A Framework of Cloud-computing-based BIM Service for Building Lifecycle

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ABSTRACT

With the amount increasing, the BIM (Building Information Modeling or Building Information Model) data exchange and sharing face a series of challenges including integration of disparate data models, fast information extraction and data consistency maintenance. Since the existing BIM data storing and transferring method based on neutral files or a centralized database cannot meet the above-mentioned requirements, a framework of distributed BIM service on a private cloud platform was proposed. By this BIM service, multi-stage participants store relevant data on their own servers, which are virtually integrated through a CC (cloud computing) platform to form a logically complete BIM. It supports participants to establish, manage and transfer consistent BIM data efficiently with ensuring of data privacy. To achieve this BIM service, a BIM integration and service platform (BIMISP) based on IFC (Industry Foundation Classes) and CC was developed. Proved by experiments, the research achievements are useful for improving the efficiency and quality of information extraction and delivery, ensuring the safety and legality of data sharing during building lifecycle.
Keywords: BIM; Distributed server; Virtual integration; Cloud computing; Building lifecycle;

INTRODUCTION

Nearly 10 years, Building Information Modeling (BIM) has developed rapidly in theory, technology, standards, systems and other aspects. On the other hand, BIM data are still mainly stored and transferred in the form of files whose formats includes software vendors' internal format (i.e., Autodesk's '.rvt' format) or neutral format (i.e., Industry Foundation Classes (IFC) file format '.ifc'). For instance, a design model established using Revit is stored and transferred through '.rvt' or '.ifc' files. Other specialized software tools for performance analysis, construction management, etc. that need to share the design model have to be provided with such specific interfaces for file importing/exporting. Lately, some server-based BIM solutions were advocated to provide a unified BIM service to all participants by establishing a single-sourced data server (Faraj et al. 2000, Chen et al., 2005, Kiviniemi et al. 2005).

Accompanied by a series of technological breakthroughs, the CC (cloud computing) technologies have made great progress in recent years. Today, almost all major IT companies are involved and playing extremely important roles in this field. By applying CC in BIM service, a higher performance can be achieved with a relatively low cost. Although a cloud-computing-based BIM (cloud-BIM) server seems a good solution in current situations, there is still a question to be answered: as a service, who should be the host in building projects? In typical commercial cloud computing applications, normally the software vendors provide hardware, software or platform services to handle the users' requests. But in the construction industry, this is a complex issue that involves benefits, legal and intellectual property. A construction project involves enterprises including owners, designers, contractors, consulters and so on. Each of them has its own privacy and responsibilities, even though the owners own the products, they don't have the access to the entire data. It is more infeasible to deliver the project data to a third-party vendor.

This paper proposes a framework of distributed BIM service on private cloud platform, providing a solution to the aforementioned problems. The distributed data storage and the private cloud platform can ensure the security of data benefiting from the CC technology.

LITERATURE REVIEW

BIM server. Faraj et al. (2000) proposed a collaborative construction computer environment, WISPER, which was established on a web server, the underlying data is stored using an object-oriented database, designed to integrate visualization, cost estimating, project management, and supplier information. Chen, P. H. et al. (2005) proposed a browser-server (B/S) structured information server, in which Java and Java3D were applied to achieve user interaction and visualization, and a useful algorithm to transfer the architectural model into structural model was also proposed by analyzing the topological relationship between building components. Plume and Mitchell (2007) reported a use case of BIM server for collaborative design process in a teaching context where Express data management technology (EDM) Model Server was adopted to process and share IFC model data. The report noted that EDM Model Server deals with overall models rather than achieving sub-models extraction or delivery. In fact, most existing BIM servers published by research institutions and software vendors still have potentials for improvement in both functionality and performance.

1) IFC Model Server is a SQL Server-based BIM server developed by VTT Building and Transport and SECOM Co., Ltd. Based on B/S structure, it allows variety of users to interact with the server through a browser. IFC Model Server realized BIM data storage, extraction and management based on sub-model query language PMQL. However it does not provide strict sub-model validation, mechanism of data consistency maintenance (Kiviniemi et al., 2005).
2) EDM Model Server is an IFC model server based on EDM developed by Jotne EPM Technology (Jørgensen et al., 2008). EDM Model Server is client-server (C/S) structured, enables to import and export the IFC model with version control. The server also remains to be improved in sub-models integration, sub-model view definition and non-IFC format engineering information management and harmonization.
3) Bimserver.org is an IFC-based open source BIM server developed by TNO Netherlands and TU of Eindhoven, which is a C/S structured system. Bimserver.org covers the functions of IFC model import, export, modify tracking, model filtering and query (Beetz et al., 2010). The sub-models extraction and integration, the concurrent access control, and the model consistency constraints methods are not yet complete.

In short, the sub-models extraction and integration, non-IFC format information harmonization, data consistency maintenance and concurrent access control in BIM servers need further studies. Also, the existing BIM servers using C/S or B/S structure are not adapted to the decentralized, heterogeneous and dynamic created engineering information, thus not totally supporting the lifecycle BIM application with enough efficiency, performance and stability.

Review on Cloud BIM. Last few years, with changes in the field of computer science raised by CC technology spreading to all areas, Cloud BIM becomes a new research area. Chuang et al. (2011) utilized CC to develop a visual system for BIM visualization and manipulation through the web without the limitations of time or distance. Amarnath et al. (2011) proposed a conceptual framework using BIM on the cloud for construction project, and developed a Revit Server for testing. Redmond et al. (2012) conducted a semi-structured interview of 11 expert respondents, on using CC as integration platform for BIM applications, followed by discussion on how information could be exchanged through Cloud BIM. By adopting CC and augmented reality technology in BIM, Jiao et al. (2013) developed systems that integrated with business social networking services. Associated with the BIM server, Cheng and Das (2013) proposed a cloud based framework to support partial data retrieval and updating using a centralized server.

As applications based on CC have the efficient and low-cost advantages, the CC technology has great potential values in various fields. Meanwhile, in contrast, the existing BIM applications in desktop mode have disadvantages of lack of computing capacity, application range limitation and higher cost, showing that the combination of BIM and CC is a promising trend. Most current researches focused on using CC to improve the performance at specific points, the technical routes and security issues of the cloud-based BIM approach still need to be studied.

ARCHITECTURE OF CLOUD-COMPUTING-BASED BIM SERVICE

As mentioned before, the existing file-based data transfer method is not suitable for BIM applications because of incapability of managing data redundancy and inconsistencies, with occupation of network resources, while the centralized BIM service approach solves these problems, but it causes data permission problems when obtaining engineering data from project participants. Under these circumstances, it is expected to build distributed BIM services. **Figure 1** shows the difference in these three BIM data sharing modes. The distributed BIM service mode is evolved from the centralized mode with difference of that multiple enterprise servers are used instead of a central server, and these servers together constitute a virtual integration platform in the distributed mode.

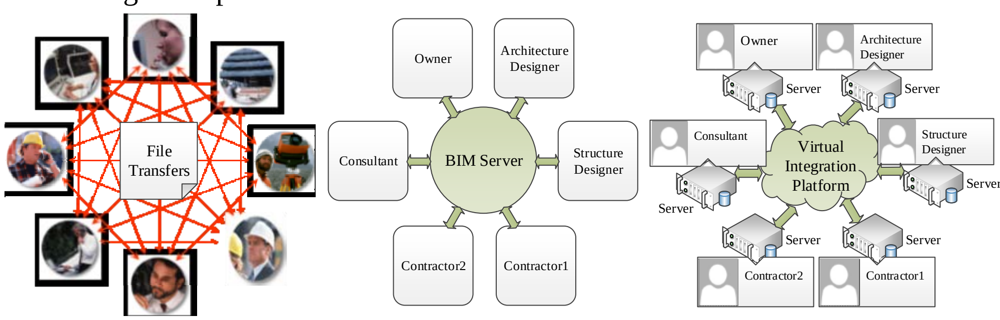

Figure 1. File transfers, centralized service, and distributed service

Normally, a construction project involves a number of enterprises, and each enterprise may operate multiple projects simultaneously. Therefore, the information management and service can be either project-oriented or enterprise-oriented. Combining the project information service for BIM with the enterprise information management is worth of consideration. Once the multi-participants' enterprise databases and servers are linked together within a cloud data platform, data of each participant serves as a sub-model of the overall BIM. Also, there is a virtual platform dealing with the integration, data exchange and sharing, model management and other matters instead of a central server as shown in **Figure 2**.

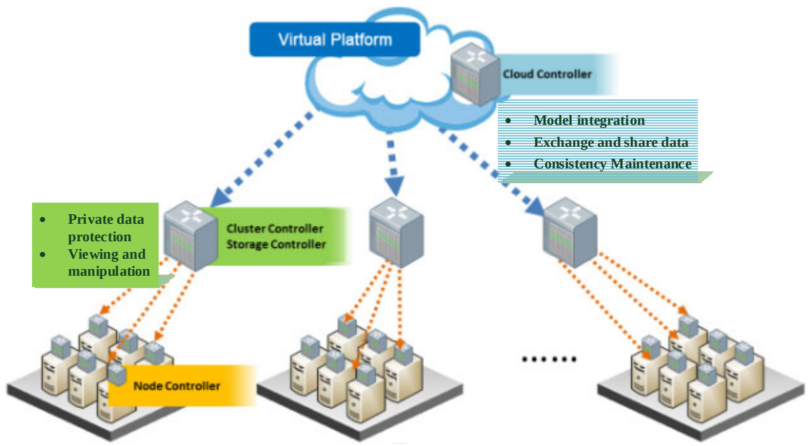

Figure 2. Schematic view of distributed cloud platform

There are two meanings of distribution in general, one is the data sliced into blocks and stored in different physical locations, and the other is the data stored in cluster of computers with duplication. Meaning of the term in the preceding text is the former, but the latter distribution also exists inside the enterprise server. **Figure 2** shows the concept of this two-level distribution, in this architecture, Hadoop clusters are used to set up the enterprise servers. Hadoop is a framework that allows for the distributed processing of large data sets across clusters of computers using simple programming models. **Figure 3** is the physical structure based on Hadoop framework, each enterprise server comprises of the distributed file system layer, the distributed database layer and the platform communication layer, and the users get the result of unified resources allocation among these enterprise servers through a web service, thereby minimizing the network transmission load.

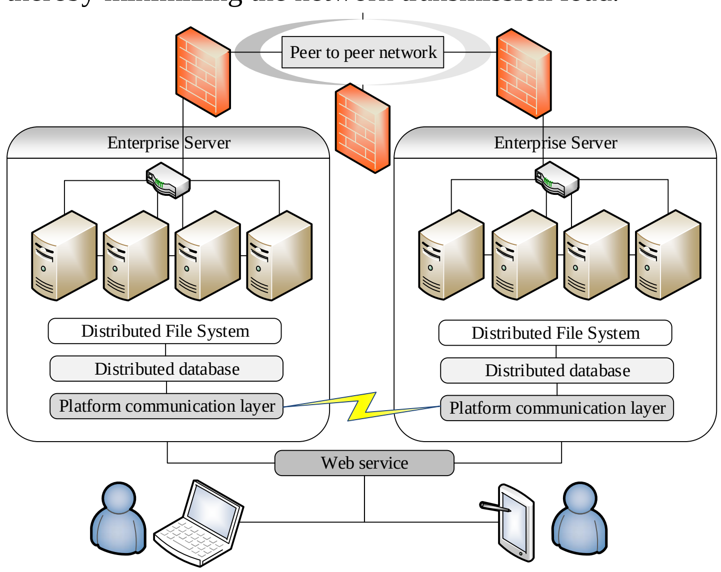

Figure 3. The physical structure of distributed BIM service

DEVELOPMENT AND USE CASE STUDY

Based on the preceding approach of cloud-computing-based BIM service, the BIM integration and service platform (BIMISP) is proposed to provide a platform for BIM data integration and sub-models extraction for multi-disciplinary users. The BIMISP primarily includes modules of distributed data storage, distributed BIM data integration and management, and sub-model extraction. It was developed on a BIM platform by Zhang (2009), which is a C/S structured system using SQL Server and provides functions of IFC parsing, sub-models extraction and integration, 3D visualization, etc.

In addition to the existing features, a semi structured distributed BIM storage system has also been developed. The storage system is built on Hadoop Hbase, which is a typical open source NoSQL database used in large companies like Facebook. HBase is column-oriented and suitable for storing structured IFC data and supports users to query BIM data in many ways. As the object-oriented features of the IFC data, to define a table for each class is inefficient for requiring a large number of "Join" operations. Therefore, a semi-structured IFC storage method is proposed. According to the IFC, only independent exchangeable entities (with GlobalId) will be extracted or modified and the resource entities cannot be accessed independently, so the corresponding table for resource entities may not be created, and these entities are serialized into binary data stored in the corresponding unit (Cell in Hbase) as attributes of independent exchangeable entities. To reduce data redundancy, if an attribute is also an independent exchangeable entity, only the GlobalId will be stored. Thus, we can extract information directly from the IfcProduct table by GlobalId without the need for complex multi-table "Join" operation so that greatly improves the efficiency. **Table 1** shows the table of IfcProduct as an example.

Table 1. Table of IfcProduct

Column family	Column	Value
B (base)	Row Key	GlobalId
	Timestamp	Timestamp
	OwnerHistory	Serialization of IfcOwnerHistory
	Name	String
	Description	String
	ObjectType	String
G (geometry)	ObjectPlacement	Serialization of IfcObjectPlacement
	Representation	Serialization of IfcProductRepresentation

The tests are running on the Xing Fen highway project, which is located in Hebei and Shanxi Province with total length of 84.329 km. Xing Fen highway is divided into 14 sections involving a total of 16 companies. We build data nodes at three different sections and stored the section BIM in distributed servers. The study presented a comparative efficiency analysis of a centralized BIM server using relational database (Zhang, 2009) with the cloud BIM server proposed in this paper. **Table 2** lists the performance comparison between the relational database server and the Hbase-based server. The size of all original step format IFC files for geometric models is about 200M, the data size is about 800M saved in the relational database, and about 1120M in the Hbase-based server, which is 142% of the former. However, the time occupied for sub-models extraction in the former one is about 10 times in the latter one, apparently the Hbase-based BIM server has obvious efficiency advantages.

Table 2. The comparison of Hbase BIM databases and relational databases

	RDBMS	Hbase	Ratio (Hbase/RDBMS)
Size (mb)	800	1120	140%
Time for loading (s)	543	230	42%
Time for sub-models extraction (s)	1240	132	10%

1. CONCLUSION AND OUTLOOK

By considering the problems of distributed BIM data sharing and management in construction projects, a framework of cloud BIM service for building lifecycle was proposed. In this framework, the multi-disciplinary users are allowed to store the relevant data in their own server while the overall data were virtually integrated through a CC platform. Specifically, a semi structured distributed BIM storage system based on the IFC was developed. Tests and comparison showed that this storage system avoided the complex multi-table join operation through semi-structured data storage, improving the efficiency of information extraction, with sufficient extensibility for the growing BIM data. It also proved that the proposed framework was suitable for multi-participants BIM applications. In summary, the proposed cloud BIM service has significant advantages in the data storage strategy, transfer efficiency, consistency and security compared to most of the existing methods, and thus has great potential values in research and application.

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