OPENING BIM IN A NEW DIMENSION

A simple, OpenBIM standards based Virtual reality collaboration technique for BIM

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Abstract. This work explores the possibility of leveraging the OpenBIM standards to create an interactive Virtual Reality (VR) tool for collaboration in the BIM ecosystem, independent of any vendor-specific software. The highlight of the work is integration of BCF issue mark-ups and a mechanism to add doors and windows from VR with correct semantic relationships to an IFC model. We also lay foundation for a networked, multi-user environment using the same approach.

Keywords. IFC; VR; BIM; Interactive; OpenBIM.

1. Introduction:

In the era of Industry 4.0, where digitization is poised to bring about a major industrial revolution, construction industry is now set to face major challenges in integrating digitization into the standard processes that dictate the industry. Being one of the least digitized industries (figure 1 *R*), it is yet to adopt many concepts of Industry 4.0 (Oesterreich and Teuteberg, 2016).

Nevertheless, Building Information Modelling (BIM) is a major step towards digitization of construction industry and is not a very new development. The concept of representing building products as structured data is present since early 90's (Eastman, 2018). By creating a digital twin of the building project, BIM augments the 3D representation with construction schedules (4D BIM) and budgets (5D BIM). Integrating Sustainability (6D BIM) and life-cycle management (7D BIM) are also possible, but not widely implemented (Sampaio, 2018). With such advanced applications possible, the industry has a lot of scope for development in the digitization aspect. BIM, in fact can be considered as the central technology for digitization of the construction industry (Oesterreich and Teuteberg, 2016).

In discussing the digital future for the construction industry, digital collaboration and mobility have been identified as one of the key enablers (figure

1 L) in the Industry 4.0 context (Agarwal et al., 2016). One of the goals of BIM is enabling collaboration among the project participants using a large amount of digital data, centralized and shared among all. To enable seamless sharing of BIM data and to integrate many BIM software vendors in a project, buildingSMART (www.buildingsmart.org) has introduced a vendor neutral approach - OpenBIM. Two important OpenBIM standards are Industry Foundation Classes (IFC) and BIM Collaboration Format (BCF), which enable exchange of data between various BIM authoring tools and enable a seamless workflow for BIM data in a project.

However, the large amount of data generated by various participants in BIM projects could lead to an overload of information which could negatively impact the stakeholders if not communicated properly (Chu et al., 2018). Therefore, it is very important to use and visualize just the relevant data for collaboration in construction projects. Industry 4.0 digital technologies can play a key role in improving the collaboration and real time data synchronization in BIM. Virtual Reality (VR) is one of the Industry 4.0 trends that has potential applications in the Construction 4.0, a term defined to address the major digitization aspects of this industry (FIEC, 2017). In fact VR, Augmented Reality (AR), Mixed Reality (MR) and Human-Computer-Interaction (HCI) are the key Industry 4.0 factors that could enable digitization in the Construction 4.0 (Oesterreich and Teuteberg, 2016). Rightly described, BIM is not merely a production tool but a socio-technical communication and social networking tool (Goulding et al., 2014). This perspective can now be realized with help of state-of-the art VR technologies.
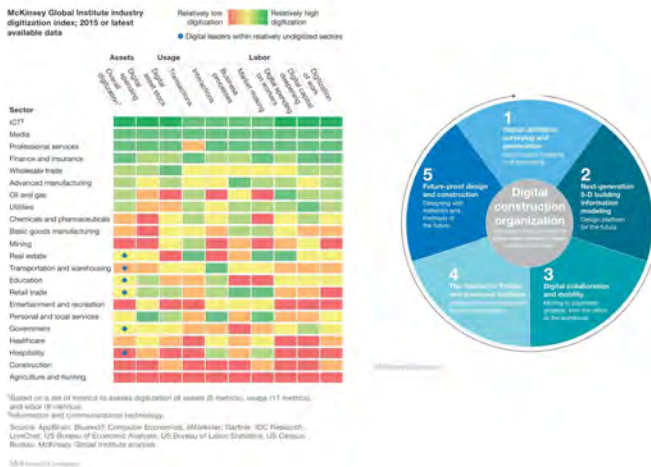

Figure 1. (R) Comparision of digitzation in the construction industry and (L) the key factors for digitizing the construction industry. Images sourced from https://www.mckinsey.com.

Despite the growing importance of VR in the context of BIM and construction industry, only a handful of published research is present (Zaker and Coloma, 2018). Many of them focus on leveraging the BIM model available from certain software vendors for visualization and interaction in VR (Edwards et al., 2015; Woessner

and Kieferle, 2016; Johansson, 2016). On the other hand, the major software solutions present in the market support a wide range of virtual collaboration for their own BIM data formats, making the solution usable only limited to participants using a certain BIM software. Standalone VR collaboration tools that support a range of BIM data formats exist, but none of them provide a complete closed loop solution that allow the participants to visualize, interact and create design iterations from an IFC model. Since it is people but not the systems who collaborate in BIM ecosystem (Zaker and Coloma, 2018), we see an opportunity to make usage of VR in BIM as a collaboration tool more accessible by applying the OpenBIM standards. We believe it could be a valuable contribution to the AEC industry in the context of Construction 4.0.

In our approach to this research, we have reviewed published literature and state-of-the-art in the software tools offering a BIM-VR integration to assess the opportunities of applying the OpenBIM concepts to make the VR collaboration vendor-neutral. Furthermore, we have undertaken a thorough study of the IFC standard to implement some new features in our previously developed system. Based on the findings, the following **research questions** have been investigated:

1. How to improve the integration of an IFC based VR system into the BIM ecosystem using OpenBIM standards?
2. How to design the data exchange in the system to enable a real-time synchronization between multiple users and multiple end devices?

Developing on our previous research that demonstrated a method to establish a bi-directional pipeline between BIM and VR based on IFC, we have improvised on the performance of the system and implemented two important features: *(a) Generating BCF markups from the VR environment* and *(b) a mechanism to convert IFC data into a custom data structure to be shared and synchronized across networks of multiple users.* Finally, we have enabled advanced model manipulation options that cloud help the users in generating multiple designs iterations on an IFC model.

2. Research

Since the topic of collaboration using VR in BIM is relatively new, published research on these topics are not vast. Many researchers have published using BIM as a data source for enabling better visualization, collaboration and communication using VR, AR, IoT concepts and so on. (Wang et al., 2018) present a comprehensive review of using VR in construction engineering, covering various aspects encompassed by BIM and collaboration. The most interesting aspect of all these researches is that most of them focus on integrating VR with standard BIM authoring tools, specifically Autodesk(TM) Revit® (Johansson, 2016; Roupé et al., 2016; Johansson et al., 2015; Du et al., 2018; Chu et al., 2018). A few (Chen et al., 2005; Hilfert et al., 2016; Dris et al., 2018) have used the IFC format, but none of them offer a solution for a vendor independent OpenBIM based integration with possibilities to edit the model independent of a BIM authoring software.

In our previous research (Nandavar et al., 2018), we described a system capable of achieving visualization, interaction and manipulation based on IFC files, we

want to now focus on integrating more OpenBIM standards into the system, enabling a better fit into standard BIM workflows.

2.1. LITERATURE REVIEW

Collaboration of multiple participants in a Virtual Environment such as a CAVE is presented by (Woessner and Kieferle, 2016). They have implemented an automated Minutes-of-meeting generator, which is generated based on the user annotations containing snapshots and markers placed in the Virtual Environment. They also extend this concept to their Revit Plug-In (Kieferle and Woessner, 2015) to create annotations in the 3D BIM model as TextNotes. Their concept is very close to that of OpenBIM BCF standard but does not consider collaboration based on IFC files alone in their ecosystem.

A Unity 3D based multi-user environment based on BIM for Facility Management scenarios has been proposed by (Shi et al., 2016). Similarly, focusing on improving communication of design aspects in a virtual environment, (Wu et al., 2017) present an excellent system called Virtual BIM Reviewer (VBR) based on Unity 3D to enable multiple participants to explore, communicate and collaborate in a BIM Model. They introduce a marker tool which allows the users to place notices in the 3D scene, which the collaborators can review in an immersive scale. The system depends on Revit to extract the BIM information and in future, perform model manipulations.

A comprehensive collaboration system in the BIM-VR scenario is CoVR (Du et al., 2018a; Du et al., 2018b), a cloud-based multi user BIM-VR system that enables intuitive inter personal communication within VR. It demonstrates three important aspects of collaboration: *BIM data interaction, human-building interaction in VR, and human-human interaction in VR*. For generating a Virtual Model for the VR scene, the system uses Autodesk 3DSmax and then uses Unity and Photon Unity Networking (PUN) to achieve the multi-user VR interactions. Their architecture is robust and supports multiple users from multiple end devices participating in the design review process. Nevertheless, the system works on Revit and achieves only one-way design updates made in Revit to the VR scene. The authors have also reported using the concept of IFC to design their data classes, prompting the suitability of OpenBIM in the BIM-VR context.

An OpenBIM based Interactive Virtual Environment (IVE) is presented by (Dris et al., 2018) for development of a domain ontology for OpenBIM and Interaction in VR. The authors have demonstrated the use of metadata associated to an IFC model for defining intractability with a component or automatically generate some errors in the model for risk evaluation. This approach is very interesting and supports the potential use of IFC as basis for creating a collaborative, interactive VR environment. The authors have addressed the necessity of integrating BCF in such environments to enhance the collaboration aspect of such applications.

2.2. REVIEW OF COMMERCIAL BIM-VR COLLABORATION SOFTWARE TOOLS

Enscape (www.enscape3d.com) integrates VR in architectural design. The real-time rendering plugin is compatible with several software vendors and offers virtual walkthroughs in a rendered model. By editing the native model in the design software (e.g., Revit), the rendered model in Enscape is updated in real-time.

A very promising product is offered by IrisVR (irisvr.com). It offers collaborative meetings in virtual environments. Furthermore, the product offers a fully automatic conversion from SketchUp, Revit, Rhino and other 3D formats to their product. This also includes the transfer of metadata, which enables the user in VR to retrieve attributes like material or name of a selected building element. Reflecting changes to the architectural model in VR on the native formats are not possible.

ALLVR (www.allvr.net) provides a solution for distributed meetings where several project members can communicate about the current state of the planning tasks in real time. It also provides all metadata of the building components in VR and the users can edit the model in real-time. Compared to the other software solutions, it is the only tool which includes BCF for mark-ups from VR.

Based on our research on BIM collaboration in VR, we have thus observed that there is a scope for developing an OpenBIM based BIM-VR system in contrast to the predominantly specific BIM vendor-based collaboration. The system was designed based on research question that have been defined in the Introduction.

3. System Description

The IFC-VR integration presented in this work is an improvised version of the system we already developed using a two-subsystems architecture. An xBIM (docs.xbim.net) service was being used to parse and compile IFC files and Unity engine was handling all the user interactions and rendering in VR. An XML file was used to interface between them. Presently, we have overhauled the system to work with a JSON file that encapsulates all the IFC data in a Unity compatible format and at the same time enabling the data to be distributed seamlessly over a network for multiple end devices to collaborate.

We have also implemented a new set of C-Sharp helper classes that reside on every component of the IFC model in Unity to handle all the user interactions and synchronize it across all the users and sub-systems. The new approach has enabled us to implement advanced manipulations to the IFC model, namely *(a) Relocate elements, (b) Rotate elements and (c) Add openings, windows and Doors to walls and roofs in the model From the VR environment*, independent of any BIM authoring tool required in conjunction to reflect these manipulations in the original model.

Also, we have implemented an issue mark-up tool that at the end of each session generates a BCFZIP file to extend usability of our system with standard BIM software. To address the topic of collaboration, we have implemented a web version of the system using the same JSON file and

synchronized with other participants using Photon Unity Networking or PUN (www.photonengine.com/en/PUN).
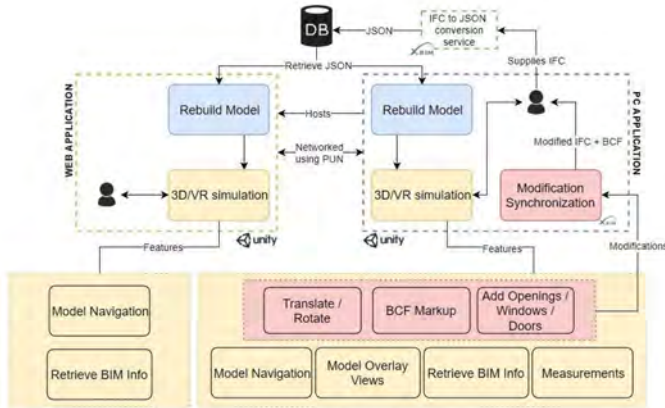

Figure 2. Illustration of the system functionalities.

3.1. DATA EXCHANGE MECHANISM

The system is composed of two major sub-systems: (a) A data conversion service based on xBIM toolkit and (b) The collaboration ecosystem based on Unity3D. The data conversion service is an xBIM application that is called through the UI in Unity by supplying an IFC file and compiles the JSON file with all the necessary information for the virtual environment generation. The conversion service extracts and sorts the mesh and material data, grouping them based on a style layer defined by the material's color. This data is then saved in a custom object alongside the metadata and serialized as a JSON file

The JSON data is then pushed to a file server that is accessible from either the stand-alone windows application or the web application of the tool. A converter class in these systems is called when the user loads a model and is built as a Gameobject in unity using a custom procedural mesh builder implemented as a C-Sharp class to deserialize the JSON file. The rebuilt model has a root object (or the parent - IfcProject) which houses (children) Gameobjects that represent individual IfcElements of the model.

3.2. THE JSON DATA EXCHANGE INTERFACE

The JSON file replaces the XML previously used in the prototype since they are much lighter and faster to transfer, write and read. In addition, this file is represented as a custom object in both the sub-systems, which allows for a more intuitive way of handling the data. It contains the geometric information such as the meshes and materials, which are composed of the vertices, normals, triangles, and the color as a red-green-blue-alpha 4D vector. The metadata is also attached for every element.

3.3. INTERACTION MECHANISM

In the previous approach, we inefficiently accessed the BIM information of a given element during run-time based on object GUID from the XML file used to transfer the IFC data. We have now implemented an Object Meta-Information Class to reside directly on the Gameobject, thereby making it easy to retrieve the BIM data in a faster way. Also, we have implemented a C-Sharp class to record the initial and final translation and rotations of the element, which is updated when the user moves or rotates the element using the HTC VIVE controller inputs in the VR runtime.

3.4. MANIPULATION MECHANISM

A manipulation monitoring C-Sharp class is attached to the root Gameobject, which at the end of the session calculates the transformation changes and the state of the objects deleted by the user based on the GUID of the manipulated elements. This class calls an xBIM based IFC compiler that updates the original IFC model with all the changes recorded.

Previously, we were using an XML file to summarize the changes and send it to a separate xBIM based change synchronization service, which has been now overhauled. With the latest version of Unity engine, we could install xBIM libraries except the xBIM Geometry library, which is incompatible with the Unity compiler backend. Due to this, we can now use the xBIM IFC schema-agnostic interfaces to update the transformation changes, element deletions, addition of openings and opening elements like windows and doors. This eliminates the necessity for having a backward communication interface layer with the IFC toolkit.

3.5. SYSTEM FEATURES

In our previous research, we had already presented some interactive features like navigating around the model, retrieving BIM information and moving or deleting building elements. In this paper, we wish to highlight three major features that have been added to system:

3.5.1. Adding Windows and Doors to the model

It is now possible to import Windows and Doors (void fillers) as individual IFC models, which are cataloged for the users to access from our tool. When the user wants to add a window or door to a wall, it is possible to select the model from the catalog and insert it at a certain location on the wall. We use the dimensions available in the IfcProperties of the window/door to create a placeholder for the chosen model. Once the user places this placeholder on the Wall, we record GUID of the elements and the insertion point in a custom C-Sharp class implemented in Unity. Once the session ends, we retrieve the information stored and use xBIM to first create an opening in the selected wall and fill the opening with the chosen void filling element.

3.5.2. BCF mark-up feature

We implemented a comprehensive UI in Unity, using which the user can create issue mark-ups from VR and share them as per the BCF standard. The user can select element(s) involved in the issue, take snapshots, add due dates, priority, issue assignee and comments to the mark-up. We implemented a Speech-To-Text (STT) feature to enable the user to speak out the issue descriptions and comments to ease the process of entering text in VR mode. The services we are using the background gives us the possibility to support translation of various languages on-the-fly in addition to the STT feature, thus making it easy to address global collaboration. Each instance of a mark-up is stored in a custom C-Sharp class, which at the end of each session uses the xBIM-BCF library to compile a structured BCF/BCFZIP file to be shared among the collaborators.
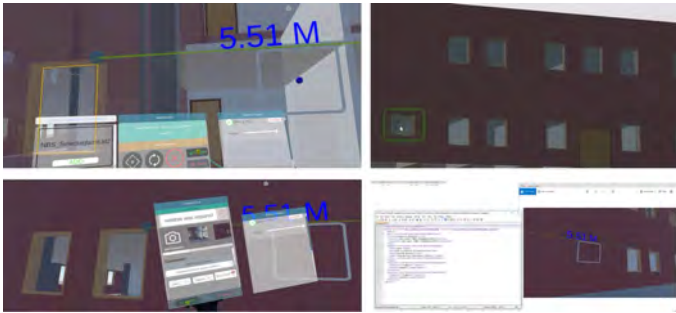

Figure 3. (Top)Window Addition and (Bottom)BCF features. The images on the right illustrate the results of changes made in VR.

3.5.3. Web Browser support

To support remote participation from various end-devices, we implemented a web-browser integration of the app, from which the user can join a VR session hosted elsewhere. This feature offers limited interaction with the model, wherein the user can navigate around the model and retrieve BIM information. Since the tool supports multi-user feature (under development), it will be possible to synchronize changes to the web app in real time.

Figure 4. WebGL version of the tool. The user can query BIM information from the elements and navigate around the model. It is also possible to join a session hosted on a PC version of the tool and collaborate. VR via Web is supported.

4. Conclusion and future outlook

Through this research, we believe to have demonstrated the possibilities of developing a BIM-VR collaboration system based entirely on OpenBIM standards by *(a) using BCF to make the system integral with other tools in the BIM ecosystem* and *(b) Enabling complex interactions independent of BIM authoring software*. These features based on IFC models alone, which to the best of our knowledge, haven't been achieved yet. It is also noteworthy that our system synchronizes the changes back to the original model on the same lines.

Nevertheless, what we presented here is only a prototype of the developed concept and hence needs further refinement and development to be stabilized and usable in standard BIM practices. A major development underway is the complete integration of the multiplayer support based on PUN and building a file server for the system. On implementing this feature, we are positive about making this tool a true multi-user, multi-device supportive OpenBIM based BIM-VR ecosystem. We are also investigating the usage of alternative data exchange mechanism, which could possibly reduce the complexity of interfacing IFC data. With continuous updates to Unity3D, we believe the xBIM libraries can be entirely integrated with it in the near future, eliminating the need for any complex data exchange mechanisms. Very recent tools such as Tridify (www.tridify.com) promise a seamless IFC data integration to the VR environment. Nevertheless, we would like to focus on the aspect of making the backward communication from VR interactions to IFC as seamless as possible.

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