Cloud-based BIM Data Transmission: Current Status and Challenges

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Abstract –

In the architecture, engineering and construction (AEC) industry model-based data exchange methods are mainly based on manual file transfer, data conversion, and data-merge. File-based Building Information Model (BIM) data exchange is either in vendor specific file formats or neutral format using Industry Foundation Classes (IFC). IFC Model View Definitions (MVDs) proposed by the US National BIM Standard can assist cross-platform BIM data exchange. Since BIM applications are steadily moving to the Cloud, the study of Cloud-based BIM data transmission techniques become significant. The main objective of this paper is to investigate how building data transmission can be managed in current Cloud-BIM applications and what challenges exist in the current systems. Therefore, in this study, methodologies for Cloud-BIM data integration are investigated. Features of each technique is specified. The strengths and weaknesses of current systems are indicated with regard to data transmission requirements for Cloud-based BIM applications. In addition, the study investigates the challenges to cross-platform BIM data transfer in making multiple Cloud-BIM applications interoperate. The challenges in current data transmission approaches highlight the need for an effective network-based BIM data exchange to address a collaborative BIM work flow in the Cloud.

Keywords –

BIM; Cloud Computing; Data Exchange; IFC

1 Introduction

As a rapidly emerging technology, Cloud-BIM has become a new research area in architecture, engineering and construction (AEC) industry since 2010 [1, 2]. It is believed that Cloud-BIM could provide project partners and design disciplines with the capabilities to share and exchange design data requirements and solutions [3]. Cloud computing can perform as an effective means to overcome current BIM challenges by providing real-time access to a pool of data, on-demand access to computing resources (e.g. storage, servers) and applications, and potentially better interoperability [4]. The question is whether existing Cloud-BIM interoperability efforts have been successful in achieving this vision or not. The objective of this research is to investigate current Cloud-based BIM data transfer methodologies and to study the advantages and disadvantages of each approach to outline existing challenges. Therefore, in this paper, the significance of Cloud-based BIM development is discussed and existing Cloud-BIM data integration solutions are investigated. Moreover, the paper provides a comparison of current Cloud-based BIM interoperability architectures.

2 BIM and Cloud Computing

Cloud-based BIM technology is known as a cost effective alternative to current state of data exchange and storage [4]. Since potential values of Cloud-based applications such as efficiency and low-cost has been recognized, the combination of BIM and Cloud computing is believed to be a promising trend [2, 4]. As a result, BIM applications are gradually moving to the Cloud and BIM web services and Cloud-based apps are becoming more and more popular [5, 6, 7]. Some examples of the Cloud-BIM services are GRAPHISOFT's BIM Explorer (BIMx) and BIMcloud, AutoCAD WS, Autodesk's A360 and BIM360, BIMServer, ONUMA System [1, 5], Trimble Quadri^{DCM} [18] and Trimble Connect [25], as well as third party packages such as Assemble Insight by Assemble Systems [23], and BIM Assure by invicara [24]. With the growing development of Cloud-based BIM technologies, there is a need to reconsider the approach to interoperability of new Cloud-BIM services [8].

In addition, Cloud-BIM can facilitate a distributed system environment for multi-user collaborative interaction [9]. Cloud-BIM is anticipated to change the AEC industry although the technology is still relatively new [1]. The development of Cloud-based BIM services has already created a new direction in BIM implementation to support collaborative BIM data generation and consumption among project partners [5]. Therefore, Cloud-BIM technology is believed to provide higher levels of information interaction further cross-disciplinary collaboration [1, 9].

Most importantly, interoperability is the key to the success of Cloud services implementation [1]. However, the challenge is that making multiple Cloud-BIM applications interoperate would be very difficult when they are developed by different vendors running on different Cloud platforms [10]. Therefore, the issue of data exchange and interoperability for Cloud-based BIM applications needs further studies [5]. Thus this paper investigates interoperability architectures in current Cloud-BIM data integration solutions.

3 BIM Interoperability Standards

Information sharing which is the basis for collaboration requires applications to be able to exchange data regardless of vendors and data formats. To achieve this, in the AEC industry, building data is described in Industry Foundation Classes (IFC) specification to support a neutral data format and to facilitate cross-platform BIM interoperability [11, 12]. IFC is in fact the international openBIM standard [13].

Besides, Model View Definitions (MVDs) proposed by the US National BIM Standard (NBIMS) is supposed to assist BIM data exchange [14] in cross-platform collaborations. The NBIMS process [14] shown in Figure 1, first organizes the team that will participate in defining data exchanges for a specific domain or stage of the project and determines the functional requirements for the identified exchanges. It is the fundamental step that defines the functionality of exchanges to be supported later by MVDs. The result of the works such as forming a workgroup, developing a process map for the identified work flow, defining the set of use case exchanges being addressed by the workgroup, describing the activities involved especially the exchange requirements creates the basis of the Information Delivery Manual (IDM) for a given NBIMS project. IDM [13] captures the user needs and specification of the exchanges in a form that can be translated into technical exchange specifications. The design phase of NBIMS creates the MVD binding and specification required to implement the exchanges defined in the IDM [14].

An MVD or what is known as an IFC view definition, specifies a subset of the IFC schema that is needed to satisfy one or many exchange requirements of the AEC industry [13]. MVD consists of one or multiple exchange requirements which must be provided by the sender of data to support work in the receiving application. Sender uses an MVD to generate the exported IFC model in a BIM application and then passes the file to the receiver of data. Upon receiving the exported IFC model, the receiver of data imports the model in the receiving application which uses an IFC importer module to translate the IFC file to native binding. This process is illustrated in Figure 2.

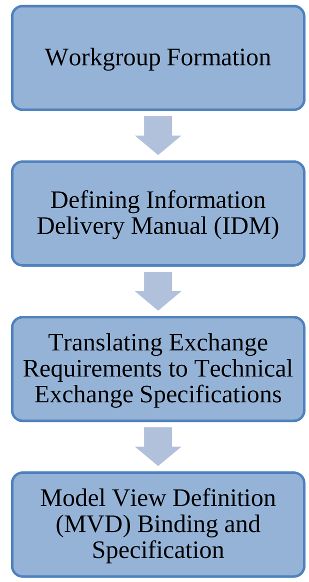

Figure 1 NBIMS development process for cross-platform BIM data exchange

In this process, the request for data, exporting the BIM model from the sending application and importing it in the receiver application should be done manually, usually through emails or other methods of correspondence.

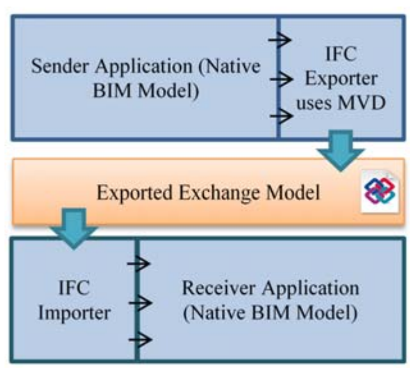

Figure 2 IFC-based BIM data exchange process

On the other hand, as stated in NIST Cloud Computing Technology Roadmap, interoperability relates to communication and data transfer between different systems. Interoperability decreases the need for manual intervention or providing the same information to multiple systems. Therefore, Cloud providers need to deliver standards-based systems to allow the provisioning of data to the users [15]. BIMSie project [6] has worked towards introducing a standardized Service Interface for Cloud-BIM solutions. This standard Service Interface is supposed to automate interaction between Cloud-BIM applications by introducing an Application programming Interface (API) for Cloud-BIM applications with standardized methods [6]. In the BIMSie initiative when services are connected, the data exchange relies on file-based data using industry standards such as IFC files.

4 Cloud-BIM Data Integration

Available Cloud-BIM data integration solutions on the market mainly address the idea of centralization of BIM data. The emergence of server-based BIM solutions have provided a central BIM service to all project members [2, 7]. These model server technologies establish a single-sourced data server [2] that uses data directly from the models (i.e. sub-models) and with a consolidated model it can improve multidisciplinary collaboration [7]. BIM server implementations are still limited [7] but BIM server technology has changed BIM work sharing with a database driven approach [5, 16, 7].

Current BIM server technologies on the market provide functionalities like querying BIM models as well as graphical interfaces for sharing and viewing BIM models in a team on a centralized platform. Examples of these BIM server technologies are GRAPHISOFT® BIMcloud® for design process [17], Trimble® Connect for project collaboration [25], Autodesk® A360 for design delivery [19] and BIM360 for construction project delivery [20]. Also Autodesk® Revit® Server is the server application for Revit® Architecture, Revit® Structure, and Revit® MEP performs as a server-based worksharing platform for Revit® projects. In addition to proprietary BIM server technologies, BIMServer.org as an open source technology has been developed by TNO and the University of Eindhoven [16]. BIMServer.org architecture is shown in Figure 3. BIMserver centralizes the information of a project with a core that is based on IFC and shares its information to client applications through some interfaces. This solution is not a file server but its architecture interprets IFC data from a file and stores it in a database. Therefore, it can merge and query the model and it eventually generates IFC files [21]. Other examples of IFC-based BIM server implementation are IFC model server developed by VTT Building and Transport and SECOM Co., Ltd. And also EDM Model Server which is an IFC model server based on EDM developed by Jotne EPM Technology [2].

These Cloud-based BIM servers could be theoretically a good solution however in practice they have faced major challenges [2] such as scalability and robustness [5]. BIM server technology overcomes the issue with full-size model synchronization [5] while the integration of BIM models in the Cloud provides a network-based data exchange [1]. However, the technology is not robust [5]. In this type of Cloud-based collaboration some data management issues exist especially in combining models [1] and in sub-model extraction [2]. Also, these solutions require more powerful Web-based operating systems, file-sharing platforms and hardware controllers [1].

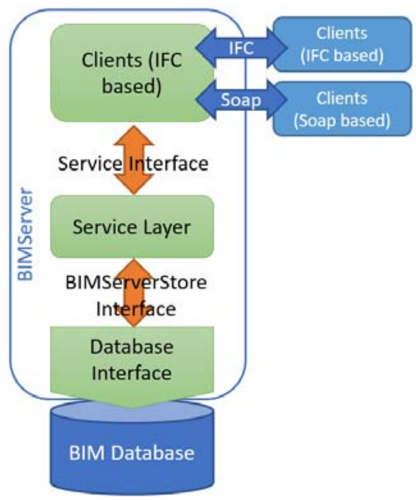

Figure 3 BIMServer.org architecture

Studies identified that existing BIM servers require functional and performance improvements [2, 7] as well as coordination with vendor specific format data [2].

Figure 4 Architecture of a BIM server solution

Most importantly, the input and output of these systems, as shown in Figure 4, is heavily based on files. For instance, input and output of BIMServer.org is based on IFC files. Also, the existing BIM servers cannot work with the decentralized, heterogeneous and dynamic design data and as a result cannot support the whole lifecycle of the project [2].

In addition to BIM server solutions, Flux project [22] which was started in late-2010 at Google[x], Google's research lab, is a cloud-based collaboration tools for design process to assist architects, engineers, and contractors with exchanging data. Unlike conventional file-based data transfer, Flux acts as an interchange point for sharing project data such as design, analysis, and schedules. Flux plugins should be installed on design software applications to automate data transfer to and from Flux. Currently, Flux works with limited number of applications such as Rhino/Grasshopper, Excel, Revit/Dynamo, and SketchUp. Figure 5 illustrates the data flow between applications and Flux.

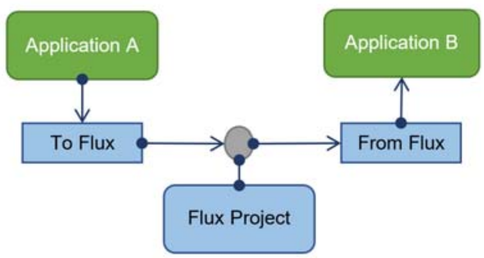

Figure 5 Flux data flow for design data exchange

5 Comparison of Data Integration Approaches

The study of the existing Cloud-BIM data integration methodologies suggests that there are three main categories of BIM data integration in the Cloud that allows cross-platform data exchange.

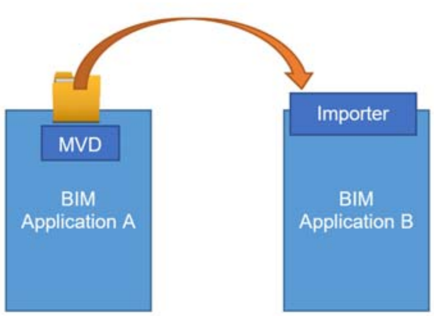

Figure 6 Data flow for manual file transfer

1. **Manual File Transfer**: Manual file transfer can be based on BIM open standard as well as vendor specific formats. Using neutral file format based on IFC data model and established MVDs can be potentially advantageous to help AEC industry stick to a common language to improve collaboration. However, file-based data transfer is a one-way communication that should be repeated for each design iteration to include constant design changes. In addition, in this process, there are methods to validate the exported model against the initial exchange requirements but how to validate the imported model is still vague. This data flow is shown in Figure 6. Existing file-based data transfer technologies are not suitable for BIM applications because of incapability of managing data redundancy and inconsistencies [2].
2. **BIM Server Technology**: BIM server centralizes BIM data in a database and can improve collaboration in an integrated model. But the technology is limited and has performance and scalability issues in dealing with complex and big projects.

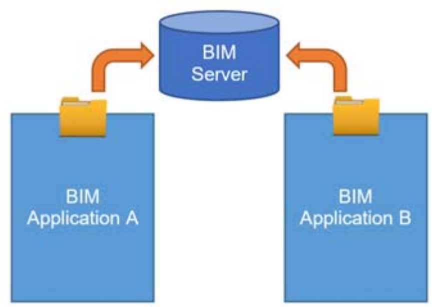

Figure 7 Integration data flow for BIM server technology in data transmission between applications developed by different vendors.

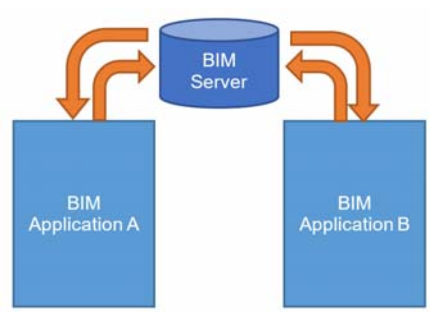

Figure 8 Integration data flow for BIM server technology in data transmission between applications developed by one vendor.

The integration data flow for this methodology is shown in Figure 7 and 8. BIM server technology provides a centralized and accessible repository for the project and can provide access to project data almost anytime and anywhere throughout the building lifecycle. However, since these solutions only support a limited number of data formats as inputs and outputs (i.e. mainly data formats supported by one vendor), the centralized model can be disconnected from the origin of data if the data is provided by a different vendor whose format is not supported. In this case data transfer should be tackled with exporting and importing files (Figure 7). This makes the integration to rely on manual file transfer. In BIMServer.org for instance, a user (e.g. an architect) should check in a file-based IFC instance model and the model will communicate with server in the Graphical User Interface (GUI). Similarly, the outputs of the service are based on files as well if needed to be transferred after analysis, simulation, etc.

3. **Data Interchange Hub**: DIH technology such as Flux project can automate data flow between certain applications. This solution can reflect the changes in real-time while each user and application controls when to synchronize data with the project. Data Interchange solution allows users to work in isolation and share their changes when they are ready [22]. But this solution currently supports very few design applications to exchange data. In addition, the applications are dependent on Flux although the model can be updated on each platform on its own. The integration data flow for Data Interchange Hub solution is shown in Figure 9.

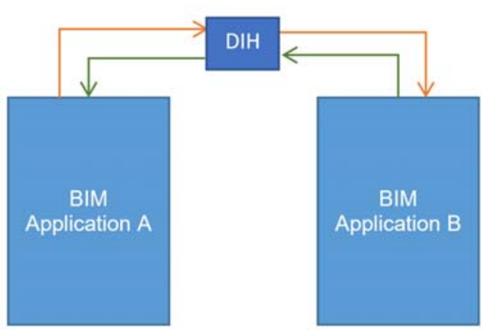

Figure 9 Integration data flow for Data Interchange Hub (i.e. Flux) solution

Comparison of these three methodologies are summarized in Table 1. Advantages and disadvantages of each method are specified.

In addition to these BIM data integration solutions that are developed to enable cross-platform data exchange and to provide cross-disciplinary collaboration solutions, there are other third party solutions developed for a specific purpose. These cloud-based third party solutions extract data from the BIM models in BIM authoring tools through some plug-ins to publish the model in a new environment so that they can provide additional specialized services such as analysis.

Table 1 Comparison of Cloud-BIM data integration methodologies

Cloud-BIM Data Integration Technique	Pros	Cons
Manual File Transfer	Could be based on established standards and MVDs	One-way data transfer and data import issues
	Can use neutral data format	Repeats for each design iteration
BIM Server Technologies	Centralizes BIM data	Scalability and performance issues
	Improves collaboration in an integrated Model	Depends on the server platform and not completely connected to the origin of data
Data Interchange Hub	Automates data flow	Supports very few applications
	Reflects design changes in real-time within each BIM application	Depends on the interchange platform

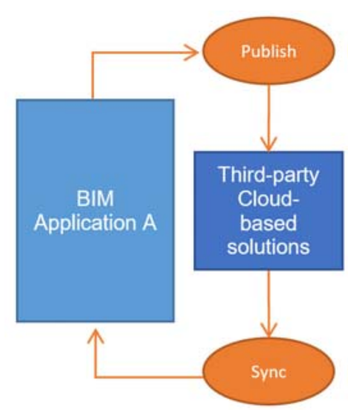

Figure 10 Data flow for third-party Cloud-based BIM solutions

As distributed services, these Cloud-based solutions can eventually synchronize the modifications applied in the model back to the original BIM authoring tool. For instance, BIM Assure [24] provides BIM model checking service for validating the model accuracy and completeness. Also, Assemble Insight [23] provides cost estimation solutions and analyses such as value engineering. These solutions are currently limited in exchanging and mapping of data structures in different formats and can only deal with BIM data from very few BIM authoring tools and data formats, mainly supporting one vendor specific data structure. Since these type of Cloud-based BIM solutions are not considered as consolidation products and are not supposed to provide integration platforms, cross-platform data transfer solutions or solutions to connect applications, they are excluded from the comparison in this research. The overall data flow for these Cloud-based solutions is illustrated in Figure 10.

6 Key Challenges in Cloud-BIM Data Exchange

As can be seen in Table 1, Cloud-BIM data transmission for cross-platform collaboration faces several challenges.

- Standardization- There is a lack of Cloud specific standards for BIM interoperability. With the growing number of Cloud-BIM services developed by several providers, standardization among these service providers become important. Open standards like IFC data schema should be expanded to address the requirements of Cloud-based applications.
- Data interdependency- Current BIM integration solutions that deal with Cloud interoperability are either addressing model federation in a centralized platform or interconnecting a limited number of design applications on premise through a new Cloud-based platform with the help of plug-ins. These solutions integrate two or more systems to a third new system, instead of creating a loosely coupled aggregation, shown in Figure 11, where each system remains self-contained.
- Data access and security- Collaborative nature of Cloud-BIM data integration causes security challenges such as liability and BIM model ownership [1, 4]. User authentication and authorization is key to successful deployment of Cloud-BIM and therefore Cloud identity management and role-based user access becomes significant which require advancement in trust and privacy preserving techniques [4]. Providing a safe service for Cloud-BIM applications and integration solutions is critical. The issues of dealing with the data security, ownership and stability for Cloud-BIM technologies are still open research areas.

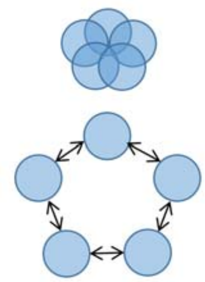

Figure 11 Tight coupling (top) vs. loose coupling (bottom) between Cloud applications

7 Discussion and Conclusion

Existing architectures for Cloud-BIM data integration face several challenges in model-based data exchange and have not fully exploit the potential of the Cloud towards a loosely coupled integration. Therefore, there is a need to develop a new architecture that redefines the data flow utilizing web-based technologies as major enablers of the Cloud. For instance, Cloud computing is based on the Transmission Control Protocol/Internet Protocol (TCP/IP). Such data transfer protocols should be considered for cross-platform BIM data exchange architecture. Therefore, future study will likely propose an architecture considering web technologies and elements of the Cloud interoperability such as Cloud APIs.

In addition, while vendor specific data formats are quite diverse, these are based on multiple and different data schemas. On the other hand though, data standards for Cloud-based cross-platform data exchange purposes are limited. IFC data model which describes building data provides a means to define building components and processes in a publicly available data schema. So far, the specification of IFC standard is provided in EXPRESS (using the STEP physical file structure) and XSD schema (using the XML document structure). As an industry-wide open standard, IFC schema definition should become the basis for Cloud-BIM integration solutions to ensure a common understanding of building data across the applications and disciplines. Future work should investigate the possibility of representation of IFC schema in data encoding suitable for web-based data transfer. In addition, the NBIMS process should be revisited considering the requirements of Cloud-based data transmission and data integration work flow with Cloud-based use cases.

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