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A multi-server information-sharing environment for cross-party collaboration on a private cloud

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ABSTRACT

Interoperability remains the key problem in multi-discipline collaboration based on building information modeling (BIM). Although various methods have been proposed to solve the technical issues of interoperability, such as data sharing and data consistency; organizational issues, including data ownership and data privacy, remain unresolved to date. These organizational issues prevent different stakeholders from sharing their data due to concerns regarding losing control of the data. This study proposes a multi-server information-sharing approach on a private cloud after analyzing the requirements for cross-party collaboration to address the aforementioned issues and prepare for massive data handling in the near future. This approach adopts a global controller to track the location, ownership and privacy of the data, which are stored in different servers that are controlled by different parties. Furthermore, data consistency conventions, parallel sub-model extraction, and sub-model integration with model verification are investigated in depth to support information sharing in a distributed environment and to maintain data consistency. Thus, with this approach, the ownership and privacy of the data can be controlled by its owner while still enabling certain required data to be shared with other parties. Application of the multi-server approach for information interoperability and cross-party collaboration is illustrated using a real construction project of an airport terminal. Validation shows that the proposed approach is feasible for maintaining the ownership and privacy of the data while supporting cross-party data sharing and collaboration at the same time, thus avoiding possible legal problems regarding data copyrights or other legal issues.

1. Introduction

The architecture, engineering, construction (AEC) industry and the facilities management (FM) profession work with highly diverse sets of information and models [20], which are fragmented into different file formats and applications. An AEC/FM project requires collaboration and exchange of information among many parties, including the owners, architects, engineers, estimators, surveyors, contractors, and regulators, among others. Building information modeling (BIM) involves not only the digital representation of physical and functional characteristics of a facility but also the process of creating, using, and maintaining a shared knowledge resource that forms the basis for decision making throughout the lifecycle of a facility [6]; BIM has now emerged as the means for information exchange among the various parties involved in construction projects [15].

With years of research and development, there have been many significant developments and implementations of BIM technologies from researchers and software vendors to support information exchange and encourage collaborations among the parties involved in a project. As the AEC/FM industry moves toward the use of BIM tools, digital design models are now being embraced as the primary medium for information exchange. There is a wide variety of BIM tools that serve the AEC/FM industry, covering many different domains [6]. However, no single application can provide all the services or functionalities required by the AEC/FM industry. Because companies use different tools, each has its own internal model and data representation; thus, interoperability has become one of the main challenging issues for collaboration [15,18].

The term "interoperability" can be defined as the ability of diverse systems and organizations to work together (interoperate). There are two fundamental interoperability issues: software interoperability and organizational interoperability. Software interoperability, as noted earlier, occurs due to the diverse sets of tools used in the AEC/FM industry. Organizational interoperability occurs due to the characteristics of distributions and collaborations in different organizations. For example, a general contractor (GC) may establish a server to manage and share all the data collected from different subcontractors to form a unified model of a large project. Since the data server is controlled by

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the GC, subcontractor loses ownership of his data actually though he should own the data as agreed in the contract. Meanwhile, a subcontractor may just want to share his cost calculated according to the contract but not to share his real cost and work efficiency, which is his core competency. The main problem of organizational interoperability involves issues of responsibility, liability, stability, model ownership as well as data consistency, and data availability [16,29].

To date, many attempts have been made to enhance software interoperability. Among them, an open BIM data standard known as Industry Foundation Classes (IFC) has been proposed. Using the IFC standard, the BIM data are delivered through a unified and open data format to enable software tools to understand the information through the IFC schema [25]. Although most current research and development efforts focus on technical implementations to support software interoperability, organizational interoperability issues [1,30], such as who owns the model and who is responsible for the usability or the validity of the model, remain unresolved.

Previous studies have largely addressed software interoperability issues without careful consideration of organizational issues [16]. In this paper, we first provide a brief review of interoperability within the AEC/FM sector and identify some of the shortcomings of the current approaches on data exchange to support cross-party collaborative environments. To address the organizational interoperability, we propose a multi-server approach based on a private cloud platform and discuss its applicability in cross-party information exchange and sharing. Specifically, a requirement analysis of BIM data services for data exchange among stakeholders is presented. Based on the requirements analysis, a multi-server service architecture that includes technical approaches that are designed for cross-party model data distribution, integration, and management is presented. Finally, a scenario that utilizes real project data is presented to illustrate the multi-server framework.

2. Review of current approaches on cross-party data exchange and collaboration

This section reviews the major approaches related to organizational interoperability issues with regard to supporting cross-party and multi-disciplinary/multi-user collaborations, namely, file transfer, central database, single server and cloud-based server (see Fig. 1).

2.1. File transfer

Analogous to the traditional practice of delivering data through drawings and documents prior to the popularization of computer and information technology (IT), the industry now delivers such information as electronic documents. Nevertheless, printed documents and drawings remain the most common norm for archiving and publishing project information. AEC/FM software tools often retain a proprietary internal file format. However, using STEP's EXPRESS\EXPRESS-G as the data modeling language to define entities, attributes, and constraints, the IFC standard has been formulated and designed to support model exchanges for a wide range of applications that are commonly used by the construction industry [20]. Many commercial vendors now provide IFC interfaces for their software tools. Many researchers and users have taken advantage of the IFC interface to enable software interoperability among the tools. However, even with the IFC interfaces, as illustrated in Fig. 1(a), the mode of data transfer is to deliver information in the form of data files among stand-alone applications.

In a multi-party scenario with this approach, each organization has many participants, and each participant has access to many applications. This practice leads to a significant number of files being transferred back and forth during a project, and object-level management of BIM data is impossible in this approach. Thus, this approach has the inherent problems of data redundancy and inconsistency because process control is difficult to enforce.

2.2. Central database

One way to avoid the data redundancy and inconsistency problem is to employ a central data repository, such as a database. As shown in Fig. 1(b), the participants of a project run their applications by accessing the data from the central, shared database. Currently, it is not uncommon that a centralized BIM database is set up by the project owner, manager, or BIM consultant for collaboration purposes. The project participants are then assigned access to the centralized BIM database. This approach provides a unified view of the BIM data for the users. However, with this approach, there lacks a generalized layer for model validation, subset extraction and integration, and thus, different participants must implement similar functions based on a central database by themselves. This approach leads to reworking the applications development and could cause data corruption and unauthorized access.

2.3. Single server

An improved method for sharing information among the participants is to set up a BIM server for different users and their systems; this approach extends beyond the central database approach and is influenced by the service-orientation concept in the software industry [28]. Different from the central database approach, the BIM server provides not only a centralized BIM database for the storage of information but also certain services (such as common functionalities and processes) for accessing information within a safe and reliable environment, as shown in Fig. 1(c). Because the server takes charge of some functional tasks, the client side (e.g., BIM tools or software) can be simplified to the maximum extent, which means that lightweight clients (e.g., web browsers or mobile devices) can run BIM applications smoothly.

Specifically, aside from data, the BIM server also provides additional functions based on the data, such as model scanning, three-dimensional viewing, versioning, and conflict checking. For example, Faraj et al. [11] proposed a collaborative construction computer environment, WISPER, which was established on a web server, where the underlying data were stored using an object-oriented database designed to integrate visualization, cost estimation, project management, and supplier information. Chen et al. [23] proposed a browser-server (B/S) structured information server, in which Java and Java3D were applied to achieve user interaction and visualization; a useful algorithm to transfer the architectural model into a structural model was also proposed by analyzing the topological relationships among the building components. Plume and Mitchell [14] reported a use case of the BIM server for a collaborative design process in a teaching context where a model server based on an express data management (EDM) technology was adapted to process and share IFC model data. The report noted that the EDM model server considered overall models rather than achieving sub-model extraction or delivery. Three representative BIM server solutions are the IFC Model Server developed by VTT Building and Transport and SECOM Co. Ltd. [2], the EDM model server developed by Jotne EPM Technology [17], and the Bimserver.org developed by TNO Netherlands and TU of Eindhoven [12]. These are B/S structured or client-server (C/S) structured, and they feature the functions of importing and exporting the IFC model.

To identify what information should be shared and how to share it, BuildingSMART presented a process definition standard called Information Delivery Manual (IDM) to address when certain types of information are required during the construction of a project or the operation of a built asset [31]. BuildingSMART also presented a model view definition (MVD) to identify the prerequisites and outcomes of the processes for information exchange. An MVD defines a subset of the IFC schema that converts the IFC model into IFC sub-models according to one or many exchange requirements of a certain process [20].

This single-server approach is advantageous due to its ability to support process-oriented sub-model applications because the sub-model