Virtual Reality in Early Phases of Architectural Studies

Experiments with first year students in immersive rear projection based virtual environments

Joachim Kieferle[1], Uwe Woessner[2]
[1] RheinMain University of Applied Sciences [2] High Performance Computing Center Stuttgart
[1] joachim.kieferle@hs-rm.de [2] woessner@hlrs.de

Virtual Reality is quite commonly used in architectural education, however mostly in higher semesters and within elective courses. This paper reports about various teaching scenarios using Virtual Reality in projection based immersive environments at very early phases of architectural studies, within the first two semesters. Various student questionnaires were carried out and clearly show benefits for students to gain spatial awareness in their design projects, and for discussing their design intentions. Experiences with cyber sickness and issues like accessibility to the immersive environments are discussed as well within the given context.

Keywords: *Virtual Reality, Education, Curriculum*

INTRODUCTION

Virtual Reality (VR) has recently risen again in popularity amongst consumers due to functionality and affordability of good and reasonably priced devices such as HMDs like the Oculus Rift and HTC VIVE as well as advances in projection technology with higher resolutions and contrast. As proven in many projects in practice and research, VR undoubtedly can support the design of architecture and foster communication between all participants involved (Portman, Natapov, Fisher-Gewirtzman, 2015). Based on the authors experience with many VR projects in practice, research and education, this paper addresses the question of how projection based immersive Virtual Reality in Powerwalls and CAVEs can be integrated into the early phases of architectural education. In this paper we present an ongoing study, which discusses the potential and difficulties that we experienced in the integration of VR into early architectural design education.

PHYSICAL SETUP AND INTERACTION CONCEPT

Recently a Powerwall with dimensions 4 x 2,5m (figure 1) was installed at the School of Architecture, RheinMain University of Applied Sciences. The system is equipped with an optical infrared tracking system (ART TRACKPACK/E) [1] with four cameras. A DigitalProjection E-Vision Laser 8500 projector with a resolution of 1920 x 1200 pixels is used for the back projection, which results in a pixel size of about 2mm on the back projection screen. Due to the limited space available, a wide angle lens is used on the projector, and a surface mirror rack to further reduce the needed space for the back projection. Projection distance behind the screen is about 3.20m. Active stereoscopic shutter glasses with RF synchronization are used for separating left and right eye images. A workstation with two NVIDIA GeForce GTX1080 Ti graphics cards is used to render the images for the VR system.

The space in front of the screen for VR users to experience the projection is about 6m wide and 4m deep, providing space for about 12 - absolute max 20 people. The intention is that students on the one hand shall interact with their virtual model and on the other hand with their fellow students and tutors. As Exner mentions: "Perceiving the spatial environment mostly occurs while we are in motion ..." (Exner, 2018) it is important to be able to walk through the models. Head tracking allows users to physically move in front of the Powerwall (e.g. a few steps to the side, squat down, etc.). This enables users to intuitively and actively interact with the model from her/his natural eye height. In order to foster active exploration, no seating is provided on purpose (which some students requested in the questionnaires - for comfort reasons). As the physical space in front of the projection screen is not large enough to explore whole buildings or even cities, virtual navigation is provided through a 3D mouse AKA Powerpoint presenter with a tracking target.

SOFTWARE SETUP AND WORKFLOW

The system is run with the open-source VR software COVISE/OpenCOVER (Rantzau, et. al, 1998) on Windows 10. To link the system with the architectural software packages Revit and 3DS Max, plug-ins on both sides (architecture software and COVISE) were developed to ensure an easy and user friendly flow of data between the systems. Whereas the Revit plug-in (Kieferle, Woessner, 2015) has a bi-directional connection Revit <-> COVISE/OpenCover, the data flow from 3DS Max to the VR software is realized in one direction only with an extended VRML 3DS Max plug-in. Additional functionality that is not provided within the standard VRML exporter such as scripting, animations opening/closing doors, navigation modes (Walk, Fly, etc.) multi texturing, environment mapping and advanced shaders are provided by the customized 3DS Max VRML exporter. The source code to the VRML expoirt plugin is published on GitHub as part of the COVISE Repository. The link with Revit is even closer with a bi-directional live update. Thus any change in Revit is instantly updated in the VR environment, changes in the VR environment like moving windows or walls are immediately transferred to Revit, constraints in Revit are validated and if satisfied, the modifications are applied to the Revit model and can then be saved either directly or as a new "design option". In addition to the basic Revit functionality, doors for example are automatically opening and closing in the VR. This is realized by analyzing the arch opening symbol in the door plan and object sub-categories to differentiate door wings from the door frame. Even though the VR system supports Head Mounted Displays (HMDs), our focus in education is on projection based VR environments like Powerwalls and CAVEs which support a physical presence in the virtual environment as well as a direct communication between all students and teachers. The interaction between students and teachers is crucial for efficient learning.

Software extensions

In order to improve the Revit/VR Workflow, we extended the functionality of the plugins in three areas:

- Doors are automatically animated when approaching them. This works for single and double swing doors as well as sliding doors. For this the door families have to meet a couple of criteria: The door frame has to be correctly attributed as Frame/Mullion category, all other categories are expected to be moving as parts. In double swing doors, subcategories need a suffix "_Left" or "_Right", sliding doors are identified by an additional "isSliding" boolean parameter.
- Revit materials are mapped to OpenGL/GLSL materials. This automatic mapping works for

Figure 1
VR lab Powerwall (left), and rear projection rack with mirror (right)

most standard materials providing a diffuse map and/or a bump map. Other types of materials have to be added on demand. A path to all standard Revit textures can be configured on the VR workstation so that those textures are available while custom user supplied textures are automatically copied to the VR Workstation whenever such a material is used.

- Links to external Revit projects linked in a Revit file are now supported. External links can be nested and each of them can have its own project origin.

RESEARCH SCENARIOS

For this research, three different project setups were chosen, two from the first semester, and one from the second. In the first semester projects, the exercises were embedded into the design studio. In the first scenario, one group of students designed a two person multi level house (semester weeks 5 - 9, project A.2) and in the second scenario another group of students designed a guest house of approximately 500 square meters (semester weeks 10 - 14, project A.3), both worked with the software Revit.

In the second semester project, the exercise was part of the combined “CAAD2” and “Design Basics and Visual Representation” course. The assignment was texturing a small physical sculpture of about 24cm (scale 1:100) and extending it with internal voids and transferring it into a 24m high building sculpture. This work was carried out using 3D Studio MAX.

All three scenarios were accompanied by questionnaires relating to students expectations and experiences. The questionnaires were composed of the same questions for all three scenarios, and some additional project specific questions. Depending on the duration of use of VR within the project, up to four questionnaires were carried out.

First semester studio

The first semester studio consists of three consecutive assignments A.1 to A.3, small architecture projects, each with a duration of about 4 to 5 weeks. The CAAD course with an introduction to Revit for the two different student groups was in sync with the assignments. Starting with semester week 8, students were introduced to the BIM software Revit for a few teaching hours only, and supported in their applied

Figure 2
Arrangement of row houses scale models (left) , and student explaining his house design in front of the Powerwall (right)

work with the software. However it still required lots of additional independent learning by the students.

Due to the successful completion of the previous assignment(s) A.1 or A.1 and A.2, the students had at least a basic understanding of architecture and initial expertise in hand drawing and model crafting.

Scenario 1: Studio project A.2. In this design project a group of 26 students used VR at the final stage of their A.2 project (weeks 8+9), the design of a multi level house for two persons with specific characters. Each student was assigned a plot of 5,5 or 8 x 18 meters for a row house, and all row houses were arranged side by side and back to back to shape an urban housing situation along parallel streets (figure 2).

The students were introduced to Revit only about two weeks before their project submission. The design studio submission A.2 was with hand drawings and physical scale models only. The VR presentation was held the day after the official submission. Due to the introduction to Revit only about 10 days earlier, the students were asked to only submit a coarse Revit 3D model of their design just a few days before the official project submission. This modeling / Revit exercise was added on top of the project work.

Each student "built" her or his design in Revit. Then the arrangement of the row houses shown in the physical scale model was realized by linking the different Revit projects into one presentation master project and moving the individual project origins into place. By doing so, even if the students did last minute changes to their project files, the latest version of their files was always available in the combined project. By extending the revit plugin, we were able to support loading Revit files with references to external projects while still keeping the functionality to modify both the master project and the linked projects in the virtual environment.

The results of the questionnaire in this scenario are quite representative already for the other scenarios. One of the most significant findings was that many students, when designing their projects with hand drawings and cardboard models, were not that aware/trained of what their design would look like in reality, at scale 1:1. Some comments were: "Everything looks ... a bit smaller than I have imagined". Or: "It's an amazing way for students to learn the measurements and how to use the inner spaces of any building. I've always had a problem imagining how measurements look in reality and this helped me to understand it. If I've had this experience a day ago [note: the project submission day] I would have absolutely corrected my projects A's inner design ... ". These two comments are representative for the student's comments regarding the perception of the real size of their design in VR. Some perceive the design smaller than anticipated, some larger. And event though the average perceived size difference is only 0.77% !, the deviation of more than 25% shows that the spatial awareness clearly differs from student to student, in both directions. Which shows a clear deficit of the students to judge sizes (figure 3).

It is also quite clear for the students, that with VR they have a better understanding of the spatial appearance of their design (average 8.5 of 10, deviation 1.3) (figure 4).

Students also state that ”Seeing my design before the submission would have helped me.” or ”VR would have helped to ”identify errors faster.” One ”immediately realizes, what works out in reality and what does not work out.” This mostly correlates to the previous statements (average 8.0 of 10, deviation 1.4) (figure 5).

Due to the direct interaction and discussion with fellow students and teachers in the VR environment students also state, that the advantage of VR for architectural education is that “Designs can be better explained to counterparts.” Statistically it’s rated with 8.3 of 10 and a deviation of 1.6 (figure 6).

Concerning the question, how and when VR should be integrated into the curriculum, if integration should be mandatory or elective, there is a clear support to use VR in early architecture studies with a 75% majority for mandatory rather than elective. Students rate the bottleneck of free accessibility to the VR environment crucial for the future use of it.

However, the majority of students are interested in using VR for future studio projects (8.3 of 10 with deviation 2) (figure 7).

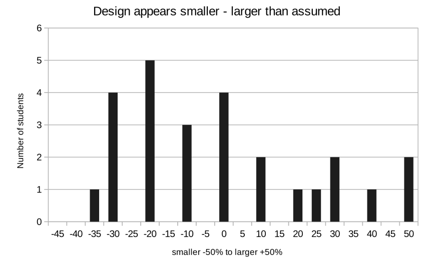

Figure 3
Assumed size comparison VR versus scaled models and drawings.

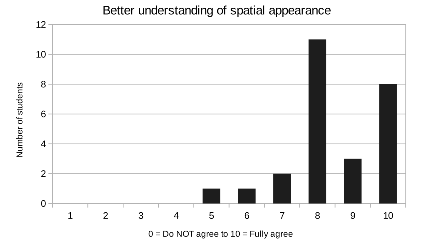

Figure 4
Figure 4: VR as a tool for better understanding of spatial appearance

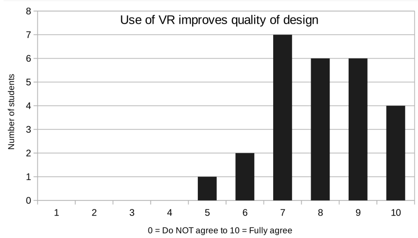

Figure 5
Use of VR improves quality of design.

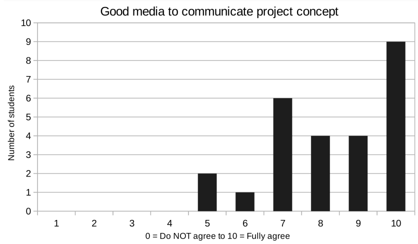

Figure 6
VR is a good media to communicate project concept

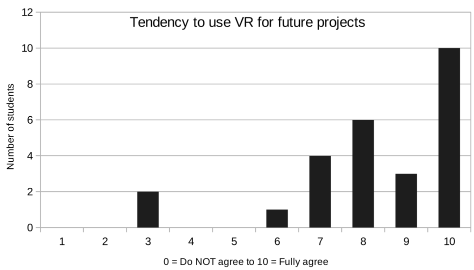

Figure 7
Students tendency to use VR for future projects

Scenario 2: Studio project A.3. In this studio project, weeks 10 - 14, another student group designed a guest house (10 guest rooms, seminar room, public functions etc.) on one of the local hills in Wiesbaden. While in scenario 1, VR was used in addition to hand drawings and the physical model, in this scenario, Revit was used to both create the drawings, and a VR model. The physical model was completely replaced by the VR model, to gain further experience, to which extent the physical models might be replaced.

Four questionnaires were carried out during the 4 weeks duration in the group of 13 participants. There were project discussions both in front of a Powerwall, and in a CAVE (figure 8). In all four questionnaires, the students rated the potential of VR for spatial perception between 7.5-8.9 of 10. This was both on average and quite consistent for both projection environments. Similarly continuous, VR was rated as a good tool for communicating the design. Over all questionnaires, it was rated between 7.6-9.3 of 10. One student commented: "Definitely better understanding and clarification of my design." Compared to that, improving the quality of the design with VR changed from initial expectation of 7.5/10 to 5.7/10 at the end with a significant deviation of 3.5. Nevertheless some students see a value: "... can better explain my design, easier recognition of mistakes." Similarly the expectation to be faster with VR continuously decreased from 7.5/10 to 3.8/10, also with a 3.5 deviation, "... takes too long to learn [necessary software (Revit)] within a short time."

Though these results could be expected to a certain degree, we were quite astonished by the high number of participants experiencing cyber sickness (on average 4.2/10 with deviation of 3.6). These numbers contradict earlier experiences with student groups from older semesters. The questionnaires did not show any relevant correlation between travel sickness indicated by students before the start of the setup, and cyber sickness.

The final question at the end of the course - if students would like to work with VR in the future - was quite polarised compared to scenario 1. Whereas about 50% strongly agreed, about 50% strongly disagreed (5.3/10 with deviation 4.2). Once students have learned digital craftsmanship, they see the benefit for their design: "... once one has learnt the tools, modelling works fast and well". Nevertheless other perceptions were made by the students: "I am unfortunately a bit underwhelmed by the quality in VR, at least at the Powerwall, but exploring the virtual building is interesting."

Scenario 3: Second semester: scaling up a sculpture to building scale

In this short exercise, in a combination of the two courses "CAAD2" and "Design Basics and Visual Representation", the students translated a spatial choreography into a system of inner voids of a small sculpture. They developed the voids in a cardboard model and then built them as a cast gypsum model (figure 9). The sculpture was textured in 3DS Max and scaled up from 1:100 model scale to 1:1 in VR. In this exercise the students were only exposed to VR for a few hours. Similarly to the first scenario, the students' perception concerning spatial perception and communication of the design was highly rated with 8.7 of 10 and 8.5 of 10 with low deviations of 1.9 and 2.5. Various students comments confirm these figures, e.g.: "A great chance to see one's project 'live' is a great opportunity." And similar to the previous setup, cyber sickness is an issue with 4.2 of 10 and a thorough deviation of 3.6.

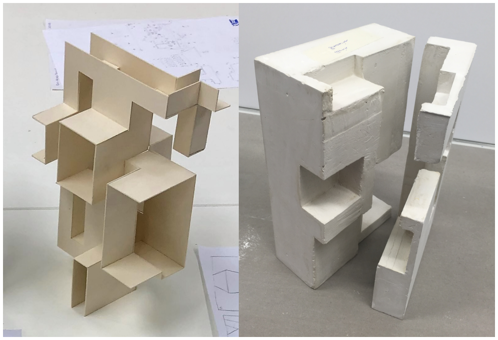

Figure 9
Cardboard model of spatial choreography (left) and cast of spaces into gypsum model (right)

Figure 8
Typical presentation and discussion situation at the Powerwall (left), and in a CAVE (right)

One of the potentials of VR, judging the real size of the space versus the imagination from a model (Kvan, Thilakaratne, 2003) was clearly shown. Similar to the first setup, the participants indicated a difference of the real size VR model to their spatial estimate in the model of up to 30% with an average of about 17% (deviation 9.1%). Spontaneous comments in the presentations like "Oh, I thought, it's much more spacious" confirm these numbers.

OVERALL FINDINGS - LESSONS LEARNED AND PLANNED IMPROVEMENTS

The overall rating from the students in the common questions was quite consistent over all three scenarios - with some exceptions. Especially in scenario 2, where students worked over a longer time on their project, the intention to work with VR in the future significantly dropped down on the day of the presentation. About half of them (13 students) clearly chose "no", whereas the other half chose clearly "yes" (average 5.3 of 10 with deviation 4.2). By contrast e.g. in scenario 1 most of the students intend to use VR in the future (average 8.3 with deviation 2).

In summary, switching from teaching VR in later phases of architecture studies and with only interested student groups to a far more general teaching in early phases of architecture studies requires a quite different approach. Especially within the first two scenarios using Revit, numerous observations for improvements were made:

- Cybersickness - Weech a.o. state that "Increasing factors such as intuitiveness of interaction and control of navigation lead to higher presence and lower CS [Cybersickness]" (Weech, Kenny, Barnett-Cowan, 2019). Due to the limited time we had to guide the students through their models quite quickly. So enough time, self navigation of students in VR, and small groups are intended once free access to the VR lab is organized.
- Difficulties of orientation in 1:1 model - Various scaled view cameras shall be implemented in future version to get a scaled model like overview and then to "dive" into 1:1 model.
- VR acceptance dropped over time - Further minimize effort of data transfer, organize continuous access to VR system, reduce the number of participants at each session

DISCUSSION AND CONCLUSIONS

What are the benefits of integrating immersive VR into the architectural education - beyond the technical expertise? One of the core arguments for implementing VR is the spatial awareness. During their architectural education, and due to the size of real architectural projects, students hardly build any 1:1 implementation of their designs but just scaled models. By integrating VR in very early stages of architectural education, the students learn to correlate space both in scaled architecture models and at scale 1:1. This significantly helps to develop their spatial awareness already throughout the education.

Physical scale models will continue to play an essential role in the architectural education. Moore states about the model that "It is essential that it be of a character and of materials that facilitate - even encourage - design changes." (Moore, 1990). Virtual realities and especially the life link between Revit and VR facilitate and encourage changes much more than physical models, while scaled architectural models allow a much better tangible and abstract exploration. Spatial awareness again is much better in a 1:1 VR model while an overview over projects is probably as good in a scale model as it is in VR at model scale. Therefore students will have to learn to work with both physical and virtual models.

VR as a tool for architecture will increase in importance in daily practice. Therefore the authors advocate a low-threshold access to VR for architecture education within the curriculum and at an early stage. By integrating VR seamlessly into the design workflow and thus only requiring minimal additional efforts will clearly increase students acceptance.

Another essential challenge is the free access to the VR lab, so that students can work together in small interest groups and at their preferred time, much like traditional working groups. Powerwalls or CAVEs have clear advantages for group discussions while VR HMDs can extend the VR usage for single users at home.

From a long experience in using VR, and now the initial tests with students in early architectural education phases, the authors are convinced and are working on fully integrating VR into the curriculum. The VR lab should become as self-evident as the workshop facilities in the faculty.

ACKNOWLEDGMENTS

We would like to thank our first year students for their active contribution to this research.

REFERENCES

Exner, U. 2018, *Spatial design Basics*, Birkhäuser, Basel

Kieferle, J. and Woessner, U. 2015 'BIM Interactive - About combining BIM and Virtual Reality - A Bidirectional Interaction Method for BIM Models in Different Environments', *Martens, B, Wurzer, G, Grasl T, Lorenz, WE and Schaffranek, R (eds.), Real Time - Proceedings of the 33rd eCAADe Conference - Volume 1*, Vienna University of Technology, Vienna, Austria, 16-18 September 2015, pp. 69-75

Kvan, T. and Thilakaratne, R. 2003 'Models in the design conversation: Architectural vs. engineering. Design + Research.', *Proceedings of the 2nd International Conference of the Association of Architecture Schools of Australasia*, Melbourne, Australia

Moore, F. 1990, *Modelbuilder's notebook : a guide for architects, landscape architects, and interior designers*, McGraw-Hill, New York [a.o.]

Portman, M. E, Natapov, A. and Fisher-Gewirtzman, D. 2015, 'To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning', *Computers, Environment and Urban Systems*, 54, pp. 376-384

Rantzau, D., Frank, K., U., Lang, Rainer, D. and Wössner, U. 1998 'COVISE in the CUBE: an environment for analyzing large and complex simulation data', *Proceedings of the 2nd Workshop on Immersive Projection Technology. Proceedings of the 2nd Workshop on Immersive Projection Technology*

Weech, S., Kenny, S. and Barnett-Cowan, M. 2019, 'Presence and Cybersickness in Virtual Reality Are Negatively Related: A Review', *Frontiers in Psychology*, 10, pp. 1-19

[1] https://www.ar-tracking.com/products/tracking-systems/trackpacke/