INTERACTIVE VIRTUAL REALITY TOOL FOR BIM BASED ON IFC

Development of OpenBIM and Game Engine Based Layout Planning Tool - A Novel Concept to Integrate BIM and VR with Bi-Directional Data Exchange

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Abstract. With recent advancements in VR (Virtual Reality) technology in the past year, it has emerged as a new paradigm in visualization and immersive HMI (Human-machine Interface). On the other hand, in the past decades, BIM (Building Information Modelling) has emerged as the new standard of implementing construction projects and is quickly becoming a norm than just a co-ordination tool in the AEC industry.Visualization of the digital data in BIM plays an important role as it is the primary communication medium to the project participants, where VR can offer a new dimension of experiencing BIM and improving the collaboration of various stakeholders of a project. There are both open source and commercial solutions to extend visualization of a BIM project in VR, but so far, there are no complete solutions that offer a pure IFC format based solution, which makes the VR integration vendor neutral. This work endeavors to develop a concept for a vendor-neutral BIM-VR integration with bi-directional data exchange in order to extend VR as a collaboration tool than a mere visualization tool in the BIM ecosystem.

Keywords. BIM; VR; IFC; Unity; BIM-VR integration; HMI.

1. Introduction

In the recent past, VR technology has become more accessible and popular due to advancements in the field of computer graphics and modern VR hardware. VR as an immersive visualization technology is now available at a consumer level. As per (Gartner & Gartner 2017), VR was one the forerunner among the technology trends in the popular Gartner's Hype cycle.

expectations

Connected Home
Deep Learning
Machine Learning
Virtual Assistants
IoT Platform
Autonomous Vehicles
Nanotube Electronics
Smart Robots
Edge Computing
Cognitive Computing
Augmented Data Discovery
Blockchain
Smart Workspace
Conversational User Interfaces
Commercial UAVs (Drones)
Brain-Computer Interface
Cognitive Expert Advisors
Volumetric Displays
Quantum Computing
Digital Twin
Serverless PaaS
5G
Human Augmentation
Neuromorphic Hardware
Deep Reinforcement Learning
Enterprise Taxonomy and Ontology Management
Software-Defined Security
Virtual Reality
Artificial General Intelligence
4D Printing
Augmented Reality
Smart Dust

As of July 2017

| Innovation Trigger | Peak of Inflated Expectations | Trough of Disillusionment | Slope of Enlightenment | Plateau of Productivity |

time

Years to mainstream adoption:
○ less than 2 years　◔ 2 to 5 years　● 5 to 10 years　▲ more than 10 years　⊗ obsolete before plateau
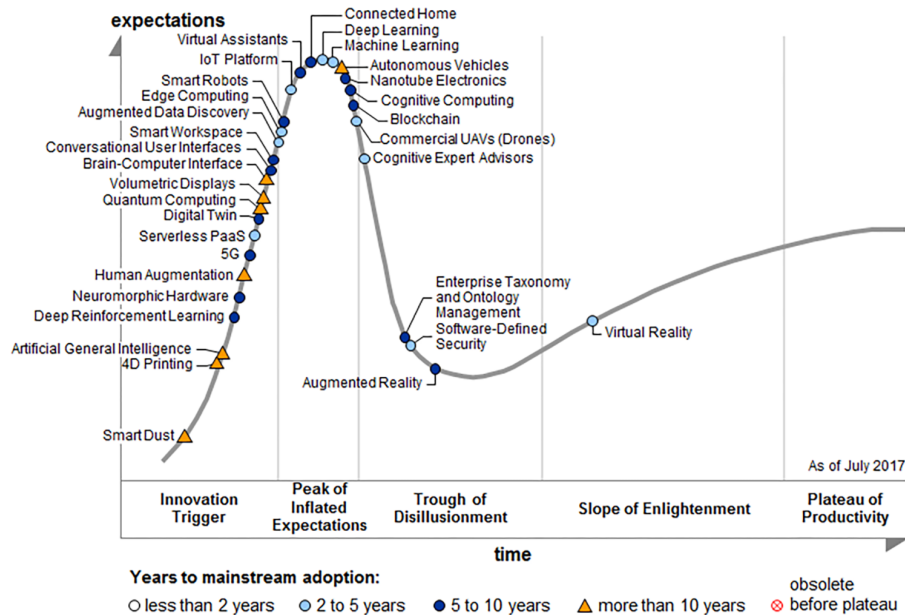
Figure 1. The Gartner Hype cycle for emerging technologies in 2017.

On the other hand, in the past decades, BIM (Building Information Modelling) has emerged as the new standard of implementing projects in the AEC (Architecture, Engineering and Construction) industry and is quickly becoming a norm than just a co-ordination tool. In BIM, visualization of the digital data plays an important role as it is the primary communication medium to the users.

When it comes to visualization of the 3D Model, VR is the only technology that is capable of offering an immersive, 1:1 scale presence in the environment. With consumer VR headsets such as HTC VIVE becoming easily accessible, room-scale tracked VR makes it simple to build a realistic walk-through experience, enabling the users to "move" around the entire virtual environment. These factors enables the user to virtually "be" in the building and observe all the aspects of the project in finer details. This eases the process of communicating technical aspects to cross-discipline technicians both on-site and off-site during the execution phase of the project (Roupé et al. 2016). Moreover, it enables a better client experience and involvement in the project, which is critical in making design decision during the conception and planning stages (Heydarian et al. 2015).

Immersive experiences in case planning of large facilities such as car manufacturing plants has a very beneficial effect on collaborating various experts that are geographically spread apart. In our case, specialists at BMW for planning various layouts of the production line often have to travel often in order to acquaint themselves to the physical space before and during the planning activities, resulting in excessive costs, time and efforts incurred by travel. Factors such as layout safety planning and spatial requirements for equipment installations require a first-person, "true scale" perspective to experience the space. To this end, a VR

tool to enable virtual walk-through, measuring distances & areas and a feature to warn the user of safety risk was developed using Unity Engine and HTC VIVE. The aim is to assist layout planners to review 3D models (BIM models) of the new layouts under planning in VR. The process of exporting BIM models to a format compatible with Unity (FBX or OBJ) is complex, repetitive and most importantly, eliminates the "Information" part of a BIM model. Furthermore, there existed no feedback from the VR system back to the BIM model in order to document the outcome of a planning session carried out in VR. To ease this bottle neck and enable an automated, rapid BIM data transfer to Unity engine and backwards, a new approach of communicating between BIM and VR based on IFC was resorted to.

Subsequently, a research on the existing solutions addressing the task of integrating VR to BIM was performed, both published literature addressing the issue of BIM-VR integration and commercial software that offer BIM-VR integration were reviewed. Though there are a few solutions that support IFC format, no solution exists, to the extent of our knowledge, that enables a user to perform interactions with model, manipulate the model in VR and synchronize the changes to the original model, all based on one unified, vendor-neutral platform which is based on the OpenBIM philosophy.

The following sections of this paper reports the development of a mechanism to exchange data between BIM and VR based on IFC and XML encoding technology. Section 2 outlines the research adopted to arrive at the research questions that have been addressed in this paper. It further reports the review of published literature and state-of-the art software solutions available on the topic of integrating BIM and VR. Section 3 describes the concept and development of our solution as a prototype. Section 4 reports the findings and conclusions that could be drawn from this work.

2. Research

Numerous published literature reporting BIM-VR integration were reviewed in order to study various applications that necessitated the data exchange between BIM and VR and mechanisms that were in-turn adopted. The major applications for adopting VR in BIM were found to be *(a) Spatial familiarization for occupants and users of the building*, (Woksepp and Olofsson 2008), (Bernstein et al. 2014), (Roupé et al. 2016) and (Jones et al. 2017), *(b) Effective communication of technical aspects to various participants* (Heydarian et al. 2015), (Roupé et al. 2016) and *(c) As a safety evaluation tool, especially for fire safety and emergency evacuation simulations* (Kinateder et al. 2014), (Rüppel and Schatz 2011),(Wang et al. 2014),(Hilfert et al. 2016) *and to check risk of falling in construction sites* (Dinis et al. 2017).

On the other hand, it was found out that there are two major approaches to achieve the integration of VR to BIM: *(a) Integrating BIM data to Game Engines* (Yan et al. 2011), (Merschbrock et al. 2014), (Edwards et al. 2015) and (Hilfert et al. 2016) and *(b) Using a customized pipeline to render BIM in VR* (Johansson et al. 2014), (Kieferle and Woessner 2015) and (Johansson et al. 2015). While

each of them have their own pros and cons, using Game engines as the VR end of the pipeline entails advantages in terms of in-built handling of the graphics optimizations and user-interactions with the VR system, (Edwards et al. 2015) presents an extensive argument for adopting game engines for integrating BIM and VR. Unity Game engine has been adopted as the VR end of the pipeline in this work, owing to the extensive VR interaction authoring resources available as plug-ins to the software and active development support for HTC VIVE.

2.1. LITERATURE REVIEW

Inherently, BIM makes available a lot of non-geometrical data about various aspects of a building, much in advance. This meta-data needs to be leveraged in immersive visualization of the models to enhance the quality of information conveyed to the user, which will enhance the experience of the user in immersive environments beyond pure visualization. In presenting a comprehensive overview of extending BIM into game engines, (Bille et al. 2014) report a dearth in research on integrating meta-data of BIM into game engine formats.

One of the key constraint with Revit, the most commonly adopted BIM program for immersive VR is that it is only available on Microsoft Windows platform. During the runtime of a BIM-VR system, it is imperative to access Revit API for all the geometric and parametric information to be able to establish a bidirectional data exchange. In solving this issue, (Kieferle and Woessner 2015) present a novel approach by decoupling Revit from the Virtual Environment renderer, in their case OpenCOVER.

A very commendable work in interactive, immersive, VR based BIM visualizations has been contributed by (Johansson et al. 2014) in form of a plugin to Autodesk ® Revit. Their system, unlike other similar solutions is a game-engine independent BIM viewer with high level of graphics-based optimizations implemented for viewing large scale BIM models (Johansson et al. 2015). The approach is restricted to using Autodesk REVIT as the BIM end of the BIM-VR pipeline, which cannot include collaboration BIM formats like IFC.

A working prototype of a bidirectional communication between BIM program and game engine has been developed and tested using Autodesk® Revit and Unity 3D (Edwards et al. 2015). They use a custom OBJ class to achieve the data transfer. However, the major issue reported in testing the system is reported to be updating changes made in VR scene back to the BIM program based on the custom OBJ class. It can be safely assumed that the root of the problem lies in the difference in the way data (geometric and semantic) is represented in Unity in comparison to Revit. The work concludes suggesting usage of IFC as a resolution to the issue of communicating back to BIM, emphasizing the potential of IFC in the BIM-VR pipeline.

Hilfert et al. (2016) have developed such an IFC based system, using Unreal engine as the VR platform. However, their system doesn't address a mechanism to have feedback from the VR end back to the BIM system.

2.2. STATE-OF-THE-ART SOFTWARE SOLUTIONS FOR BIM-VR INTEROPERABILITY

Revizto (www.revizto.com) is a visual BIM collaboration tool that offers various collaborative planning tools for diverse, leading BIM programs available in the market. It is a software that is aimed at enabling visualization of various collaborations in a typical BIM project.

Fuzor (www.kalloctech.com) is one of the most powerful VR solutions available for the AEC industry, which enables multiple user to collaborate their BIM project on a centralized platform. It offers a live link between Revit and VR seesion, whcih enables the users to manipulate the model on-the-fly in VR.

Autodesk Live for Revit is a cloud-based solution by Autodesk® for enabling "One-click VR" for BIM models in Revit (www.autodesk.com/products/revit-live). It is a subscription based service that can add VR functionality to the BIM models. This service is a one-way integration to VR, which lacks on-the-fly model manipulation feature and a solution restricted to a particular BIM software.

BIMXplorer (www.bimxplorer.com) is an interactive VR visualization for BIM, which is available as a standalone program and a Revit plug-in. It is capable of importing IFC files directly and hence is a potential VR solution for OpenBIM philosophy. It offers a direct link from BIM to VR through Autodesk Revit, which enables the user to make design iterations to BIM models on-the-fly. Nevertheless, it doesn't offer this feature in the satndalone soltion for IFC files.

2.3. SUMMARY OF RESEARCH FINDINGS

- Of the nine published research on immersive, interactive visualization of BIM, *six of them promote using a game engine* for rendering the model and interacting with it.
- Of these nine, five of the works have enabled at least a uni-directional link between BIM and VR.
- Only two of them [(Edwards et al. 2015) and (Kieferle and Woessner 2015)] report a complete bi-directional model data synchronization between BIM and VR, both of which are based on Revit API.
- Only (Hilfert et al. 2016) have provided a completely IFC based BIM-VR integration. However, the backward link from VR to BIM was not achieved using this method.
- Though all software solutions support integrating VR into BIM, only *Fuzor* and *BIMXplorer* provide a complete data exchange between BIM and the VR tool. However, none of the solutions support such a link based purely on IFC, independent of any particular vendor of BIM software.

3. Solution Concept

The core concept of the solution presented here is an automated mechanism for bi-directional data exchange of Building Information between native IFC files of BIM models and Unity engine based on XML encoding. Since game engines use triangulated geometry to render the 3D content, it is necessary to translate the

geometry of the BIM models into such a format. Though majority BIM programs are capable of exporting 3D models to FBX or OBJ file formats, it doesn't include the meta-data data attached to the 3D model. Lastly, to enable manipulating the 3D model and synchronize it to the original model, it is necessary to communicate with the IFC files and register the changes, which establishes the *closed-loop* data exchange from VR to BIM.

There are four major tasks to realize this mechanism:

1. Transfer of geometry from the BIM Model to Unity as procedural polygons, along with the object specific information (meta-data) as textual content.
2. Rebuilding the model in Unity with correct mapping of object data to its geometry.
3. Enabling VR visualization and user interactions with the re-generated geometry.
4. Synchronization of user generated changes to the model in Unity with the original BIM Model

To realize task (1), we have developed a program using the xBIM Toolkit, which is an open-source SDK for handling IFC files. The program is capable of parsing the entire model and generating an XML file with a customized encoding of geometric and meta-data of the BIM model in order to be understandable by the Unity engine. It generates what is named as in IFC_VRXML file, which is the sole forward-communication from the BIM system to the VR system. Task (2) is handled by a custom C-sharp class in Unity, which rebuilds the 3D geometry with the same hierarchical structure of the BIM model. Task (3) is accomplished by a set of C-sharp classes in Unity, which handle all the user-VR system interfacing. They also rely on the IFC_VRXML file to query and fetch the object-specific data to users during run-time. Task (4) is accomplished by class in Unity which generates another XML file summarizing all the manipulations to the model, which is subsequently parsed by another xBIM based program that registers all the changes to the IFC file. In the end a new IFC file with all changes registered to the original model is compiled with a nomenclature that suffixes a time-stamp to the original name for the purpose of version-tracking the model.

4. System Description

The system is mainly composed of 2 layers, viz. the Unity engine Layer (UeL) which represents the VR end of the system and the xBIM layer (xBL), interfaced by customized XML files that exchange the data back and forth. UeL represents the C-Sharp classes that handle the task of parsing the IFC_VRXML file, handling the user inputs for navigating in the VR scene, querying BIM information, manipulating models and finally a class that translates all the changes made to the model into an XML file, named the Changes_XML file. On the other hand, xBL represents the calss which parses the IFC file and compiles the IFC_VRXML file and the class that parse the Changes_XML file to register the changes to the IFC file and compile a new IFC file.

IFC_VRXML file is an XML file with a customized structure that encapsulates all the relevant information about of a BIM model required in the UeL. Geometric information like the triangulation data of an element along with meta-data such as the property sets and material quantities are encoded as children

nodes of each model element. Attributes such a the element ID and flags, which prompt the UeL to understand the element hierarchy and mesh-generation are attached as well. The entire file mimics the parent-children hierarchy of the BIM model in order to preserve the hierarchy in the Unity VR scene.

Changes_XML file is also a customized XML file which helps in communicating from the VR end of the system with the IFC file. The element ID of building elements that have been manipulated are listed as child nodes of respective nodes that that specify the nature of manipulation (e.g. moved and deleted elements). A custom class in xBL processes this information and applies the respective changes to the original IFC file (BIM model).
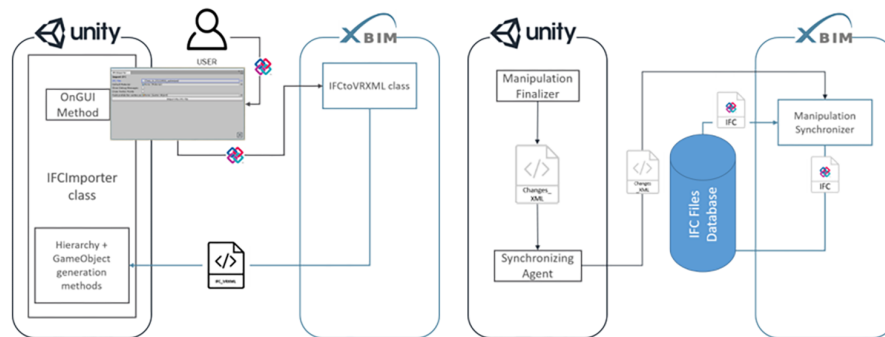

Figure 2. Illustration of the mechanisms. (L) converting IFC into Unity VR Scene (R) Translating changes from VR scene to IFC.

4.1. FEATURES

With layout planning as the purpose, a few features to test the concept have been implemented in the prototype of the developed mechanism. The current version of the prototype is capable of 6 main features, viz. *(1) Walk-through feature*, which lets the user explore and familiarize himself with the building, complete with a warning system if a user is vulnerable to falling. *(2) Measurement feature*, which allows the user to mark any number of points and measure distances (in case of only 2 points) and areas. *(3) Element Query feature*, which fetches the meta-data attached to the building element chosen and displays it on a virtual UI board to the user. *(4) Element relocation*, which allows the planner to edit the layout by moving elements *(5) Element deleting*, which enables deleting an element in order to edit the layout. Finally, *(6) Issue tracking feature*, which allows the user to mark an issue, mark the Point of Interest (PoI) and click a snapshot of the situation. Furthermore, the user can leave voice messages a comments about the issue.

On ending a VR session, the manipulations to the scene (Element relocation, deletion) are synchronized and a new IFC model is generated in the same directory as the original file. The issues marked are stored and available to review (until deleted) in further sessions.

4.2. PERFORMANCE

The prototype was tested with nine different IFC models categorized as explained in the table 1. The System was tested for Geometry retainment, import speed and interaction responsiveness. The following outcomes were observed:

- High speed of importing the BIM models to Unity (Model with >4000 geometric elements in 45 seconds on a standard VR-ready gaming PC)
- High rate of retention of geometries (measured as a **ratio of** *no. of geometries in BIM model* **to** *no. of visible geometries regenerated in Unity scene*) : **0.991 (average)**
- Quick response to Information query: **ca. 1 Second (average)**
- Very complex geometric shapes (3D object) were retained
- After ending the VR session, all relocation and deletions of building elements were reflected in the new IFC file generated
- A compilation of all the features and performance of the system is available as video under the following link: *https:drive.google.com/open?id=0ByTXTd12UtbHQlAtVDRCdTVIQlU*

Table 1. Categories of IFC test models.

Simple	Fairly Detailed	Complex
< 100 Building Elements, only basic building elements	100 < Building Elements < 1000, may have other details such as building services and furniture	> 1000 Building Elements, may have other details such as building services and furniture

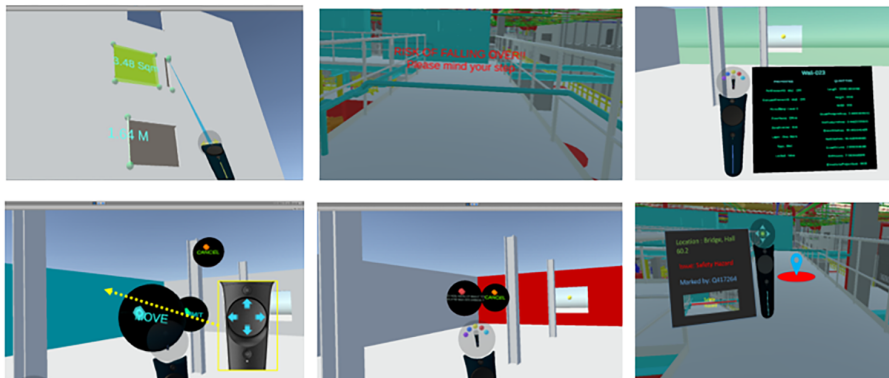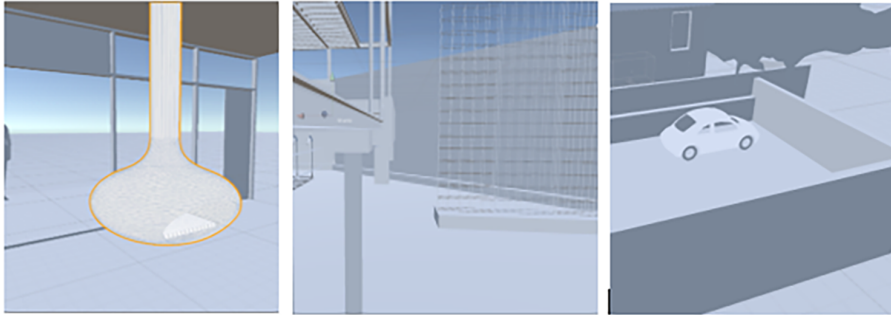Figure 3. Features implemented in the prototype.

Figure 4. Complex geometries recreated in Unity from IFC_VRXML file.

5. Conclusion and further work

The mechanism developed in the current work lays the foundation to build upon for developing an OpenBIM philosophy oriented integration of VR to the BIM ecosystem. The prototype fared well in the testing stage and provided a quick, automated way of importing BIM data into VR environment based on the IFC format. Furthermore, it enabled a range of interactions with the BIM model in the VR environment, making it potentially useful as a layout planning tool. Since the solution is based on a game engine, it has the advantage of incorporating the agile, state-of-the art advancements in the VR technology with great ease. Following were the key capabilities of the system:

- Information-enriched, interactive VR
- Design Iterations in VR &
- Mechanism to synchronize design iterations to original model
- In the process, a custom UI class for using HTC VIVE Hardware in Unity has also been realized. It is capable of accommodating future addition of features and is also under constant improvement based on user feedback.

The solution provided here is unique in terms of complying with the OpenBIM philosophy. It offers a better range of interactions and functionality than the current best solution that is available for importing IFC models to VR. Anyhow, unlike the commercially available BIM-VR solutions it lacks the capability to handle very large BIM models and is yet to achieve a high-quality rendering of the model in VR

The system described here is under development and all the authors are actively involved in the process. Features such as enabling multi-player support over network , possibility to resize and add new elements to the model and integrating BCF support will be realized in the upcoming prototypes. We also take the opportunity to declare no conflicts of interests and ideas in publishing our work.

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