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Research Article

Towards a BIM-based System Integrated to a Virtual Reality Platform

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Abstract: Based on the advancement in information and computational technologies (ICT), Building Information Modeling (BIM) now offers collaboration with additional applications that can improve the use of 3D modeling. One way to make the 3D platform more effective is to integrate models to virtual environment, where users can walk through the design in its infancy. Immersive Virtual Reality (VR) offers high levels of interactivity and visualization for Architecture, Engineering, and Construction (AEC) industry when successfully utilized with BIM. The question here is how to achieve a successful connection between BIM and VR to present a dynamic demonstration of real-case complex models. This paper aims to develop a conceptual map, which presents the successful integration of BIM and VR systems. The methodology will include the development of a 3D model, evaluation and improvement of the design for VR purposes, and integration of BIM and VR systems. The integrated BIM-VR system will offer a virtual mock up assess and enhance BIM by designers, contractors, as well as users of buildings. The results will include the development steps of the BIM-VR system and its testing through virtual walk-throughs.

Keywords: building information modeling, immersive virtual reality, systems integration.

1. INTRODUCTION

It was more than a decade ago when BIM was introduced into the AEC industry and has continued to improve since then (Wang and Leite 2014). BIM is defined as an intelligent process to create intelligent 3D models for generating, using, and managing high-quality digital information for the sake of project in terms of decreased duration, cost, and environmental impact promises (Smith and Tardif 2009). BIM usage has significantly improved in the construction industry in the past few years (Nawari 2012). According to McGraw-Hill Construction's Smart Market Report, BIM usage has been increased from 28% in 2007 to 71% in 2012 (McGrawHill 2012). Considering its benefits in 3D modelling, BIM is now used with an emerging technology, immersive VR, to improve interactivity and visualization for AEC users.

The evolvement of VR has started with flight simulations (Furness 1989) and real-time visualizations has been used ever since. Immersive and non-immersive VR have been popular in construction research, where they have been used to visualize project designs (Messner et al. 2002) and construction plans and schedules (Haymaker and Fischer 2001). Although the increased interactivity has brought benefits in understanding complex designs, it was a challenge to extract 3D data from BIM, and integrate VR and BIM to achieve real-time visualizations of real building models. In

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order to address this situation, this study focuses on how to achieve a successful connection between BIM and VR to present a dynamic demonstration of real-case complex models. This paper aims to develop a conceptual map, which presents the successful integration of BIM and VR systems.

2. **Background**

Immersive Virtual Reality (VR) and BIM

The term 'virtual reality' was first used by Sutherland and continued to be used ever since to describe non-immersive and immersive VR systems (Sutherland 1965). Virtual environments simply presented on a computer and controlled through a keyboard and a mouse is called non-immersive due to their limited interaction capabilities. On the other hand, fully immersive virtual environments are experienced by HMDs, where users use a head set and controllers to experience different aspects of the virtual world. In the scope of this study, HMDs are used to perform real-time virtual walkthroughs to explore and navigate through interior and exterior spaces of a virtual building model (Liu et al. 2014).

A building information model (BIM) stores specifications and information related to building elements, while displaying 3D geometrical properties. A building model is represented as architectural, structural, mechanical, electrical, plumbing, and site plans, all of which are integrated. Changes performed on one view or element property is automatically reflected to other views, which makes BIM preferable by many AEC users. By storing different disciplines' plans and information, BIM allows many applications along the design and construction process, including cost-estimation, energy analysis and production planning (Eastman et al. 2011). Through its object-oriented 3D models with information and auto-update properties, BIM supports easier integration of VR especially during the design process.

BIM was integrated with VR role-playing scenarios to enhance AEC student learning previously. A virtual BIM environment was used for collaboration as well as creating a 'green' training environment for virtual on-site visits. The experimented virtual environment showed potential in improving large-scale green building training, while reducing data interoperability issues (Shen et al. 2012). BIM real-time visualizations were practiced from many ends, such as using game engines to produce improved quality. A typical BIM to VR software workflow was proposed before (Halaby 2015). Step 1 created 3D model by using Autodesk Revit, Step 2 involved using Autodesk 3DS Max to for model optimization and bake lighting, and Step 3 inlcludes Unity and WorldViz for stereoscopic integration. Several steps of optimization and increased visualization were performed to make sure complex models were ready for the virtual world. Despite recent studies, it is still believed that VR has not reached its full potential in the AEC education and industry and its development will continue with emerging technologies to help reshape the industry (Messner et al. 2003).

Concept Maps

BIM-VR systems integration is presented as a concept map in this study. Concepts maps are usually created as top-to-down diagrams to show the relationship among concepts and their sub-groups. They are designed parallel to human cognitive structure the holistic representation of scientific knowledge (Wandersee 1990). Novak (Novak 1977) used concept maps as a graphical display of knowledge that is comprised of concepts represented by boxes or circles and connected by linking phrases and verbs between pairs of concepts. Concept maps were proved successful for knowledge representation and acquisition. With the recent improvements of technology and the integration of concept mapping with information resources (Cañas et al. 1994), now concept maps have a new role of integrating knowledge visualization and information visualization.

Methodology

The methodology will include the development of a 3D model, evaluation and improvement of the design for VR purposes, and integration of BIM and VR systems (
Figure **1**). The integrated BIM-VR system will offer a virtual mock up, assess and enhance BIM by designers, contractors, as well as users of buildings.

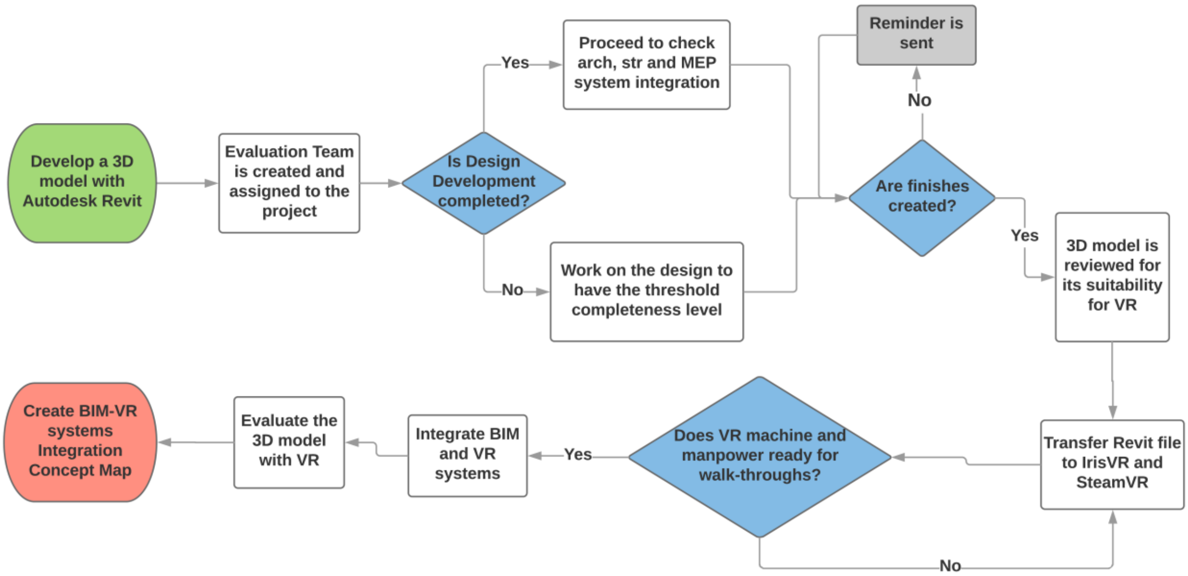

Figure 1: BIM-VR integration flowchart

Development of the 3D Model

Model-based design process started with developing the 3D model of the sample project by using Autodesk Revit. A sample project was selected to be a 14,500SF building at Jefferson-East Falls Campus. The campus building was composed of two-story, one ground and one mezzanine level. Ground level was composed of faculty and staff offices, classrooms, a computer lab, a laser cutter lab, and two bathrooms. Mezzanine level was designed with cubical-rooms and half-walls to allow view to downstairs. Building structure started with a reinforced concrete foundation wall and footings and rise up with wood framing and brick veneer. Evaluation Team was created and asked to chare various parts of the project for design development. The team included designer (i.e. architect) and non-designer (i.e. construction manager and civil engineer) members. The team was asked to create a 3D model with basic elements. Architectural (arch) elements included exterior and interior walls, doors, windows, curtain walls, stairs, floors, finishes, ceiling systems, bathroom fixtures, structural (str) elements include foundation wall and continuous footing, and mechanical, electrical, and plumbing (MEP) elements included electrical fixtures, air diffusers, and duct systems.

When design development was completed (

Figure **1**), the team was responsible to reach a certain threshold completeness level. This was specifically required to be able to use the model in virtual walk-throughs. As an example, if finishes were not detailed and completed, the VR experience would not result in the desired outcomes. Therefore, after the integration of arch, str, and MEP elements was performed, the creation of finishes were double-checked by the team.

The next step was to review this model for its suitability to be used in VR. This was performed by a team of Information Technology (IT) personnel and construction managers, who were experienced in using VR for virtual mock-ups. The first version of the 3D model is given in Figure 2. The main improvements suggested from the review team were based on the finishes. Some finishes in the Revit model was different that the finishes in the actual building. The differences were listed as color of toilet partitions, color and pattern of carpet, and missing carpets in certain areas. Additionally, lack of interior furniture was reported as a potential parameter to decrease the quality of the VR experience. In order for BIM and VR systems to integrate successfully, the review team focused on the visualization properties of the design and the Revit model. The Revit model had a complete set of elements as required, therefore the focus was on improving essential elements for a better VR experience. The 3D model ready for its use in VR is given in Figure 3.

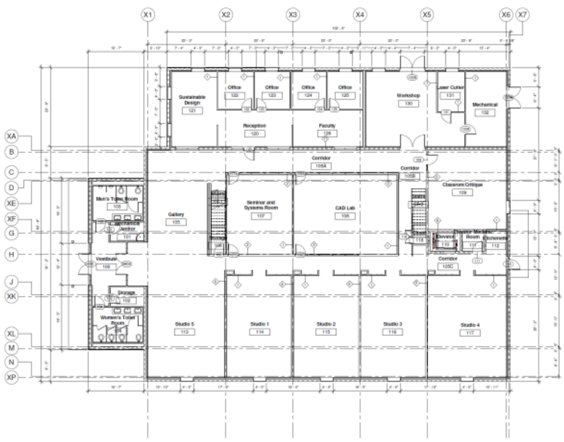

Figure 2a: Grade Level

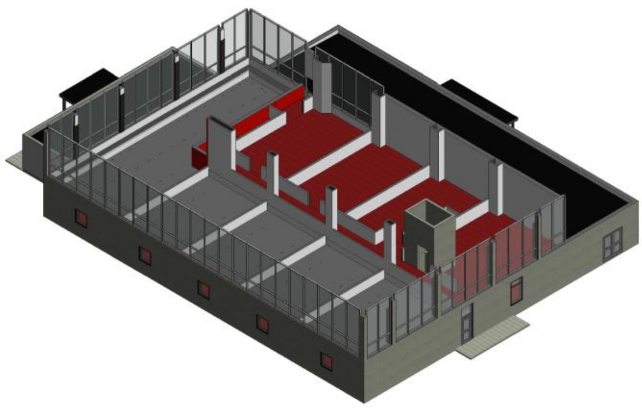

Figure 2b: 3D View

Figure 2: Preliminary Revit model

Figure 3a: Grade Level

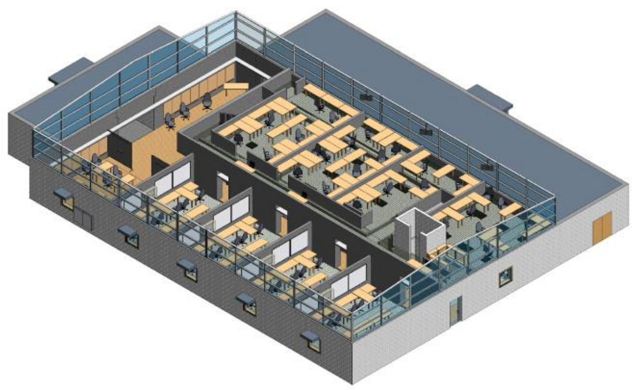

Figure 3b: 3D View

Figure 3: Revit model ready for VR

Evaluation and Improvement through VR

The completed 3D Revit model needed to be transferred into different software platforms. The first step was to purchase IrisVR software (2018), which allows 3D Revit models to be used in virtual walk-throughs. Additionally, IrisVR allows for in model markups, drawing, and annotation which can be screen captured for later use. Prospect Pro Plus was used in this project, as it was used with a VR headset. Secondly, SteamVR (2018), the software to run the HTC Vive head set, was used.

When the VR software applications were ready, Revit 3D model was transferred in to IrisVR and was run through SteamVR. In order to create a more comprehensive concept map, both architect and construction manager VR users were invited to evaluate the same campus model. Both architect and construction manager users were briefly interviewed before the actual walk-throughs to learn about their knowledge and perception of VR use in the construction industry. All users were aware of the technology, but most of them had not used HTC Vive headset continuously in their projects.

Users were first informed about the campus building and was given PDF plans to get familiar with the model. They were trained about the HTC VR system through a tutorial and was navigated through the model during their own VR walk-throughs. The users evaluated the model separately and then exchanged information about their VR experiences. This process was recorded to create the essentials of the BIM-VR Systems Integrated Concept Map.

Recordings of the VR walk-throughs and exit interviews with VR users in this campus process resulted in the following points:

- Final 3D Revit model used in this experiment was found as an enhanced version of 2D plans and BIM-VR combination was reported to be successful in leading to a realistic comparison of virtual and actual building models.
- Architects emphasized their appreciation on the high level of visualization in terms of finishes and improvements from preliminary to final Revit models.
- As VR walk-throughs allow taking pictures during the process, architects found VR process useful to create photo-realistic renderings.
- Construction managers was fond of collaboration aspects through visual clash detection options. As an example, during the process a clash through the duct system was found, while walking above the ceiling grids and through the ducts and air diffusers.
- Both users were interested in the life cycle aspects of BIM-VR integration and suggested to involve facility managers in the next round of walk-throughs.
- Construction managers stated the power of VR as the whole-building mock-up, which would be a beneficial investment to optimize discussions with owners and other parties.
- The VR walk-throughs in the Campus Revit Model was found successful to perform design integration among different systems.
- Users stated that the VR walk-through process would be a successful method to demonstrate real-case complex models, especially to non-designers.

Finalized Concept Map for the Integration of BIM and VR Systems

Evaluation and feedback of VR users were utilized to create the finalized concept map of BIM and VR system integration Figure 4.

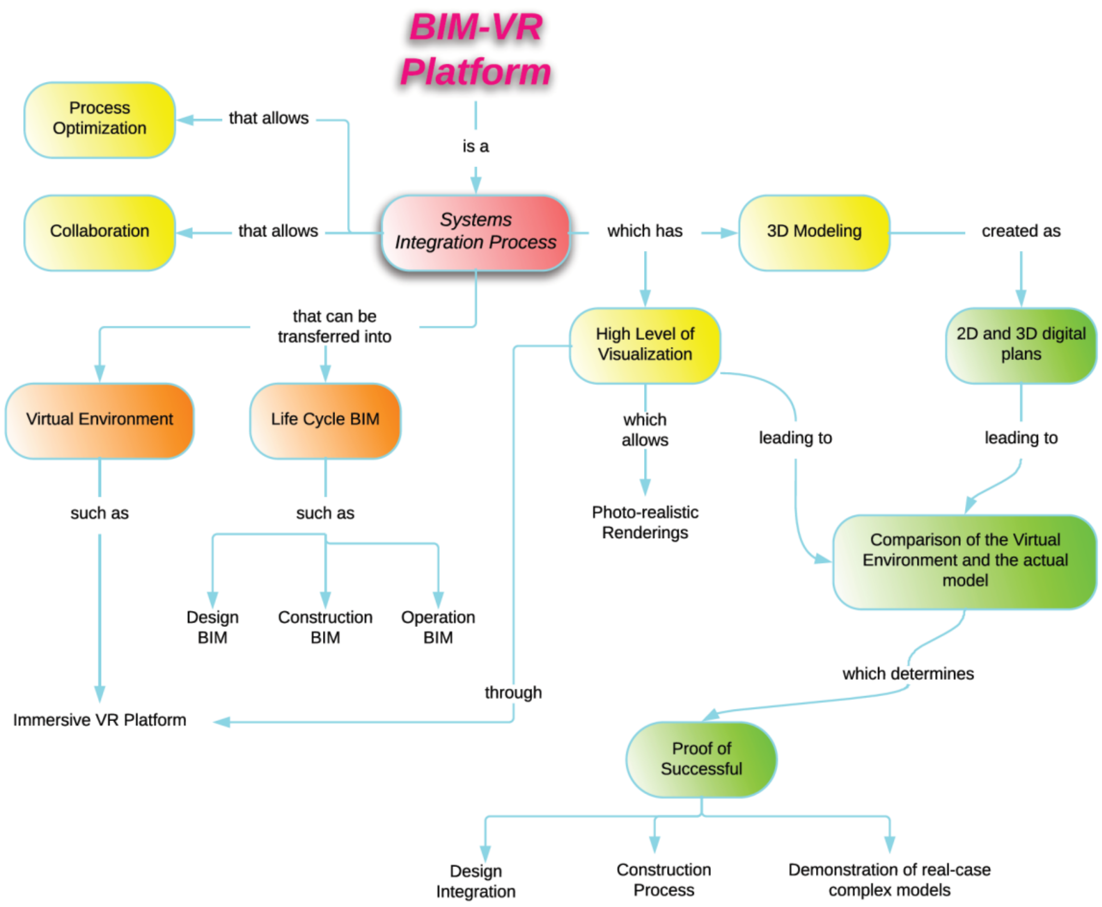

Figure 4: BIM-VR systems integrated concept map

BIM-VR platform is defined as a systems integration process, due to the combination of two emerging and powerful technologies. This process is reported to emphasize process optimization and collaboration through allowing architectural, structural, and MEP systems and users simultaneously into the process. BIM-VR process starts with the creation of a 3D model and the integration of the virtual environment and its high-level of visualization, which indeed results in an effective comparison of the designed vs. actual building models. Immersive VR platform and its integration with BIM/Revit models is found successful to enhance design and construction processes, as well as to demonstrate complex building models.

Conclusions

This study examined the integration of BIM and immersive VR systems for a dynamic demonstration of real-case complex models through a campus building case study. Users experienced VR in an improved 3D Revit modeled and evaluated the best potential integration of BIM and VR for the AEC industry. The results of users' experiences were implemented in a concept map of BIM-VR integration, which is the concrete output of this study. The concept map summarizes the best ways to use the integrated BIM-VR systems and direct users from different backgrounds (architecture, structure, MEP, and construction management) to use both BIM and VR effectively. The current concept map presents the successful integration of BIM and VR systems, which would be beneficial to first-time and continuous immersive VR users in the AEC education and industry. Some details of the process could not be included here due to the length limit, however next phases of this experiment are planned to be performed with facility managers and actual building users to observe their experiences of the immersive VR technology in a 3D Revit model.

Collaborative VR technology will allow users and designer and construction manager parties to evaluate BIM-VR system simultaneously, which will be used to improve the proposed concept map.

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