Conveying Architectural Form and Space with Virtual Reality

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The purpose of this study was to explore the user experience of non-specialists viewing and navigating in an architectural native (Revit) BIM model in Virtual Reality (VR) with a head mounted display (HMD). The perceived sense of presence as well as the quality of vision and total VR experience was examined and also compared with standard computer screen display. The study shows that conveying architectural form and space to non-specialists can be done with reasonable good results with the use of present time real-time rendered BIM models in VR even if the HMD is not calibrated individually. The study also shows that development of VR hardware and real-time render software as well as the practical use must be further developed to fully utilize the VR potential.

Keywords: Virtual Reality, HMD Head Mounted Display, Oculus Rift, Real-time Render, BIM-Viewer

INTRODUCTION

The revitalisation of Virtual Reality caused by development of cheap desktop hardware, portable VR systems and highly optimised real-time renderers, has introduced VR as a spatial evaluation tool in the architectural design process. The accessibility also suggests new possibilities for introducing VR as a means of conveying architectural form and space to a non-expert audience outside the lab.

Presenting spatial representations to non-experts often involves optimising or refining the original 3D design model as well as adding lighting and textures for realism before rendering images or animations ready for post-production, where the final composition is made. VR is not precomputed but renders in real-time.

Driven by the gaming industry, but also used for learning and training among others, the most popular real-time renderers are game-engines like Unity3D [1] and Unreal4 [2] that include specialised features for creating advanced interactive VR output. The game-engines can, with proper programming, display realistic surface properties and direct as well as indirect lighting in the model, at a level similar to visualisation renderings.

Generally geometry must be highly optimized in order to achieve a sufficient visual quality and at the same time facilitate the ongoing real-time calculation of collision detection and rendering. In order to display large architectural models in VR major simplifications of the mesh geometry must usually be performed.

When examining the 3D model during the design process, the model should ideally be displayed directly in VR from within the modelling software and not through the extra step of importing into mid-
Middleware like a game-engine for preparation and programming. Moreover extra finish with simulation of physically correct lighting and textures may not be required in the design process. VR add-ins and plug-ins for a variety of 3D geometry modelling software are already commercially available [3], although some of them are game-engine applications rendering exported models, rather than rendering directly from within the 3D modelling programs [4].

**Real-time rendering of BIM model**
The BIM model differs from other 3D geometric models for visualisation in terms of complexity and would usually not be considered suitable for real-time rendering without major geometric optimisations.

Taking advantage of repetitive geometry and occlusion culling in the BIM model, researchers at Chalmers University of Technology, Sweden have written a real-time renderer; the BIM-Viewer (Johansson et al. 2014) capable of rendering native Autodesk Revit [5] BIM models at a sufficient number of frames per second to achieve a comfortable experience in VR without lacking and visual delay.

Using the BIM-Viewer together with Autodesk Revit, complex architectural designs can be viewed, navigated and examined in VR without further optimisation or preparation. The BIM model can be viewed from within the native BIM software or via a stand-alone player, suitable for distribution.

**BACKGROUND & MOTIVATION**

**VR in the Architectural design process**
At several workshops at The Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation (KADK) Virtual Reality has been introduced to smaller groups of architecture students as a way to investigate their own conceptual designs with the Oculus Rift DK1 [6] head mounted display directly from within the 3D sketching software [7] via the WalkAbout3D plugin [3] (Bohn, Kreutzberg 2014, Kreutzberg 2014). The results were positive, students had a better sense of the three-dimensional space compared to viewing on a computer screen (see figure 1). The drawbacks were the limited capacity of the Oculus Rift DK1 suffering from severe lacking and a low resolution screen resulting in simulator sickness (Kolanski 1995).

Next generation of the Oculus Rift, the DK2 [8] was released in summer 2014 with a HD screen displaying 960 x 1080 pixels per eye and supporting a refresh rate of up to 75 Hz.

The BIM-Viewer was updated to support Oculus DK2 in time to let third year architecture students test the setup at a scheduled BIM course. The students used VR as a checking or rather confirming tool when constructing their BIM models in Revit, and found the same benefits of qualifying their designs as they did when examining their conceptual models in VR from within the sketching software in previous workshops.

**VR for communicating architectural space**
When exploring unknown spatial designs all recognised references are used to help perceive the space and for presentation and communicative purposes architectural representations are often based on "photo real" renderings using highly detailed surface properties in textures reacting close to physically correct on simulated photometric lighting.

When architectural specialists explore own spatial designs in VR, details and photo real surface representation may not be required, but we do not know if this "photo real" appearance is necessary in VR for non-specialists to perceive 3D virtual space correct.

The BIM model often contains many geometric
details, but might lack the detailed surface properties from the visualisation model.

The study described in this paper aimed at investigating if an existing BIM model could be used directly without further processing for conveying architectural form and space with Virtual Reality to a non-specialist audience. It would be very time efficient and save money to use the existing BIM model directly in VR.

The study focused on the potential communicative value for non-specialists experiencing architectural Revit BIM models displayed in VR with the BIM-Viewer and the Oculus DK2 Head Mounted Display (HMD) at a public event with a large number of visitors.

**METHODS**

A study was conducted at KADK at Kulturnatten 2014 (Cultural Night), a yearly cultural event giving access to cultural institutions for the public [9].

At the School of Architecture results from the common semester start of all the bachelor studies were exhibited. The student BIM model used in the case study was representing the results from the 3rd year introductory BIM course.

**Practical set up**

A test area was set up for a 6 hours period during the public cultural event to accommodate the study and to handle an unknown number of participants.

The walls displayed posters with architectural plans, elevations and sections from the student BIM model to be experienced on screen and in VR. Other posters displayed images from workshops with students wearing HMD displays.

Two identical "stations" with guiding instructors were established each with two tables (figure 2):

- One showcasing the student BIM model as a computer game with first person controller (FPC) mouse & keyboard control on screen. At this station the users were seated.
- One with the BIM model displayed in VR with Oculus Rift HMD (and additional support screen) controlled with a Logitech Presenter. At this station the users were standing to support correct height perception in the visual field (Cutting 1995, Leurer et al. 2011).

Rows of chairs for spectators were provided which also were used when answering the survey questions as were two reception tables.

The setup had several obvious constraints that will be described in the Findings section, such as lack of personal calibration of the head mounted displays as well as navigating in the BIM model with a controller out of sight.

**Technical setup**

Four stationary Dell OptiPlex 7010 computers with Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz and NVIDIA Quadro 600 graphics cards were used together with four Dell U2312HM screens.

On two computers the Standalone BIM-Viewer rendered the Revit BIM model in full screen mode (figure 3).

On two computers the BIM-Viewer rendered a split screen image + rendered to the Oculus Rift DK2 directly from within Revit (figure 4).

A Revit student BIM model was used without optimising the geometry. Frame rates were rather stable at 70fps / 13ms when viewing the model in areas without furniture. In the main hall of the model with 256 chairs represented, frame rates dropped to approximately 55fps / 17ms creating noticeable jigger and latency.
Figure 3
BIM-Viewer full screen. Main hall view with many geometric details.

Figure 4
BIM-Viever full screen. Corridor view with few geometric details.
Survey
A cross-sectional anonymous survey (Creswell 2014) was conducted collecting data from participants (N=172) exploring the architectural BIM model in virtual reality. A little more than 81% (n=139) of the participants were categorized as architectural non-specialists.

The questions were focused on spatial perception, vision quality, navigation and the spectator role. All questions were followed by comment boxes for open ended answers to be used as qualitative data.

The participants were informed that the survey results would be used in research concerning the usability of VR for conveying architectural form and space to non-specialists.

The questionnaire was designed [10] to be answered on location on a tablet (2 x iPad2) for immediate access to the collected data and a printed version was provided as backup in case of battery shortage.

Post Mortem
A project post mortem (Conradi et al. 2003) with qualitative data on experiences during the event was made by two of the instructors including user satisfaction, team satisfaction, potential reusability and perceived quality of end-deliverables.

FINDINGS / EXPERIENCES
The general impression with the VR experience (see figure 5) was positive and since almost all participants were first time VR users, they did not know what to expect and were taken by surprise.

Previous use of the VR equipment had shown the importance of avoiding sudden head movement to keep the experience comfortable (Kolanski 1995).

Instructions were specifically given to only use slow and limited head rotations to avoid simulator sickness. Filling out the questionnaire was an opportunity to sit down for a while afterwards and deal with potential uneasiness.

Vision quality
Most users expressed anticipation for higher image quality in further developments of the HMD, but were at the same time quite overwhelmed by the experience with the current development version (refer to figure 6).

One of the expected constraints in the setup was the lack of individual calibration of the VR HMD concerning Inter Pupillary Distance [11].

In spite of this constraint 74 % of survey respondents experienced the quality of colours to be "Very clear or Clear". The quality of Pixels and Flickering was considered "Very clear or Clear" by 47% and 48% of the users respectively.

3 respondents commented on not wearing their own glasses, but they still did respond having a Rather Clear and distinct experience of quality.
Comparing VR with computer screen display
Most users expressed a surprise of actually being in the 3d model. Many stated that perception of space was far better in VR than on the computer screen despite the imperfect image quality. Some users commented that the computer game version was better at giving a spatial overview, whereas the VR version was the best for spatial immersion.

Several users commented during the VR experience that having tried the computer game version first provided a feeling of already knowing the space and where to navigate to.

This suggests the value of preparing users for the VR experience and to provide several tools for exploring architectural space.

Navigation
The comparison between VR and standard computer screen display showed that navigation in the latter with mouse and keyboard was a major issue for people not used to play First Person Controlled computer games - to make a reliable comparison between the two different representations, navigation must be addressed, maybe even eliminated by using a pre-animated walkthrough.

Most users were comfortable using the PowerPoint Presenter as controller in VR. A few commented on difficulties pressing the right buttons blindfolded (figure 7).

Comments were made about too high moving speed inside the VR model and missing collision detection causing uneasiness passing through doors and furniture.

Suggestions for use in city-planning with citizen involvement
In the questionnaire the participants were asked to comment on the potential use for VR in city-planning with citizen involvement.

62 respondents commented on this question and 79% (n=49) of the answers given were very positive with only two users stating that it was not suitable because of difficulties with understanding the space as a whole or that the computer screen was sufficient.

24% (n=12) of the positive responds included comments on the need for further development to heighten vision quality, ease navigation and avoid motion sickness.

Respondents suggested several other architectural scenarios that could possibly benefit from VR:

- Real estate sales
- Interior design
- Landscape design
- Architectural Design competitions
- Kitchen design
- Lighting scenarios
- Wind mill placement
- Testing of fire escape
- Furniture display
- Communicating with developers
- Presenting architecture for all involved parties from citizen to investor.

Guided experience
The extended view on the computer screen worked well as a guiding tool for the instructors and made it possible for other visitors to "follow along" and have discussions with the test person exploring the VR world (figure 8; also refer to the survey results in figure 9 which highlights the benefits of being a spectator).

It was difficult at times to keep the "safe space" around the test persons - being pushed or otherwise touched while wearing the VR headset can be very discomforting as can any uncontrolled movement in VR.

Figure 7
Navigating with the PowerPoint Presenter.
Post mortem

In the post mortem some issues with the practical implementation of the event were discussed. The instructors were not prepared for the large amount of visitors and were forced to speed up instructions and guiding time to prevent too long waiting lines at the stations. 172 visitors answered the questionnaire after the VR sessions giving an average time of 4 min. pro visitor spent with the VR setup during the 6 hours event. Many visitors spent ½ hour waiting for their turn and future similar events may utilize this time by preparing instructional material that can be examined while waiting for the "main attraction".

The lenses in the Oculus HMDs were only cleaned sporadically. Cleaning the lenses in between every use might have improved the vision quality.

Survey

The questionnaire was designed to be answered digitally on one of two provided tablets. A printed version was prepared as backup in case of battery shortage, but the 20 printed copies were used within the first hour of the event! 101 respondents answered digitally and 71 respondents answered the printed questionnaire.

The advantage of digital replies on a tablet (see figure 10) on location was the possibility to force answers to relevant questions with validation. The answers were automatically uploaded for online analysing and data was instantly available. Finally the respondents could fill out the questionnaire sitting with the tablet in their lap - no table was required.

The few disadvantages of using tablets were related to visitors being unfamiliar with touchscreen technology and the fact that only a limited number of respondents could answer the questionnaire at the same time with only 2 iPads available.

The advantage of the printed questionnaire was undoubtedly the extra option when more than two respondents needed to fill out the questionnaire at the same time. Power issues were not encountered, but as a backup printed questionnaires would be necessary. Several children expressed their experience with small drawings which was an extra advantage.

The main disadvantage for the printed questionnaire was that answers had to be digitized manually afterwards. Furthermore the design was not intended for paper with the result that several respondents missed questions on the back side (page 2), this can of course be addressed with one-sided print and special layout for printed versions for future surveys.

CONCLUSIONS AND FUTURE WORK

The study shows that architectural form and space can be conveyed to non-specialists with reasonable good results using BIM models and a present time available real-time renderer and VR headset. Limi-
tations in size and complexity of the BIM model will probably be solved in further developments.

The vision quality was not ideal and is expected to be improved further, but a majority of respondents still concluded there being a great potential for using VR in city-planning involving citizens.

Being prepared for the VR session by first exploring the architectural space on a computer screen, seem to enhance the perceived spatial experience. Several respondents put this to words in the survey, pointing out the qualities of computer screen display for generating an overview of the displayed space, compared to the qualities of VR display for better understanding scale, proportions and dimensions of the displayed space. An animated walk-through can be provided in stead of fpc controlled content to accommodate non-gaming users.

Wearing the VR headset occludes the surrounding physical world completely. It seemed to be comforting for the users to be grounded in physical space by voice communication with other visitors about the experienced VR world, discussing navigation and obstacles in the model.

Simulator sickness is still an issue but will hopefully be solved in the final consumer version Cresent Bay announced to be available in Q1 2016. Until then a stabilized view can be achieved by placing the user in a fixed position and thereby also solving the problem with blindfolded navigation.

Further studies should include practical implementation of VR with HMD in public spaces including experiments with non-guided usage and intuitive navigation and interaction.

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