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IMMERSIVE VISUALIZATION OF BUILDING INFORMATION MODELS

Usage and future possibilities during design and construction

Mattias Roupé, Mikael Johansson, Mikael Viklund Tallgren, Fredrik Jörnebrant, Petru Andrei Tomsa
Chalmers University of Technology, Göteborg, Sweden
{roupe, jomi,mikael.tallgren}@chalmers.se

Abstract. The design process of a building often involves many different actors and people with different experiences, level of knowledge and ability to interpret information. The most common information media in these processes are 2D-drawings, documents and 3D images of design. These media can be difficult to interpret and understand and could cause communication difficulties and design errors. However, in this context, Building Information Modelling (BIM) and Virtual Reality (VR) have been shown to offer an efficient communication platform. In this paper we present and evaluate a portable immersive visualization system that uses the BIMs directly from the design tools. The system is validated in a real construction project, where the different disciplines in the design process used the system. The result was collected through interviews and observation during usage of the system. All the participants expressed that this type of visual interface helped them to get another level of understanding and perception of space, which lead to better decision-making process and resolving of design issues.

Keywords. Building Information Modelling (BIM); Virtual Reality (VR), Head Mounted Display (HMD), Oculus Rift

1. Introduction

During the design process of a building the outcome depends on the involved people's interpretations, perceptions, and prejudices (Colin & Hughes 2007). As each design team member will have individual perceptions of the design problem and ideas of how to solve it, it is important that all the involved actors understand, participate, communicate, and collaborate with each other to obtain a high quality outcome of the design process. Communication difficulties mainly occur as a result of the different cultures, and because there is insufficient collaboration and information sharing during the process. The most common problem is that the information is not presented in such a way that people can understand it. In this context, real-time visualizations and Virtual Reality (VR) have been shown to offer an efficient communication platform (Bouchlaghem, 2005; Roupé, 2013). With the ability to navigate freely through 3D scenes from a first-person perspective, it is possible to present and communicate ideas regarding future buildings in a way that facilitates understanding among all involved parties, despite their background or professional expertise. While the use of this technology has been naturally limited in the past due to lack of available 3D data from the design process, the concept of Building Information Models (BIM) has opened up new possibilities. As the required 3D data can be extracted from the architect's own design-environment, the use of real-time visualizations has become more accessible in practice (Johansson and Roupé, 2012; Johansson et al. (2015)).

To further enhance user experience it is commonly advocated to take advantage of immersive display technologies. Although real-time visualizations have been shown to be useful per se, stereoscopy, large screen and wide field of view all provide additional benefits (Shiratuddin et al., 2004; Castronovo et al., 2013). Nevertheless, when considering the integration and use of immersive VR within the actual design process, the current adaptation still suffers from a number of limitations such as high cost and limited accessibility (e.g. CAVEs or Panoramas are still expensive and are restrict to a specific room or location) as well as limited BIM support (e.g. BIMs are typical too large and complex to be visualized in real-time without further optimization and preparation).

However, in a recent study, Johansson et al. (2014) presented a system that allows immersive VR to become a natural and integrated part of the design process. It was realized through the use of the Oculus Rift Head Mounted Display (HMD) - a comparably low cost device that supports a large field of view, stereoscopic viewing and physically rotation - together with a rendering engine specifically designed to manage large and complex BIMs in real-time. With the system implemented as a plug-in in Autodesk Revit and connected to a high-end laptop, it serves as a portable system for immersive BIM visualization.

In this paper we focus on how this system has been used and integrated into the design process in a real-life project. We will present results from observations during usages of the VR-system together with semi-structured interviews with different clients and design team members that has used the VR-system in the case project. The interviews addressed the current usage and future possible usage of the VR-system in construction project and benefits or challenges connected to this type of tool in the design process.

2. Method

This paper is based on a qualitative study where semi-structured interviews and observation during usages of the VR-system has been done. Participants of the study were people which were involved in the case study project of a new office building. In total 9 interviews has been conducted. The participants had the following work titles in the case project; Property Developer (Construction company), Property Owner, Facility Manager, Architect, VDC-coordinator, Structural Engineer, Site manager, Assembling supervisor, Steel Workers.

2.1 CASE PROJECT – THE OFFICE BUILDING

The new office building will have an office area of 25 000 m^2 and will provide about 1000 workplaces. The office building is mainly constructed from prefabricated concrete with a steel structure. The project delivery method is design-build and the project time plan is scheduled to year 2013-2016. The interviews and usage of the VR-system were conducted during detail design and the construction and assembling of the pre-fabricated concrete and the steel structure. Selling price was 868 million SEK.

2.2 THE VR-SYSTEM

As described in (Johansson et. al., 2014), the VR-system is based on the Oculus Rift HMD DK2 and a real-time viewer application implemented as a plug-in in Autodesk Revit. For all the visualization sessions within the scope of this paper, the VR-system was connected to a laptop equipped with an Intel Core i7-4860HQ CPU and an Nvidia GeForce GTX 980M GPU. To allow for a wide range of users, the system features a very simple navigation interface by means of a so-called PowerPoint remote control. As illustrated in Figure 1, a user can move forward or back by pressing the corresponding buttons on the remote control, with the direction of movement being decided by the user's orientation of the head, see Figure 1.

During the interviews, the BIMs from the real new office building were used. Two different visualization sessions were considered according to the background of the interviewee – one featuring primarily the architectural model (Figure 2, top), and one featuring all the different disciplines (Figure 2, bottom). In the complete model, eleven BIMs from different disciplines were visualized together, and color-coded according to the different construction worker trades. The VR-system supported filtering of these models, e.g. switching on and off the different models for the different disciplines.

Figure 1. The navigation user interface.

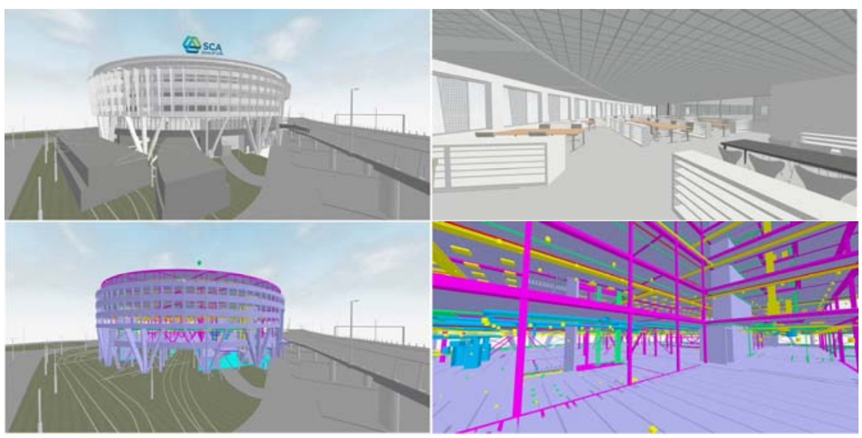

Figure 2. The upper model; the office building from the architectural model. The lower model; the color-coded model with all the disciplines.

Both visualization sessions were extracted directly from Revit using the viewer plug-in. Except for assigning a specific color to each sub-model (i.e. discipline), no other preparation or optimization of the models were done. The architectural model contained 13,377 objects and 3,358,715 triangles. The complete model contained 83,032 objects and 23,470,848 triangles.

The participants used the VR-system to explore the BIM for approximately ten minutes before the questions were asked. This was done to provide the user with the immediate experience, allowing a better insight in answering the interview questions. Often the participants navigated to the place in the model where they currently worked e.g. in design or construction.

3. Results

Both the observations and the interviews showed that the participants could easily navigate in the model using the presented VR-system. Almost directly all participants explored and navigated freely in the model. However, the structural engineer mentioned that shortcuts or jump to specific viewpoints are necessary; otherwise navigation with the VR-system will take too much time. Most of the interviewees shared this opinion and mentioned that it would be good to navigate fast to different parts of the building, instead of walking through the "whole" building to come the specific viewpoint.

Furthermore, all the participants expressed that this type of visual interface helped them to get a better understanding, not only in terms of specific details, but also for the project as a whole. Site-manger, VDC-coordinator, architect, facility manager mentioned that it gave them a better understanding of space and mentioned that this type of visual interface makes you experience the virtual building in 1:1 scale. Furthermore, they mention that this type of visual interface gives them new possibilities to understand, share, experience and provides a better decision-making process.

3.1 SUPPORTING UNDERSTANDING AND PERCEPTION OF SPACE

In this context, the ***architect*** expressed that this type of visualization can be a good way to communicate and share designs ideas to their co-workers and clients. "*It can be a new approach to design a space and communicate with colleagues, to get the feeling of a room, heights and other details that simulate the actual reality. It is a very good tool for us when we work, like just checking out how the rooms will look, and to try different ideas with our co-workers*". Furthermore, the architect mentioned that the visualization could also support the decision-making when considering a certain solution. In the case project there had been major discussions regarding the stairs in the atrium e.g. entrance lobby, an issue that would have been easier to solve if the VR-system had been available. Additionally, the architect expressed that the HMD visualization gives "*another level of perception considering the natural scale 1:1 combined with the level of realism. This can help to understand how big or small a room needs to be, how other objects in that room fits. This level of perception is hard to experience in other type of visualizations."* An annotation from his experience was that the architect bought a HMD-system after his interview, to make it possible to work in the above-described way.

From the perspective of a ***property developer*** and ***property owner***, the communication point is mainly orientated towards the client, which may be a tenant or an investor. Both the property developer and property owner mentioned that many times the client or tenant may have limited understanding of how a future acquisition or rental may look, judging only from 2D drawings and even 3D representations. The property developer argued that the VR-system can be very helpful in this context. Using the tool for client visualizations can be a complement to the pictures and drawings, and perhaps a more powerful experience. According to the property developer; "*I think this tool can help clients get in love with the project, and if they get to that step, it helps a lot*."

The property developer and the property owner further explained that the perception and the capability to understand space is one of the most important capabilities with the VR-system.

The ***facility managers*** work assignment in the project was to communicate both with the contractor, but also internally with own employees. As the facility manager started to navigate only for a short distance in the model, it was explained that the HMD visualization contributes with a better understanding. Furthermore, experiencing the model at a scale 1:1 was explained as beneficial compared to 2D-drawings. More specifically she used the HMD visualization for spatial function analyses of the building design. To be exact she mentions: *"the tool makes it easier to see how many doors are needed to be opened before reaching a specific area. Also, it can be helpful to be aware how to find different locations or objects inside the building. For instance, finding the right suitable elevator, where the HMD visualization may help to simulate the reality to a higher extent"*. Finally, the facility manager considered that the tool can be part of the decision-making process, where different interior setups with equipment, as part of the collaboration between the lab teams and the architects, could be judged. Using it early in this process, the amount of drawings showing many different solutions could be decreased and the BIM together with the VR-system could be the carrier of information.

The ***site manager*** sees the tool useful within the design phase in helping to understand details and to support the decision-making when considering a certain solution. The tool is further explained to give another level of understanding and perception of space and that this is hard to experience in other type of visualizations. According to the site manager, "*this is just the beginning, in a couple of years the HMD visualization will be a useful accessory, where one may have them on site and just put them on to see something which is not clear*."

3.2 SUPPORTING DECISION-MAKING AND RESOLVING OF DESIGN ISSUES

In the case project, the VR-system was introduced during a design review meeting and was immediately used in an actual decision-making process concerning the design of the solar shading system. The first issue was regarding aesthetics, where the architect argued that the solar shading panels were too large and that they would block the view too much and be "perceived as a peaked cap when a personnel sitting inside the office", see figure 3. The second issue concerned whether or not the window cleaner could stand and walk on the solar shading panels while cleaning the windows, and what dimensions and design of the panels that would be required.

Figure 3. By experiencing the solar shading system in VR-system, the design team could come to consensus and resolved the design issue.

By using the VR-system the different participants from the design team explored the BIM and investigated how the solar shading panels would be experienced in its natural 1:1 scale. All in the design team were amazed how the HMD visualization gives another level of understanding and perception of space and that this is hard to experience in other type of visualizations. When the site manager explored and tested the window cleaning possibility, e.g. of standing on the solar shading panels and walking between the vertical panels and the building façade, he actually pulled in his stomach when passing the vertical panel. This type of behaviour shows that he was fully immersed in his experience of the virtual environment.

The end result from the HMD visualization session was that the design issues regarding the solar shading panels were solved e.g. they decided that the solar shading panels did not block the view, as the architect had earlier stressed and argued. Based on the virtual test, the design team also agreed that the window cleaning procedure would be functional in practise.

During the interview later, the site manager explained that the use of the BIM and HMD visualization of the model at a scale 1:1 creates a better understanding regarding design issue, which could shorten time to decision. Decisions that involve large costs and where project participants need to have a wider understanding, was presented as problematic in the design decision-making process by the site manager. The site manager mentioned that *if we would have had the HMD visualisation earlier, we could have saved numerous hours and money*.

3.3 SUPPORTING CONSTRUCTION PLANNING AND ASSEMBLING

The site manager explained the VR-system as providing a more natural way of looking at things compared to on screen visualisations, and that it can complement the working environment; both in design phase as in construction, to easier understand how parts should be designed and then further understand how to actually assemble them. This was also mentioned by the ***structural engineer**, stating that*: "*the site manager can see the structure in scale 1:1 and then notice problems or solutions regarding how to produce or assemble"*. Furthermore, when using the structural model in combination with only the interior ceiling (architect model) turned on, the ***supervisor for assembling*** came with *new insights* during his exploring in the HMD. By viewing these two disciplines in parallel, it was easier to understand where the joints in the concrete floor would end up being visible. He also mentioned that if the workers can see the model early in the project, their knowledge can affect the structural design in a good way, as to fit the assemble work better. Several ***steel workers*** in the case project, who tried and used the VR-system, highlighted this as well. Also, when trying the VR-system it was observed that they directly navigated to the specific places where they were currently doing work (i.e. at the real construction site) and started discussion about the structural model with steel parts. The VR-system was explained to create a deeper understanding on how the assembly work from different disciplines affect each other. In this context, the color coding and the ability to hide/show other disciplines was highlighted as an advantage in that each discipline could focus on their details and responsibilities, but also give them an overview of others responsibilities. Regarding integration, both steel workers and the supervisor for assembling stressed that the VR-system can be something natural to use daily before entering the construction site. The site manager, VDC-coordinator, structural engineer, also mentioned this type of daily use of the VR-system.

3.5 INTEGRATION ASPECTS OF A NEW TOOL IN PRACTICE

The structural engineer, site manager, as well as the VDC-coordinator all mentioned that the most benefit with the VR-system is for people with less knowledge in reading and understanding of construction drawings, and that for people with much experience in using 2D drawings and 3D models, the tool is not really that big of a help. The VDC-coordinator further explained that for clients in the collaboration with architects, or during assembly planning for workers on the construction site, the VR-system could support these processes. For example, before the assembly of some elements e.g. columns, beams, each worker could use the VR-system to enter the BIM and see how it is suppose to be assembled. "*Considering that category of people, the HMD visualizing is a powerful experience that helps to better understand the 3D model. To be in the model at a scale 1:1, it is a real world, a total new way to experience things, you can't misunderstand*."

Another issue that was mentioned by the architect and the facility manager was the willingness to share the design. The architect mentioned that in the discussion with the client it is better to have a higher level of realism, but with in-house design work, high realism is not that important. The architect pointed out that it is important to consider how much you show. It is depending on the design stage, because the end product may look different, leading to different expectations.

According to the facility manager, the employees have not been involved in all details with the reason that the facility steering group wants to be more ready. When reaching that stage, the VR-system was explained as a possibility to use. Considering this tool, "*I think it is good to use the VR-system in communications, but at the same time as you are changing things, people may be upset if it is not the correct version*." Not using the tool too early in the feasibility phase is due to the level of realism. "*The model is so real when using the VR-system. The tool gives you a real impression, e.g. how the desks are positioned. This is why we need to be a bit wise to not use the tool too early*."

4. Conclusions and Discussion

As the result section shows, all the participants expressed that this type of visual interface helped them to get a better understanding of space and mentioned that this type of visual interface makes you experience the virtual building in "1:1 scale". Everyone in the design team was amazed how the HMD visualization gave another level of understanding and perception of space and that this is hard to experience in other type of visualizations. Additionally, they mention that this will give new possibilities to better understanding and perception of the designed space, which will support a better decision-making and resolving of design issues. The result from the case project also showed that the VR-system could support construction and assembly planning and to give construction workers better understanding of how the structure and the elements are assembled together, something that was expressed as much aided by the ability to show/hide different disciplines.

An integration issue surrounding BIM visualization using the presented VR-system was the willingness to share the design. Both the architect and the facility manager mentioned that they had fear and limited willingness to share the design with other actors/receivers in the process. Both were afraid that the end product may not look the same and will lead to miss-expectations by the end-user. The facility manager also mentioned that she was afraid of getting questions, why they will not get a certain type of furniture etc. The property owner and the property developer, on the other hand, pointed out this as one of the benefits with the VR-system, where the possibility to try different designs with furniture, colours etc. together with the end-user. This will support the decision-making when considering a certain solution for the client or tenant.

It could be concluded that the VR-system can facilitate better shared perceptions, interpretation and understanding of the design problem in the design team. Additionally, this will facilitate a better communication, which leads to better decision-making process and resolving of design issues.

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