BIM data exchange methods are comprehensively reviewed. For the file-based data exchange method, it is regarded as the most straightforward way. Still, its disadvantages lie in its one-way file-transfer manner and incapability to manipulate at an object level. For cloud-based data exchange method, it is praised by efficiency, low cost, real-time access to data, and on-demand access. However, the cloud BIM also faces the problem of lack of open cloud BIM standards, and too much organizational and legal issues, such as privacy, information security, lack of sufficient technicians, and ownership and responsibility clarity. There are some local data exchange approaches developed for partial model exchange. The "flattening" method dissolves all nested relationships between objects and identifies an object by a unique string. Others tried to convert IFC files into a graphic structure. However, these methods are not applicable to large IFC files and depend on the unstable GUID more or less. For the transaction-based method, most of them are based on the GUID, which might be inconsistent. With the help of blockchain, a novel semantic differential transaction (SDT) approach collects the model changes into a blockchain, better solving the problem of redundancy. However, this is a brand-new method, requiring more consideration, such as conflict-resolving mechanisms, extensibility, and compatibility.

Future research directions should focus on: (1) developing an algorithm to deal with large IFC files with less computing time and resources; (2) finding a unique, stable, consistent, and easy-to-use identifier to track IFC objects throughout the building life-cycle; (3) exploring more about the potential of blockchain and other emerging technologies in facilitating BIM data exchange.

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