Virtual Reality to Support the Integrated Design Process: A Retrofit Case Study

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ABSTRACT

Virtual Reality (VR) technologies have been used in building design and construction for many years. VR has primarily been applied for design review, worker and end-user training, 3D coordination, marketing, and demonstration. Previous research shows that VR technologies, such as interactive virtual walkthroughs, help the design team effectively convey design ideas, aid in the evaluation of architectural alternatives, and assist in the identification of design errors. Despite the benefits, VR has not yet been widely adopted in actual design practice. This paper examines the use of a VR media and display system in the design process of an energy retrofit project and identifies the benefits and challenges of using VR technologies for the project. The project team had access to an immersive display system throughout the design process. A research team supported the design team with the development of virtual reality solutions. The research team also documented and evaluated the uses of the immersive display system through surveys and case study analysis techniques. The case study shows that using VR tools and an immersive display system makes the design meetings more productive and the reviews more effective, provided the VR models are developed with appropriate level of detail and functionalities. The industry still lacks a general understanding of the benefit and use cases of VR technology. In addition, the lack of expertise in VR tools and VR display systems also impedes the wider adoption of the VR technologies in the current practice.

VIRTUAL REALITY IN BUILDING INDUSTRY

The term virtual reality (VR) has been defined and interpreted by many researchers with different meanings. Some define VR as a collection of technologies that include a virtual environment and sensory input, such as a head mounted display and glove input device. Other people with a broader definition believe VR includes books, movies or pure fantasy and imagination (Isdale 1998). In the building industry, even though researchers have come up with various definitions of VR, the term typically means computer mediated systems, environments, and experiences. Zikic (2007) defines VR as “a computer generated three dimensional environment which responds in real time to the activity of the users”. Otto (2002) argues that VR is the user experience of interaction with simulated objects and environments, through the use of interactive computing and multimedia display technologies. Whyte (2002) summarizes the three mediums or characteristics of VR as interactivity, three-dimensionality, and real-time response to actions. Another additional criterion/characteristic that is often associated with VR is the sense of immersion, which evaluates both the VR content and the VR hardware and describes the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant (Slater and Wilbur 1997). VR hardware, such as the display system, has great impact on the effectiveness of VR media and can be divided into three categories: immersive, such as the CAVE™ (Cave Automated Virtual Environment); semi-immersive, such as dome or large size multiple screen display system; and non-immersive, such as a desktop monitor. As desktop monitors are more of a general display device, we categorize the semi-immersive and immersive display system as specialized VR display systems.

Research on the adoption of VR in the building industry shows that VR tools have been used for many purposes including design review, scheduling, coordination of detailed design, simulation of dynamic operation, and marketing (Whyte 2003). Research focused on evaluating the value of VR tools and VR displays for different use cases showed that VR and specialized VR display systems generate value for a project team by facilitating effective communication, improving meeting productivity, and soliciting improved feedback (Maldovan and Messner 2006; Shiratuddin et al. 2004; Messner et al. 2006). Despite the identified benefits, VR tools and VR display systems are not widely used in practice. This paper provides a case study aimed at understanding more about the challenges, as well as benefits, of using VR tools and specialized VR display systems in an energy retrofit project and provides insight into the future implementation of VR in the building design and construction process.

CASE STUDY: AN ADVANCED ENERGY RETROFIT PROJECT

The case study project is a public funded advanced energy retrofit project. Although the project's design process focused on implementing an integrated design process, the project funding source and associated procurement regulations necessitated a multiple-prime delivery method with a CM Agent that was brought into the project very soon after the Architect was hired. Even though separate contracts were awarded for electrical, HVAC, plumbing, and general construction, the parties on the project, including the architects, engineers, consultants, construction managers, and the prime contractors, were bound by a collaboration addendum in their contracts to work collaboratively as an integrated team. The project was both fast tracked and utilized an intensive integrative process, playing off the expertise of the future building research and industry occupants of the building.

Through the collaborative environment, a value-based decision making matrix and BIM execution plan were developed and relied upon in the design process. According the project's BIM execution plan, part of the contract document, the project team is required to implement 16 BIM uses in the planning and design process, including 3D coordination, 4D modeling, design reviews, energy analysis, lighting analysis, as well as others. Among those BIM uses, the use of the Unity rendering engine for virtual walkthroughs in design review meetings and the use of Autodesk Navisworks for clash detection and 4D simulations can be defined as VR uses. However, the use of VR in this research mostly refers to interactive virtual walkthrough since using Navisworks for clash detection and 4D simulation has become a more common practice and their value has been more widely recognized.

THE IMMERSIVE CONSTRUCTION LAB

Located 0.2 miles away from the jobsite, the Immersive Construction (ICon) Lab (Figure 1) is an interactive collaborative workspace featuring a semi-immersive display system consisting of three stereoscopic 3D enabled 8’ x 6’ screens with a total system resolution of 5120 x 1200 pixels. The display system features a tracking system with four tracking cameras, which track user head and hand movement during a virtual walkthrough. In addition to the interactive immersive display system, which serves as VR facility, the ICon Lab is also designed to maximize the interaction between the space’s users. A touchscreen SMART Board® is available for the team to brainstorm and sketch on drawings electronically. The three-screen display system flexibly allows user to push various content sources to any of the screens. A video conferencing system with two high definition video cameras on the ceiling and front of the room enables video streaming of the activities in the lab with remote users.

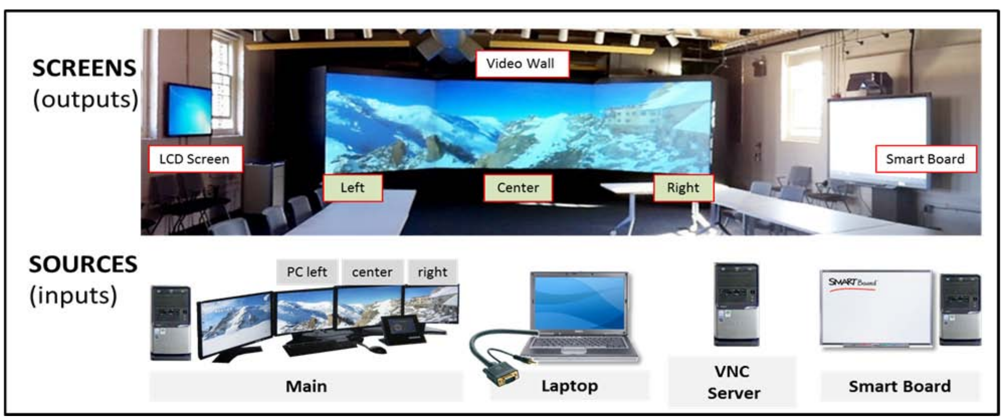

Figure 1: The Immersive Construction Lab(Nikolic n.d.)

USE OF VR IN THE DESIGN PROCESS

Throughout the design process, a set of integrated design models, which included all building systems, was developed and maintained in Autodesk Revit by the design professionals. The Revit models were exported and prepared in a VR software (Unity), which is a real-time rendering game engine. The VR models contain a human avatar and widgets that allow for the filtering of models by discipline, transporting to points of interests, and performing solar shading analysis for any time of the year. The VR models were updated at the end of major design phases when the central design models were updated. These models were then put into the immersive display system to be viewed using stereoscopic vision during meetings for various purposes including integrated design and design review meetings; presenting the design ideas to decision makers; demonstrating the technical and design features to the future user group; and reviewing the design for facility maintenance purposes.

METHODOLOGY

To understand the case study project design process, and especially the process of implementing the VR technology, we examined the BIM execution plan for the project to understand how digital tools and models were used in the design process and identify the relative BIM uses that involved using VR technology and the ICon Lab. An interview plan was then developed with a focus on the VR and ICon Lab uses. Our major data source came from 6 in-depth semi-structured interviews with various project participants involved in the integrated design process, including owners, architects, construction managers, embedded researchers, and end users. We also surveyed the participants during a design review meeting that used the ICon Lab and VR tools.

EVALUATION OF THE USE OF VR AND IMMERSIVE DISPLAY SYSTEM

The interview questions mainly focused on understanding how the VR tools and the immersive display system were used, the advantages and benefits of using those tools, and the challenges in using specific tools and the facility in the actual design process. All interviewees recognized that VR tools combined with the immersive display system brings value to design review, communication of design intent, and helps improve the meeting efficiency. Compared to the traditional drawing and static rendering based design review, the VR model allowed users to walkthrough the virtual building and understand the building aesthetics in a flexible way. Users of VR models in the immersive display were also able to view the building from a spatial perspective and get a more direct feel of the depth and volume of the space by viewing the model in the stereoscopic display and at full scale. This experience was valuable since visualizing space is cognitively demanding for many people(Leicht 2009), and by shifting that cognitive load to the computer, people can perform deeper analysis such as visualizing themselves performing tasks in the space.

Users also reflected that meetings and discussions that took place in the ICon Lab were far more efficient and participants acted more professional in this space, especially with the use of the VR tools. One observed difference is that participants were more engaged in the meetings. There are multiple factors that could contribute to this phenomenon. Viewing the building design in a virtual environment quickly brings external people up to speed to the current design status and features, leveling the expertise and familiarity with design between disciplines, professions, and technical background. Being able to collectively view the model keeps participants with a consistent understanding of the discussion, whereas when discussing based solely upon drawings, people may experience trouble fully understanding drawings that are out of their discipline, and thus not engaged in the issues of other disciplines, discouraging participation. Another engaging factor is the ability to view the virtual building at full scale in using the stereoscopic display with a very large field of view, which creates the feeling of immersion. Design content is viewed from the perspective of an occupant, relating content viewed in VR to the typical real world building-person relationship.

It was also observed multiple times in several design review meetings that viewing the design through the virtual model in the immersive display can spark deep questions and lead to the discovery of unexpected issues in the design that are not usually seen in the review of static renderings, drawings, and traditional BIM models. In a design review meetings with facility managers, a major safety issue was discovered when they saw the model and walked through typical maintenance routines. The roof hatch in relation to the mechanical penthouse passed too close to a sloped roof and had a long span which needed access 4-6 times a year. Four fall hazards were easily identified. The discovery sparked major discussion on location and type of roof hatch, which were previously undiscussed. Typically such issues are not discovered until building turnover leading to client dissatisfaction and potentially a costly change order.

However, the effect of the model review can also yield some challenges. The discovery of too many trivial issues can be counterproductive and derail the original purpose of the design meetings from making key design decisions to the discussion of details such as the material or representation of a component. The lessons learned by the team were that having an appropriate level of detail of the virtual model and focusing on only showing the related information is very important for soliciting quality decisions and keeping the design meeting productive. Depending on the purpose of the design meetings, realism of the virtual environment can be harmful to the efficiency of the design meetings. It is desirable to have a realistic design model when presenting a finished design. However, during the design development, it is often better to reduce the level of realism and level of detail of the virtual environment unless needed by certain discussion, because architects usually leave placeholders or known issues in the intermediate design to be resolved in later design iterations and showing too much information on those elements will create a wrong interpretation of the design, especially for those not familiar with the design process.

Despite the various benefits brought to the design team by the virtual reality models and immersive display systems, the team felt that they still underutilized the VR display considering the lack of variation in the type of usage and the relatively few times that design reviews were conducted with interactive VR tools compared to the usage of more traditional BIM tools like Autodesk Navisworks and Revit. The first challenge that kept the project team from using virtual reality and the immersive display system for walkthroughs and design reviews was a lack of general understanding of the technology, the benefit of the technology and the use case of the technology within the design process. In the case study project, the project team would have not done anything with interactive walkthroughs and the immersive display system if it were not for the access along with suggestion and development support from a research team. Another challenge is a VR model review meeting requires significant coordination effort to get people from different disciplines to join, especially when collocation of the design team is not implemented. VR model preparation and turnaround time is also a factor that limited the more extensive use of the VR model. Unlike a Revit walkthrough which can be prepared in minutes, to prepare an interactive VR model required much more time, usually several days or even longer depending on the functional requirements and available resources. At the time when the virtual model was finished, the design would have changed. In the case study project, the design was still changing 10 minutes before the design review meeting and they did not want to show an outdated model. In addition, using interactive virtual walkthroughs for design meetings require changes in the process from the traditional way of presenting which may not be easily adopted due to a relatively high learning curve.

Model capacity and functionality, specifically during the fast pace of design progression, is another limitation of getting more value out of the interactive model. In the design review meetings, designers wanted to cut sections of components, and check out more information related to components, such as thermal properties and cost of walls and windows. These features were not incorporated due to the limited model development timeframe and availability of the data to embed within the model.

Besides interviews, we conducted a survey with designers and construction managers after the handoff constructability meeting in the ICon Lab. The survey asked about the benefits and challenges of using virtual reality media in the immersive display environment. The survey consisted of qualitative questions, which asked for comments, and quantitative questions, which asked for their level of agreement towards various statements, with 1 being strongly disagree and 5 being strongly agree. The results of the survey shows that users think the virtual reality interactive model helped their understanding of the design and facilitated team collaboration. Several highlights from the survey are:

- All the participants gave a rating of 5, which means they strongly agreed, to the statement that viewing the model helped them understand the design better.
- Participants rated an average of 4.5 to the statement that they felt more confident about the design after viewing the virtual reality model and they think the model is helpful to review specific design criteria
- The feeling of immersion from using the immersive display system is moderate as the participants rated an average of 3 towards the statement that “I felt I was physically in the designed space”, and an average of 2.5

towards the statement "I felt immersed in the virtual model in the ICon Lab."

- The participants recognized the value of the large screen space, high screen resolution and viewing the model at a large scale. The average rating for these statements is 4.25. The participants also emphasized the value of having the entire design review team instead of a single person in the same immersive virtual environment.

CONCLUSION

This case study shows that the use of virtual reality models and a specialty immersive display system in an integrated design process brings value to a design team, such as more productive meetings and the identification of hidden design issues. However, the false impression of realism brought by the virtual environment could cause misinterpretation of the design intent. This requires careful planning when preparing the interactive walkthrough model and conscious management of the discussion during the design meetings to guide the use of the interactive walkthrough model. The adoption of virtual reality tools like interactive walkthroughs for design review meetings still contain challenges, such as a lack of understanding of the value of the tools and the expertise needed to use the tools. Heavy coordination for a review meeting using VR tools and the relatively long model preparation time also impede the more frequent use of the tools. Looking forward, as the development of workflows and features for use cases of VR models become more mature, as industry professionals become more comfortable with operating and developing VR models, and as the process of incorporating VR tools in the industry becomes better defined, VR models in the design process should see increased industry adoption.

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