TOWARDS AFFORDABLE BIM ADOPTION IN EXTENDED CONSTRUCTION SUPPLY CHAINS

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ABSTRACT

The UK Government is committed to making BIM compulsory on all government projects by 2016. There is currently significant interest in adopting BIM systems in the design, construction, operation and refurbishment of buildings to deliver a low carbon future. As a result, there is currently a burgeoning interest in BIM and many of the major contractors are increasingly adopting BIM and reviewing their BIM strategies and how they can work with their supply chain to create, manage and share information about projects. However, about 99% of the firms in the construction supply chains are SMEs. They face significant challenges in adoption such as choice of system to implement given that they are frequently involved in projects using different tools which may not easily interoperate and the high costs implementation. There is therefore a need for innovation in developing affordable BIM systems offering new and alternative business models to meet the needs of the significant majority in the industry. This paper presents work being undertaken to allow SMEs to be able to choose and adopt a single affordable tool for their internal use and still be able to interoperate and seamlessly share information with supply chain partners in various modes of operation using emerging standards and protocols, services-oriented architectures and open innovation business models.

Keywords: Building Information Modelling (BIM), interoperability, interoperability service utility, services-oriented architecture

1. INTRODUCTION

The construction industry is experiencing unprecedented change and dynamic conditions resulting from societal demands for low impact buildings and infrastructural assets with ever increasing standards of performance, constantly diminishing environmental impacts, and steadily reducing costs of construction, operation, and decommissioning. This is fuelling the development of an increasing number of new methods, materials, technologies, processes and innovative practices aimed at improving buildings and communities with respect to a multitude of sustainability performance considerations and indicators. As the number of methods and technological options increases, so does the complexity and associated cost of choosing amongst alternative combinations for a given situation. Informed decisions require the management of vast amounts of information and knowledge about the combinations of available options and the assessment of their performance. It is almost impossible to apply manual methods and physical prototypes comprehensively.

Tools are required to help support construction supply chain participants to design and predict how buildings will perform in use, and to support the construction and operation of buildings. There is a need for tools that can allow professionals to easily predict the impact of alternative design decisions on building performance and cost - whether capital cost, whole life financial cost or carbon cost. It has been widely acknowledged that there exists a proliferation of tools which do not interoperate, do not allow multiple performance measures to be assessed simultaneously and thus do not help communicate the impact of design options and decisions between professionals and clients. However, the emergence and burgeoning interest in Building Information Modelling

(BIM) tools promises to address the short comings associated with non-interoperable and integrated tools and presents a basis for developing future decision support tools and serving as both the heart and the means of enabling coherent and improved delivery of projects. BIM encourages collaborative working, a close relationship with the supply chain and early contractor and subcontractor involvement, which are all positive aspects of using the technology. The majority of the participants in the construction supply chain are SMEs and recent surveys on the adoption of BIM have indicated a low uptake amongst SMEs. The prohibitively high cost of adoption is frequently cited as one of the reasons for the low take up by SMEs as well as the lack of interoperability between the multitude of tools involved. Thus, there is a need to develop affordable solutions and business models that would facilitate wider uptake by SMEs. The paper presents work being undertaken to address this by adopting an Open BIM approach using affordable tools and the development of interoperability service utilities based on open standards.

2. USE OF BIM IN EXTENDED CONSTRUCTION SUPPLY CHAINS

A Building Information Model as defined by buildingSMART® is a "digital representation of the physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward." (BuildingSMART, 2013). The sharing of information through collaborative working by the different stakeholders and participants in the project process are basic premises of BIM. Collaboration and sharing of information is accomplished through interoperability across a variety of platforms and software used by the multitude of disparate disciplines in the extended construction supply chain. This typically consists of clients, designers, consultants, contractors, sub-contractors, suppliers, manufacturers, facility managers, etc. Consequently, each participant or discipline in the extended construction supply chain only engages with a partial BIM by necessity to meet the business needs from their disciplinary perspective. In practice an array of partial models are combined into one model to constitute a full BIM, creating a true representation of the building throughout all life cycle phases. These models are generally referred to as federated models. It is possible to achieve some degree of federation of models where a supply chain adopts a single vendor BIM environment such as Autodesk's and Bentley's platforms. However, this is not often practical as the different participants are more likely to have invested in the different systems currently available leading to interoperability challenges. The emergence of open standards such as IFCs from buildingSMART and Open BIM servers are emerging to provide solutions for the interoperability problem for the extended supply chains if appropriately implemented. This would allow every supply chain participant to use the tools that they can afford and meet the needs of their discipline are still being able to contribute to the realization of a federated BIM.

Data interoperability between BIM software is discussed extensively in the architecture/engineering/ construction fields. With increasing interests and focuses on the use of industry foundation classes (IFC), the buildingSMART disseminates enormous amounts of information to facilitate the implementation of IFC-based applications and studies in order to accelerate its wide adoption to address interoperability problems. Most IFC interoperability studies so far concentrate on the use of the IFC format file to deliver design information. Nevertheless, the AEC industry is characterized by fragmentation in multidisciplinary specialty, geographically dispersed teams and heterogeneous ICT tools used in projects. File-based IFC interoperability solutions are not ideal for coping with the challenges in seamless information flows needed to multidisciplinary collaboration.

The use of an IFC model server has been acknowledged as a better way to support interoperability of BIM applications for multidisciplinary collaboration. This maintains a consistent project information repository for multidisciplinary working. It can also deliver advanced cloud computing and mobile applications for solving specific on-site problems. This work concentrates on the use of the server/client application development architecture using SOAP web services provided by BiMserver (BiMServer, 2013; Beetz and Berlo, 2011), which is an open source project dedicated to the AEC industry to provide an open model server based on the IFC standard. We are exploring an interoperability solution for data exchange between multiple BIM systems through BiMserver. We present relevant concepts, development considerations, prototyping and validation.

3. BIMSERVER AND ITS SOAP INTERFACE

BiMserver allows users to easily customize the server environment to suit their own needs, such as reuse, modify and adapt implementations of low-level tasks like underlying EXPRESS schema and instance parsing, persistency management and visualization. Besides the low-level operations, it provides developers with service interfaces of SOAP (Simple Object Access Protocol), JSON (JavaScript Object Notation), etc. to communicate with the server though a large collection of created methods. Developers thus can create their own client applications to fully take the advantage of BiMserver using any programming languages.

The freely accessible BiMserver provides opportunities to create advanced design decision solutions for the AEC industry. Leveraging SOAP and service oriented architecture (SOA) (Microsoft, 2013), potential software applications can be service consumers to access BiMserver, which is a service provider to enable client applications to consume its services via created methods. Because SOAP is an independent data transfer protocol, any clients can communicate with BiMserver to realise interoperability seamlessly through it. BiMserver is an IFC model server with a large number of methods wrapped in its SOAP web service interface. It allows developers to fully make use of these methods to create low level IFC objects in the BiMserver and perform high level operations such as downloading, version control, user and project management, etc. Any third party CAD and BIM software can map its native design information into neutral IFC data to be restored in BiMserver to exchange information. A functional overview shows this possibility that CAD tools like SketchUp could exchange design data with BIM tools like Revit for interoperability through the SOAP web services from BiMserver (Figure 1). This report focuses a development study of data exchange between SketchUp and BiMserver to verify an applicable data interoperability solution using SOAP web services.

Figure 1: Overview of interoperability between CAD and BIM tools through BiMserver SOAP web services

4. CAD-BIMSERVER INTEROPERABILITY DEVELOPMENT

The development of interoperability solution for data exchange between CAD tools and BiMserver has three considerations: data mapping of CAD data types and IFC entities, logical relationship mapping and corresponded IFC entities creation in the server. In the meantime, CAD-IFC data type mapping decides correct IFC entities to be involved for final objects creation according to specific CAD entities. E.g. a 2D single line represents a wall in a CAD design whilst its corresponding IFC entity is IfcWall that needs to create related object to represent the wall in BiMserver. On the other hand, logical relationship mapping helps establish a hierarchy to keep consistency with IFC specification. For example, a wall and its embedded window in a CAD design are two entities without internal relationship. It can only be recognised by human cognition instead of computer. However, mapping to IFC logical relationship, corresponding object hierarchy is IfcWall → IfcOpeningElement → IfcWindow and it can be recognised by computer.

The logical relationship mapping between a CAD building design and IFC specification suggests further considerations of both geometric and semantic data interoperability. Since CAD entities in a design has rich geometric information with less semantic information, it is compulsory to combine corresponded geometric information with related semantic information as compensation to satisfy a relevantly complete IFC-based building design. Therefore, this development study concentrates on fundamental IFC entities that help create essential semantic and geometric objects in a building design based on the IFC Specification 2x3. These entities are listed in Table 1. Because the BiMserver SOAP web services provide clients with low level methods to directly create IFC objects, edit related attributes and references, etc. in the server end, the development work was initiated by implementing these IFC entities as underlying engine so that to underpin complete building design creation in the next step.

Table 1: Involved IFC entities in the development

IfcPerson	IfcLocalPlacement
IfcOrganization	IfcRelAggregates
IfcPersonAndOrganization	IfcRelContainedInSpatialStructure
IfcApplication	IfcUnitAssignment
IfcOwnerHistory	IfcPolyLoop
IfcProject	IfcClosedShell
IfcDirection	IfcFaceOuterBound
IfcCartesianPoint	IfcFacetedBrep
IfcAxis2Placement3D	IfcFace
IfcGeometricRepresentationContext	IfcShapeRepresentation
IfcSIUnit	IfcBoundingBox
IfcDimensionalExponents	IfcProductDefinitionShape
IfcMeasureWithUnit	IfcRelVoidsElement
IfcConversionBasedUnit	IfcOpeningElement
IfcSite	IfcWall
IfcBuilding	IfcWindow
IfcBuildingStorey	IfcSlab
IfcRelFillsElement	IfcDoor

In addition to the mapping data from CAD designs, the complete IFC entities' creation is also subject to the IFC format. An IFC format file is the final result of CAD-IFC data conversion through creating mapped IFC entities for interoperability. When creating IFC entities using the SOAP interface, BiMserver can trigger a revision operation to restore these entities in the server. In accordance with BiMserver working mechanism, a building design project created in the server may contain a series of such revisions, which record design evolution from start to end. Every latest revision can merge previous revision information into the current one, and can be checked out as an IFC format file from the server. Therefore, this development study targets the IFC format as well as mapping data from CAD design to determine related IFC entities' creation to achieve interoperability.

The typical IFC format file consists of several parts including file header, file data, project structure, project hierarchy, product entities and file data end. In a revision operation, BiMserver is able to generate file header and file data automatically. The rest parts need to be created by using low level SOAP methods, which can generate required IFC entities to fill in these parts. On the basis of initial work of fundamental IFC entities' implementation, it is likely to put required IFC entities into related parts following the IFC Specification 2x3. This further step needs to create semantic information in all the rest parts, in which product entities' creation involves generating mapped geometric data from CAD design. The correspondence between IFC format and required IFC entities is listed in Table 2. Besides these required IFC entities in specific parts, many of them could also be referred and re-generated in different parts of the IFC file.

Table 2: Correspondence between IFC format and required IFC entities

IFC format	**Required IFC entities**
File header	Automatically created
File data	IfcProject, IfcOwnerHistory, IfcPersonAndOrganization, IfcPerson, IfcOrganization, IfcApplication, IfcSIUnit, IfcConversionBasedUnit, IfcDimensionalExponents, IfcMeasureWithUnit, IfcGeometricRepresentationContext , IfcAxis2Placement3D, IfcCartesianPoint, IfcUnitAssignment
Project structure	IfcSite, IfcBuilding, IfcBuildingStorey, IfcLocalPlacement, IfcDirection
Project hierarchy	IfcRelAggregates IfcRelContainedInSpatialStructure
Product entities	IfcWall, IfcWindow, IfcSlab, IfcDoor, IfcPolyLoop, IfcClosedShell, IfcFaceOuterBound, IfcFacetedBrep, IfcFace, IfcRelFillsElement, IfcShapeRepresentation, IfcBoundingBox, IfcProductDefinitionShape, IfcRelVoidsElement, IfcOpeningElement,
File data end	Automatically created

5. PROTOTYPING

A prototype was implemented for the validation of CAD-BiMserver interoperability. SketchUp was chosen to be the CAD system, in which the plug-in software Lidx (Cheung et al., 2013) was extended with several modules as a part of the prototype. The reason for using Lidx was because it provided available building design, cost planning and carbon information for easy testing. This prototype also encompassed an independent SOAP-based utility to communicate with BiMserver. The development tools used included Ruby, Microsoft Visual C++ and gSOAP. Both Ruby and VC++ were applied to extend Lidx functionalities, while gSOAP was used to obtain SOAP web services so as to automatically generate C++ methods for the utility development.

5.1 Software architecture

The prototype was composed of three communicated applications of SketchUp, SOAP-based utility and BiMserver running in the same Windows environment. Lidx as a part of SketchUp was further enhanced with two internal modules of entity sorting and logical bridging. The entity sorting module was developed using Ruby script. It took responsibility for collecting building design information such that CAD entities in the SketchUp could be sorted into walls, windows, doors, slabs, etc. following pre-defined data mapping rules. These kinds of information were then transferred through Win32 application programming interface (API) to the module of logical bridging. This module was developed using VC++, and it could further compose received information from entity sorting module to be suitable information for IFC entities' creation. Through a memory sharing approach in the Windows environment, prepared CAD design information could be delivered to the external SOAP-based utility in Windows. This utility could help convert the received CAD data into IFC entities based on the implemented IFC entity engine, and directly restored them in BiMserver though SOAP protocol.

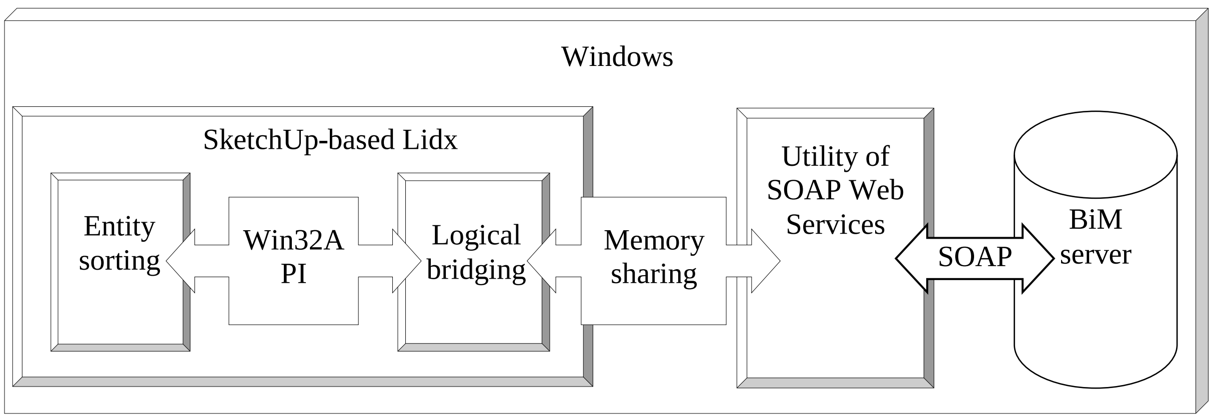

Figure 2: Software architecture of prototype

5.2 SOAP-based utility

The SOAP-based utility has four functional modules to deal with specific tasks: user authentication in BiMserver, project and its subversion management, parse received CAD design information into parametric values, create IFC entities using implemented IFC engine. Excepting the underlying IFC engine, other functionalities have corresponded user interfaces for user operation. The utility user interface integrates these functional user interfaces into two parts: SketchUp entity browser at left hand side and BiMserver user interface shown at right hand side (Figure 3).

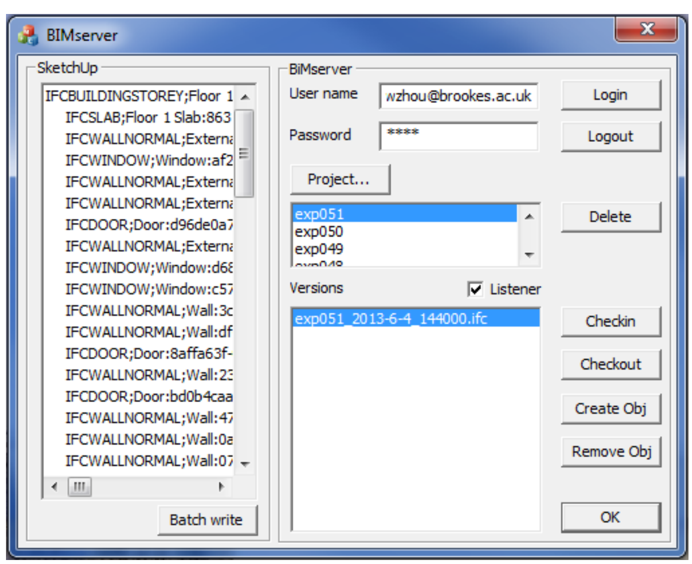

Figure 3: User interface of SOAP-based utility for SketchUp-BiMserver interoperability

The utility user interface enables the user to log in the running BiMserver first by inputting user name and password. Once completing user authentication, the utility can then retrieve related project information displayed in the project list box. Possible user cases in project and subversion management include browsing related subversions of a selected project, downloading a specific version from a selected project, deleting a selected project, checking in a version for a selected project, and creating a new project for further new revisions. The SketchUp entity browser could work when receiving upcoming information from SketchUp automatically. It can show design information in a hierarchy to mimic IFC product structure. The utility could interpret this hierarchy into corresponding IFC parametric values to generate an IFC format revision in a project. This process allows two working modes: one is manual operation that user could press the batch write button to activate the interpretation to generate objects in BiMserver. Another is automation that the utility could perform the same operation like manual operation without user input. It requires collaboration performed in the entity sorting module in SketchUp for automatic monitoring design changes. Both working mode can lead to a revision to be resorted in BiMserver for checking out manually so that to visualise it using an IFC viewer.

6. VALIDATION

A validation test was performed to check the exploration development for CAD-BiMserver interoperability. The mapping data of CAD entities was considered from a Lidx 3D building design, in which provided 2D layout plans containing 2D single lines as walls, two kinds of 2D rectangle blocks as windows and doors respectively and faces as slabs. The validation test aimed to examine both working modes of manual design data exchange and dynamic auto-data exchange with BiMserver. As a compulsory requirement, BiMserver was running in advance in both modes to guarantee data is received during the test.

6.1 Manual design data exchange

A conceptual two-storey building design was created beforehand in the Lidx-enhanced SketchUp environment. Every floor in the building contains slabs, external walls, partitions, windows and doors in the layout that satisfy the data type mapping rules. The tester can retrieve all these design data in a floor manually through a context menu. The internal module of entity sorting functioned in this procedure to collect design information and transferred it to another internal module, the logical bridging module. This manual retrieval process requires the tester to explicitly switch floor editing from one to another so as to ensure that different design information in each floor is retrieved.

After the logical bridging module obtained all design information, the tester activates the external SOAP-based utility for logging into BiMserver manually. Simultaneously, retrieved design data is transferred from the logical bridging module to the utility via a memory sharing approach in Windows. The tester selects a project for creating IFC objects in it and uses the Batch Writing button in the utility user interface to trigger the underlying IFC engine to create corresponding IFC objects according to the IFC format and CAD data mapping rules. This final procedure results in a revision to be created in the project. After checking out this revision, an IFC viewer is used to visualize the generated IFC-based model for comparison with the original SketchUp model as indicated in Figure 4.

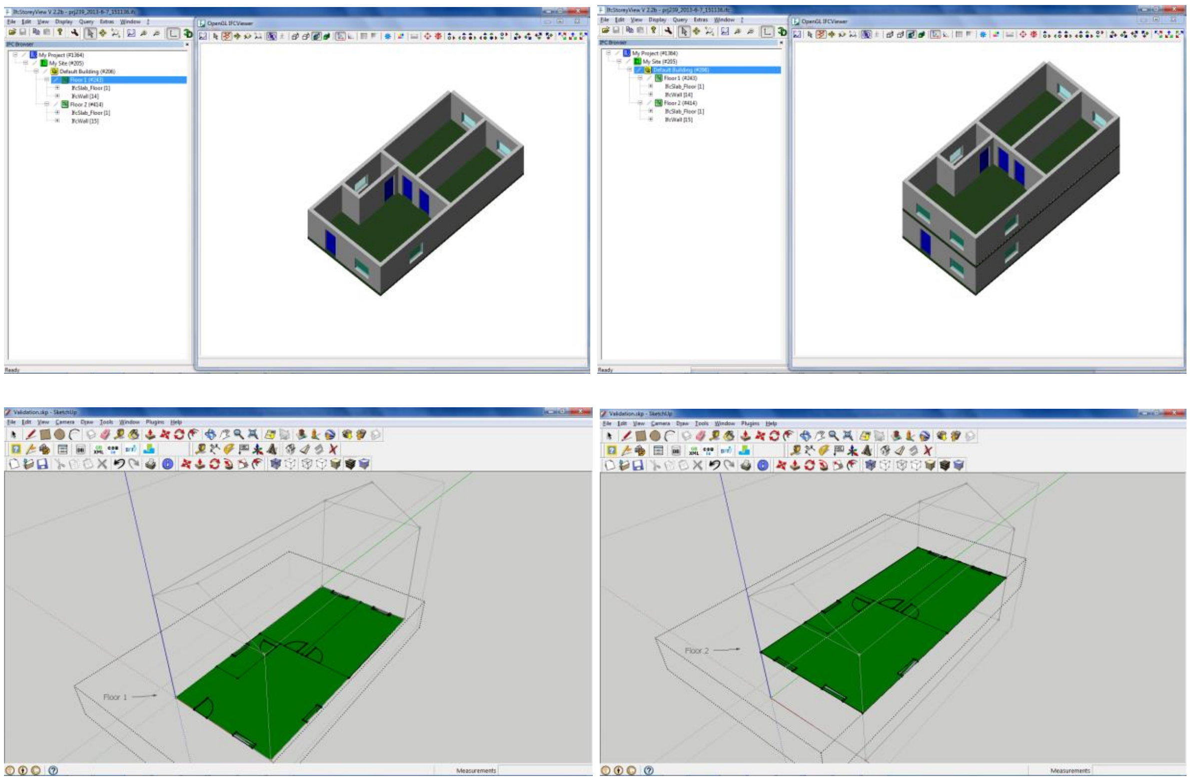

Figure 4: Comparison of BiMserver generated IFC design (Up) with its original SketchUp design (Down)

6.2 Dynamic data auto-exchange

In the dynamic data auto-exchange test, it targeted a building design process such that created design data of CAD entities could be sent instantly and automatically from the SketchUp environment to BiMserver to generate IFC format data. The test process followed several procedures. First, the tester activates the SOAP-based utility in order to log in the server to make a project ready for receiving incoming data. Afterwards, the tester starts the design work for creating a building using the Lidx plugin in SketchUp. In order to capture any design updates, the entity sorting module was called in every design operation like creating and editing building components. Collected CAD entities in each call were then transferred immediately to the logical bridging module, which passed the received CAD entities from SketchUp directly to the external SOAP-based utility through Windows memory sharing.

Interpreting the received data from SketchUp, the utility could judge the completion of data transfer and then trigger the underlying IFC engine to write the received data into BiMserver as a revision in IFC format. Since this fully automated process was repeated in response to any design updates, BiMserver could create corresponding revisions to record design evolution. This repetitive data transfer approach results in legacy and new data to be accumulated in the latest revision, which requires redundant data to be deleted so as to keep the latest version to be concise and updated. This redundant data elimination has not yet been fully tested as BiMserver currently has a bug preventing the updated revision from being downloaded. This bug has been fixed and a new BIMserver release is anticipated to be available soon which would facilitate the finalization of this last step in the validation.

7. TEST FINDINGS

The validation test confirmed the applicability of the underlying IFC engine created by using BiMserver SOAP web services. The engine could generate complete IFC format design information based on predefined CAD data mapping rules. This IFC design information contained both enhanced semantic information and mapped geometric information. Since less semantic information was available from the conceptual building design, the enhanced semantic information only created a framework filled with proxy information. Authentic semantic information is required in its detailed design in a truly BIM environment. In order to satisfy diverse design needs from conceptual building designs, the IFC engine could be further enhanced by implementing more IFC entities, especially more powerful parametric modelling functions for generating complex geometries in IFC.

Both low level SOAP methods in creating IFC engine and high level SOAP operations for user authentication as well as project and subversion management were verified to be useful. This usefulness permitted two options in collaborative design. One use case is asynchronous collaboration that users could check in their created IFC designs for collaborators to check them out from the server. This kind of asynchronous collaboration allows collaborators to work on the same project at different times supported by project and subversion management. Another option is synchronous collaboration for data auto-exchange which was tested in the validation. Its use case is referred to in Figure 1 where building design data in SketchUp can be transferred to Revit in real time through low level objects exchange via BiMserver.

Data manual exchange and auto-exchange in the validation represented two working approaches to interoperability with BiMserver. The former is an explicit mode that requires designers to access related user interface to perform specific operations. It provides certain flexibility for designers to choose partial design information to be sent to BiMserver. The latter is a fully automated process without involving the users' explicit operations on any buttons. This is an implicit working approach that the design system could capture design data to send to BiMserver automatically. In the SketchUp environment, its Ruby development interface provides a system-level monitoring mechanism to identify any design update. However, this mechanism is not robust enough to deliver correct result. This exploratory work involed the development and use of the entity sorting module to achieve the data auto-exchange aim. The full realisation of this aim is dependent on the release of the new BIMserver version soon to be available for final validation.

8. CONCLUSION

This work has explored the extent to which various utilities can be developed to facilitate information interoperability between the multitude of BIM systems and applications used in various configurations of construction supply chains involving the multiple disparate disciplines and SMEs that characterize the construction industry. The use of BiMserver as an open project repository for data interoperability in this respect appears promising. It allows heterogeneous applications to exchange data in either synchronous or asynchronous collaboration. Underpinned by the SOAP web services, this collaboration could be achieved across multiple platforms and configurations of supply chains and applications used. This exploratory study has verified the usefulness, applicability and potential of the BiMserver SOAP web services. The work done so far has been encouraging and demonstrate that each participant in the extended construction supply chain can collaborate and seamlessly share BIM information using a tool that they can afford provided an interoperability service utility can be provided to link them up to a BIMServer. BimServer is currently freely available as open source and for the interoperability service utilities to be attractive to the majority of companies in the construction industry which are largely SMEs, the utilities themselves would have to be provide freely on an open source basis. Further work is being undertaken to scale up the approach in various modes of operation in different supply chain configurations in collaboration with SMEs and to establish an open innovation business model to facilitate wider adoption.

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