BIMCloud: A Distributed Cloud-based Social BIM Framework for Project Collaboration

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ABSTRACT

Building information modeling (BIM) aims to facilitate information management and collaboration among stakeholders in different domains over the building life cycle. BIM models are increasingly used as an object-based information hub for storing, integrating and managing building information in different aspects. Over the building life cycle, stakeholders like the owner, designers and subcontractors keep reviewing and commenting on different building components, but these social interactions are often not recorded and managed in a structured manner. This paper presents a distributed cloud-based BIM framework that was designed to support collaboration among project participants and information sharing. The framework, namely BIMCloud, was developed based on Apache Cassandra which can be deployed on public cloud servers like Amazon EC2 or private cloud servers hosted in own infrastructures. A schematic data structure was also developed to capture the building component-based social interactions, which could be used for mining and post-processing to generate knowledge in the future. The BIMCloud framework stores BIM models based on the IFC schema and the developed schema for Social BIM. Therefore, people can make changes to the BIM models in the BIMCloud framework by transferring only a partial BIM model. An example scenario is presented in this paper.

INTRODUCTION

The AEC (architecture, engineering, and construction) industry requires much collaboration among the project stakeholders, which can be improved only by making the communication more efficient. As the AEC industry is information dependent, a lot of formal and informal communication take place through change orders, verbally, minutes of meeting, and documented guidelines. This information if captured well can form a body of knowledge which can be accessed by construction stakeholders throughout the lifecycle of the building under construction and other buildings. Therefore, there is a need to develop an integrated model which captures the social interactions along with building data and is easily accessible throughout the life cycle of the building. However, due to the fragmented and short-lived nature of the constructions projects, it is difficult to develop and maintain.

In this paper, we present a BIM (building information modeling) based distributed cloud framework, namely BIMCloud for capturing the social interactions of the construction industry. The architecture of this framework can facilitate Social BIM. Social BIM is a BIM which promotes collaboration among the BIM users by allowing them to work on an integrated framework. The users can comment and post information on the building elements of the building model. In our framework, we deploy an IFC (industry foundation classes) based schema which is an object based schema to capture social interactions along building information. The end users can update and comment on the building objects through this architecture. Our framework is passed on a cloud framework which is easily accessible through the Internet, requires no infrastructure implementation, and charges on a pay-per-use basis. Our framework is implemented on a distributed NoSQL database, namely Apache Cassandra which has high performance and fault tolerance. Cassandra can be implemented on Amazon EC2 cloud servers which can be easily accessible via a URL.

The rest of the paper is structured as research background, the proposed framework (BIMCloud), example scenario, and summary with future work. The research background introduces Social BIM, server based BIM and its deployability on the cloud based frameworks. The next section presents the architecture and data model of the proposed framework, BIMCloud. This is followed by an example scenario which demonstrates the use of BIMCloud in for capturing and using social interaction for a refurbishment project. This paper is concluded with summary and future work in the last section.

BACKGROUND

Social BIM and Interoperability. Social BIM is a BIM that is capable of communicating data with both building-related and non-building related applications. The opposite of Social BIM is Lonely BIM, which is the most common way of using BIM where the end users use BIM in an isolated manner and cannot encourage collaboration. The quality of collaboration depends on the effectiveness of the communication means. In Social BIM, there are two main approaches to communication between applications (Benson Sean and Fulton 2009) – (1) import and export, and (2) data synchronization through service oriented approach. In the first method, the two applications share data through a common format like IFC, COBie (Construction Operations Building Information Exchange), and XML (Extensible Markup Language) files. However, some non-building related applications created by organizations like finance, operations, and human resources (for example, organizations like SAP, Oracle, and PeopleSoft) may have their own data standards and therefore are not interoperable with BIM applications through import and export. In the second method, the BIM applications are deployed on a distributed SOA (service oriented architecture) based framework. External applications can choose from an existing pool services or deploy customized services to directly use the most updated BIM information stored on the SOA based framework. By leveraging web 2.0 technologies end users can **even** interact with the design team by sharing, posting, commenting or recommending ideas. (Suwal et al.

2013) propose a theoretical model of Social BIM for neighborhood development which allows sharing of visual plans and facilitates interaction among the people through a social framework of that area. Social BIM has potential **to** improve collaboration in the AEC industry, but the existing research does not provide much on implementation of such a framework.

Cloud Computing and BIM. A collaborative or Social BIM has the potential to change the behaviors in of the AEC industry. Cloud computing and BIM are two foundations which can facilitate the implementation of Social BIM. Cloud computing can be briefly defined as the technology to access services on the Internet. The services can be softwares (Software as a Service), infrastructure (Infrastructure as a Service), and framework (Framework as a Service). Accessibility from any location, scalability, and most importantly, cost-effectiveness are the key benefits of using cloud computing in the context of BIM. (Kumar et al. 2012) proposed a cloud based model for supply chain management. (Fathi et al. 2012) proposed a cloud computing based framework for sharing project information. This framework uses the context information of the end users like role, preferences, and site to improve collaboration between the project partners. (Redmond et al. 2012) conducted a semi-structured interview of 11 BIM experts and concluded that web based BIM exchanges on a cloud framework can lead to enhanced interoperability between different construction applications. Apart from these, there are commercially available cloud computing based frameworks like BIMServer and Autodesk 360 which store BIM information and provide functionalities like querying, merging, annotation on real time BIM model. However, none of the current approaches towards integrating BIM and cloud computing facilitates capturing of social interaction of the AEC industry along with BIM.

BIMCloud – DISTRIBUTED CLOUD BASED BIM SERVER FOR CAPTURING SOCIAL INTERACTIONS IN THE AEC INDUSTRY

Figure 1 shows our proposed framework for updating IFC building models through partial exchange of the building model. Our framework was developed based on the BIM-PDE (Cheng and Das 2013) engine that we developed earlier to manage BIM information in a distributed web server based approach. The architecture of our framework can be divided into three layers – (1) data flow controller layer, (2) data capture and extraction layer, and (3) data storage layer. The BIMCloud framework takes input in IFC data format and is extensible to comply with data formats like Excel. Customized applications are also easily deployable on top of our system to extract source data and any other data format or use the data stored in our system in external applications.

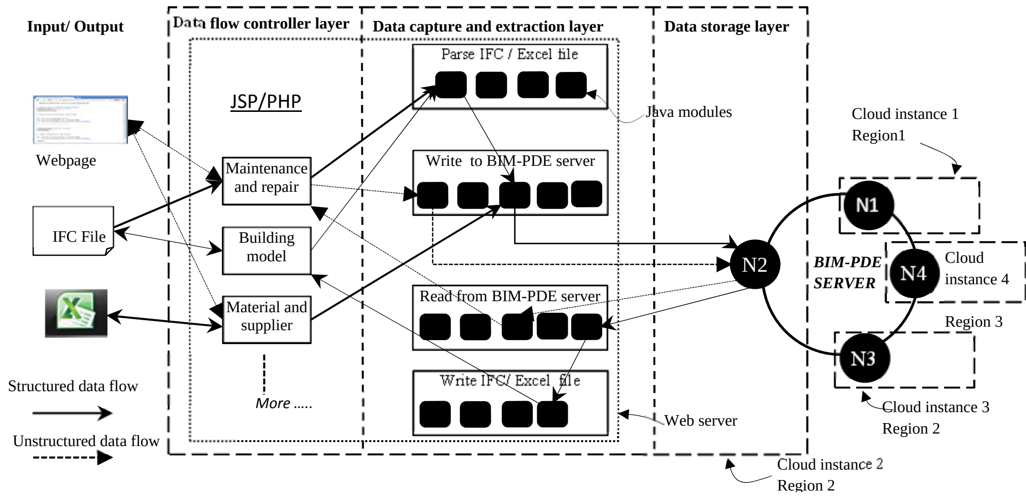

Figure 1. Schematic diagram of our proposed BIMCloud framework

Input and Output. The prototyped BIMCloud framework takes input in both structured data formats like IFC and unstructured data formats like user defined data through a user interface like a web page. Take renovation and maintenance as an example. Structured information on formal on-site communication like change orders and work orders can be represented and stored using the entities in the construction management and facility management domains of the IFC schema, which capture the information related to tasks and construction resources. Figure 2 shows the IFC schema of the IFCProjectOrder entity which is associated with one building components (as shown by HasAssignments in Figure 2) and can represent change orders, purchase orders, work orders, etc. Since, our framework is capable of performing partial information exchange, partial IFC files containing only facility management and construction management information may be inputted. Unstructured information like comments on the maintenance process being performed on a building component can be uploaded through a web page. Similarly, accidents, safety management, and supplier related data can be inputted.

Data Flow Controller Layer. This layer acts as the bridge between the cloud server and the end user. It contains web pages hosted on a web server like Tomcat web server, which can be accessed through the Internet via URL. The modules in this layer accepts request from the end users like "update maintenance data", or uploads partial building model files and passes the control to the next layer for data processing.

Data Capture and Extraction Layer. This layer facilitates the manipulation of raw data into a structured format for being uploaded to the BIMCloud server. This layer also has modules for extracting the key data from the BIM-PDE server. It has four different modules – (1) Parse IFC, (2) Write to BIM-PDE server, (3) Read from BIM-PDE Server, and (4) Write IFC.

```
ENTITY IfcProjectOrder;
    ENTITY IfcRoot;
        GlobalId                          : IfcGloballyUniqueId;
        OwnerHistory                      : IfcOwnerHistory;
        Name                              : OPTIONAL IfcLabel;
        Description                       : OPTIONAL IfcText;
    ENTITY IfcObjectDefinition;
    INVERSE
        HasAssignments                    : SET OF IfcRelAssigns FOR RelatedObjects;
        IsDecomposedBy                    : SET OF IfcRelDecomposes FOR RelatingObject;
        Decomposes                        : SET [0:1] OF IfcRelDecomposes FOR RelatedObjects;
        HasAssociations                   : SET OF IfcRelAssociates FOR RelatedObjects;
    ENTITY IfcObject;
        ObjectType                        : OPTIONAL IfcLabel;
    INVERSE
        IsDefinedBy                       : SET OF IfcRelDefines FOR RelatedObjects;
    ENTITY IfcControl;
    INVERSE
        Controls                          : SET OF IfcRelAssignsToControl FOR RelatingControl;
    ENTITY IfcProjectOrder;
        ID                                : IfcIdentifier;
        PredefinedType                    : IfcProjectOrderTypeEnum;
        Status                            : OPTIONAL IfcLabel;
END_ENTITY;
```

Figure 2. Inheritance graph of IfcProjectOrder for capturing the communications in change orders, purchase order, and work order

Data Storage Layer – A Distributed Cloud Based Server. In this layer, the building model is stored in a distributed NoSQL based database using the BIM-PDE engine (Cheng and Das 2013). The database is implemented on Amazon EC2 which provides cloud servers for implementing softwares and running them in a pay-per-use manner. EC2 supports softwares like Apache Cassandra, JSP, PHP, and Tomcat web server. Apache Cassandra has the capability to store and manipulate huge amount of data with high performance. It stores multiple copies of information in more than one location, and therefore prevents data corruption due to a faulty server component. In addition, the sever performance can be maintained to a standard as the system components can be scaled up or scaled down very easily according to the requirements. For network access control and security, Apache Cassandra provides ACLs (access control lists) only on the column family level. ACLs can be also implemented on the column level (Chervin et al. 2012).

EXAMPLE SCENARIO

In this section, we will demonstrate an example scenario for describing the functions of our proposed BIMCloud framework for capturing and accessing social interactions of the AEC industry. This scenario will describe a case of a high rise building whose second floor is under refurbishment. It is quite evident that the adjacent floors, Floor 1 (first floor) and Floor 3 (third floor) are likely to be affected. We would demonstrate how our framework, BIMCloud framework could facilitates collaboration among the construction stakeholders involved in this refurbishment project. As the project partners involved in this project like the maintenance worker, safety manager, and project manager are from different backgrounds and qualifications, they have the experience of working with different applications and data files like Excel and IFC. The

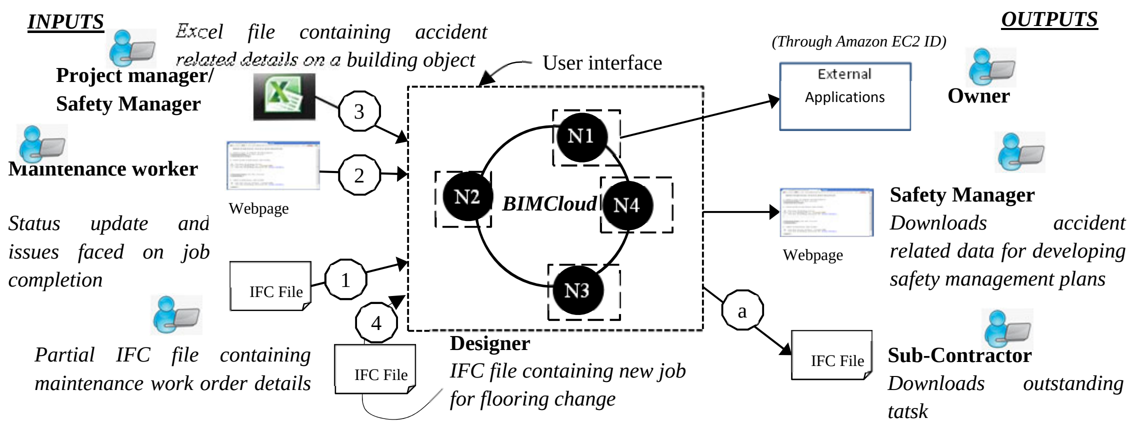

Figure 3. Example scenario demonstrating capture and retrieval of social interactions of a construction project

BIMCloud framework takes input from a variety of sources like IFC files, Excel spreadsheets, and web pages. Customized applications can also be deployed on top of BIMCloud through the URL of the instances provided by the cloud service provider.

Capturing Social Interactions for Future Projects. The site inspector employed by the owner inspects all the three floors and finds that the ceiling of Floor 1 is leaking at several places. The designer schedules the tasks for mending the leaking roof in the BIM model after the change orders for maintenance were approved by the owner. The designer then exports the IFC file of the BIM building model containing the scheduling information and uploads to the BIMCloud framework (as shown in step (1) of Figure 3). Figure 4 shows the schema for storing information from maintenance related project orders in IFC. Column family, “IFC_ProjectOrders” in Figure 4 shows the schema in the BIMCloud for storing the maintenance task related information from an IFC file. As shown in Figure 4, each maintenance task is associated with a building object or space in the column “relatedObjects”. In this case the related object is a floor designated by a unique ID, “IfcSlab_3zzzzzzzz1ALuJuYTi9$hOE” (as shown in (a) of Figure 4). The maintenance worker performs the maintenance work and updates status and comments columns of “IFC_ProjectOrders” with the status of the task and technical issues faced during the task respectively through a website interface to BIMCloud (as shown in the comments column of IFC_ProjectOrders in Figure 4). This is an example of capturing social interaction on an integrated BIM model which can be later investigated to find the most common issues faced in maintenance works.

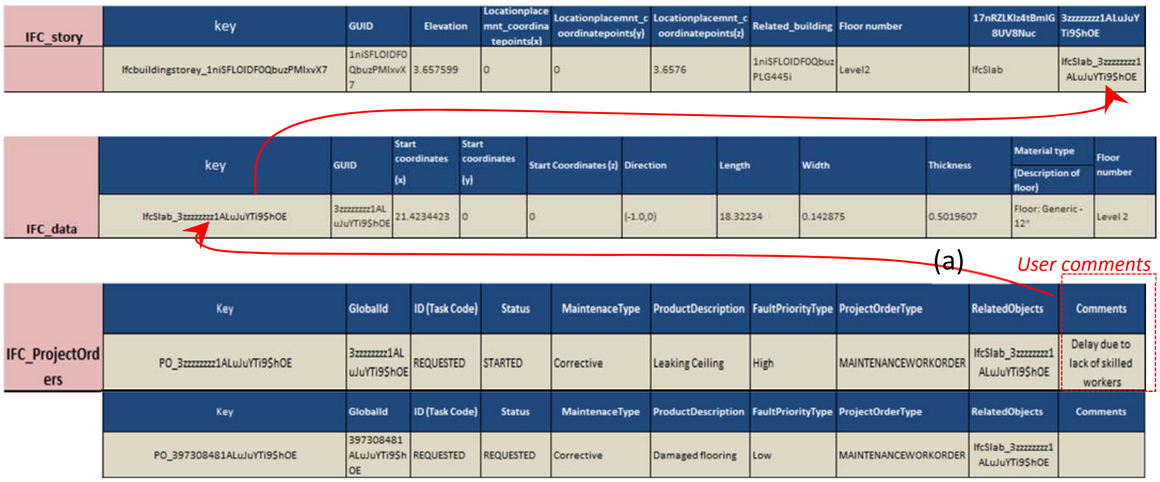

Figure 4. Data model of BIMCloud for storing social interactions in the AEC industry

Capturing Social Interactions for Decision Making in Ongoing Project. Since the ceiling of Floor 1 is leaking at many places, the HVAC system is inspected and leaking ducts are marked for repair on the BIM model in the BIMCloud by the designer. A designer updates the BIM model for changing the flooring material of Floor 2 upon owner's approval as shown by the column "PO_397308481ALuJuYTi9$hOE" of the column family IFC_ProjectOrders. The sub-contractor looks at the outstanding tasks (step (a) of Figure 3) and finds that there are two outstanding jobs to be done on the same slab, one on the upper side and one on the lower side. The subcontractor then makes the decision of either delaying one of the jobs till the other is completed or take precautions to prevent accidents if both the jobs are going on in parallel.

SUMMARY AND FUTURE WORK

This paper presents a distributed cloud based BIMCloud framework for capturing social interactions and managing BIM information in the AEC industry. Much information and communication in the AEC industry are verbal or documented on paper, which are lost sometimes as the lifecycle of a facility progresses. The proposed BIMCloud framework allows these information and interactions to be captured and associated with building components in an integrated model in the cloud environment. As the construction stakeholders are from different work and educational backgrounds, the BIMCloud framework accepts structured data like IFC files (for users like designers) as well as unstructured data (for site workers) through websites. In the future, BIMCloud will be extended to cover more non-building related applications like resource management and to include other BIM standards like Green Building XML (gbXML) improve the interoperability.

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