Immersive Teaching of AEC Construction Details using Virtual Reality

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Abstract: Designing basic construction details of buildings is a fundamental part in the course of educating students of architecture and civil engineering during their first year. To meet current challenges in education, this research is concerned with investigating the benefits of advancing VR technology for knowledge gain and supporting the understanding process for the students for teaching construction details. The objective of this research is twofold: (i) develop a VR-workflow for construction detail analysis, and (ii) conduct a survey amongst lecturers, students and laypersons to measure the acceptance, ergonomics and learning impact of the developed VR application for a prototypical construction detail. This is investigated through a VR-demonstrator, which comprises of an interactive 3D model of a construction detail of a basement wall and two different modes (*inspection* and *quiz* mode). To verify our hypothesis of a significant benefit in students' learning through the interactive and intuitive nature of VR, a pilot study with a panel consisting of 41 participants was conducted. A control group used 2D paper drawings of the basement construction, which was labelled exactly as in the VR model. It was concluded that for participants with a professional background in the AEC industry, there was no significant advantage of using VR over 2D drawings. For students without much prior knowledge VR learning was more effective. The results support the authors' core assumption for the use of VR in teaching: the presentation of contextual 3D models to illustrate content is a promising approach. To that end, VR technology will augment traditional teaching formats in architecture and civil engineering in the near future.

Keywords: Education in Architecture and Engineering, Immersive Teaching, Virtual Reality

1 Introduction

With Extended Reality (XR) and especially Virtual Reality (VR) technologies becoming more affordable, the dissemination of this technology increases steadily and hence promises new opportunities and use cases. The majority of higher education institutions in the architecture, engineering and construction (AEC) sector however have not yet adopted new digital learning technologies and XR in particular, or have done so only to a relatively small extent. Based on our previous work [1], [2] on using Augmented and Mixed Reality applications for developing novel workflows in teaching structural engineering, this paper presents a workflow for teaching construction details with VR. The findings of our past studies are in accordance with the findings in literature [3], which proof, that virtual learning environments enhance, motivate and stimulate students' understanding for the construction and analysis of AEC problems.

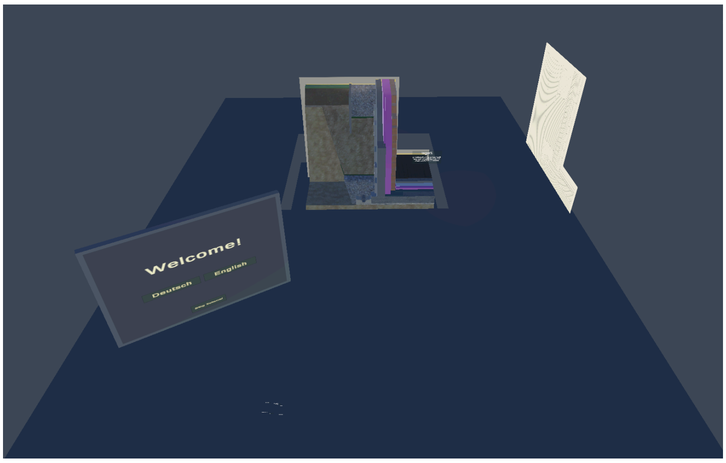

Figure 1: Total view of the VR scene: Tutorial (left), 3D construction detail (centre), and 2D detail (right)

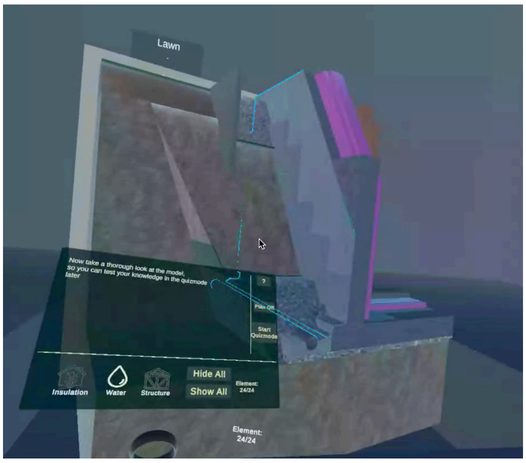
Now take a thorough look at the model, so you can test your knowledge in the quizmode later

Figure 2: Tablet that enables to highlight the water-dissipating layers

The content of introductory and fundamental lectures on design and analysis of structures and the built environment demands advanced analytical thinking and abstraction abilities for students in order to understand the content of lectures and the principles of the profession. Especially for students in architecture and civil engineering with little professional experience, this abstraction in lectures is a hurdle. A prototypical example problem category is construction detailing, where students are taught principles of functional, reliable and efficient construction details. Today, the method of conveying the content uses instructor-centred lectures together with exercises and textbooks upon two-dimensional drawings of the 3D construction elements. The content to be learned consists of considerations towards geometry, adjacency, functionality and construction sequences as construction details are usually fabricated in a complex joined fashion. Due to time, cost and availability constraints, construction site visits are hardly part of today's teaching in order to supplement the lecture material and to provide students with the real 3D content of construction details. Elgewely, Nadim, ElKassed, *et al.* [4] even state, that occasional site visits are not sufficient to establish students' understanding about construction details or their 3D configuration. In summary, the status-quo of teaching construction details in AEC actually triggers students to rather memorise the 2D representation than really gaining insight and understanding of the construction detail, its functionality and composition sequence.

To that end, the objective of this research is twofold: (i) develop a workflow for embedding construction detail analysis content into a VR application, and (ii) conduct a survey amongst lecturers, students and laypersons to measure the acceptance, ergonomics and learning impact of the developed VR application for a prototypical construction detail. All code produced within this publication is freely available and open access, see [5].

2 Related Work and Literature Review

Over the past years, some research was dedicated to assess effectiveness of XR methods in the AEC domain and relevant teaching. However, given the brevity and scope of this paper, only VR-related literature in AEC and teaching is considered.

A VR interface for developing construction plans of a nuclear power plant within an hour was implemented by Messner, Yerrapathruni, Baratta, *et al.* [6] and assessed in undergraduate AEC programs. The study showed, that immersive VR displays are beneficial for this type of lecture and the technology allowed an understanding for planning issues beyond their prior knowledge and visualisation capacities concerning buildings and infrastructures. Liarokapis [7] provides an educational XR application to enable user interaction with 3D content via web technology and AR/VR techniques. Häfner, Häfner, and Ovtcharova [8] curated a university-level course for teaching students the use of VR hardware, software and applications in engineering, where the study found a higher motivation with the students at given tasks when VR was used. Dinis, Guimaraes, Carvalho, *et al.* [9] developed VR and AR applications for students of an introductory class of the Integrated Masters in Civil Engineering and tested those in two trials. Further successful development of VR applications in design and education tasks are reported by Sampaio and Martins [10] and Wolfartsberger [11].

A VR application created by Maghool, Amir, Moeini, *et al.* [12] enables architecture students to experience a construction site, closely investigating details, and testing their knowledge. The study revealed, that a significant proportion of learners have been left out in the current teaching system. They showed, that a VR teaching method is superior compared to traditional means since it allows for problem-based and experiential learning. The paper concludes learning construction details in VR to carry notable benefits for the students and in addition will be part of future education. Elgewely, Nadim, ElKassed, *et al.* [4] also observe a lack of experiential learning in current architectural education. The study relates this mainly to the low number of site visits as an important extension of classroom activity. An educational VR experience with BIM integration hence was developed. Further potentials beyond regular site visits were seen in the more engaging teaching styles enabled by VR. While Maghool, Amir, Moeini, *et al.* [12] concluded that integrating models into the VRE is time consuming and tedious, Elgewely, Nadim, ElKassed, *et al.* [4] take BIM models and databases as a source of technical information. Finally, Kraus, Custovic, and Kaufmann [1] take a different approach, where instead of simulating construction sites, the lecture is complemented by Augmented Reality (AR) applications. AR apps allow students to conduct in-depth and true-scale assessments of 3D structural engineering details with interactive supplemental information. With this approach, the advantages of both teaching modes are harnessed. Statistical evaluation of the conducted surveys amongst students and lecturers revealed, that XR technologies possess great potential for improving effectiveness of teaching by displaying environments and associated information in an intuitive way similar to real objects. In addition, they observed that users reported higher enjoyment of the learning process when using XR technology.

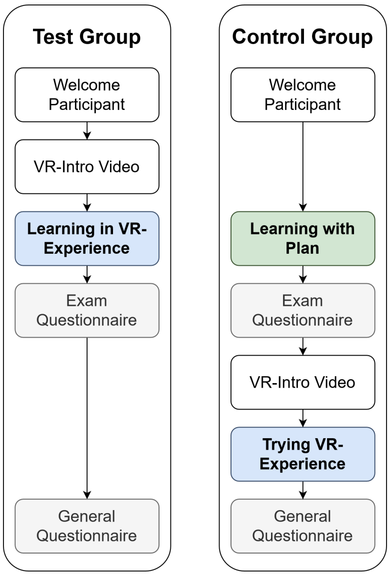

Figure 3: Different study journeys of the participants.

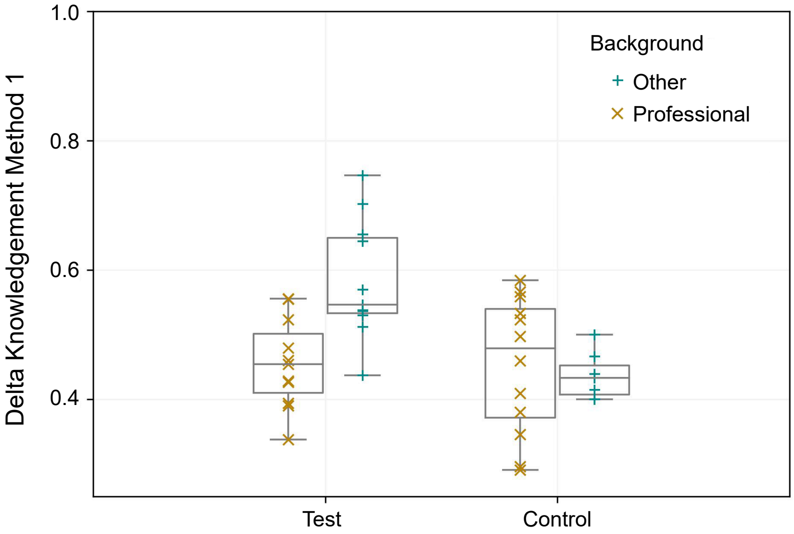

Figure 4: Measured knowledge gain conditioned on professional background and group

3 Methods

This research developed a Virtual Reality Environment (VRE) experience and subsequently assessed the novel method with a pilot study. We used a basement wall construction detail as prototypical content of a construction detail and deploy it as a learning task to a panel, which is split into a test group (using the VRE) and a control group (employing 2D drawings).

3.1 Virtual Reality Environment (VRE) and its components

The VRE is conceived as a medium sized room, where users can freely navigate using the controller buttons or a teleportation ray (cf. Fig. 1). This study employed the Oculus Quest 2. The means of displaying the construction detail are (i) traditional construction detail displayed as a 2D section, and (ii) as an interactive 3D model with augmented information. Within the VRE, the user can inspect the model from different angles, and the controllers allow the user to rotate and lift the model. In addition, the construction sequences together with explanations on functionalities and properties of the respective building component are available, where the 3D model can be assembled or disassembled element by element. A functionality to highlight certain groups of construction elements further improves the understanding of the construction and their relation. Most functionalities described so far are accessible from the controllers as these are required a great number of times. Other less often consulted functions are sourced to a screen (called the 'Tablet', see Fig. 2), which hosts a number of buttons as well as a text field. The buttons enable interaction for the user with higherlevel functionalities, e.g. highlighting certain element groups. A text field on the tablet enables communication between app and user.

The user experience within the VR follows the steps of (i) tutorial, (ii) learning phase, and (iii) examination through a *quiz* mode. As we expect many panellists to be unfamiliar with VR, an introductory tutorial for explaining the most important functionalities to use the VRE is provided. The learning phase is student-centred, where the described functionalities can be used to learn about the construction detail and explore it. To make the learning experience interactive, we introduce the *quiz* mode, where users are provided multiple choice or written-answer questions about the construction. The knowledge of the users is hence tested while at the same time we receive feedback on what has been learned so far.

3.2 Examining Effectivity of the VRE

This study was conducted with 41 participants, who were randomly divided into the test and control group. During a predefined time frame of at least 3 minutes, the participants were asked to learn about the construction detail employing either the VRE (test group) or a 2D drawing (control group). After the learning phase, both groups were examined. After the exam, participants in the control group had the opportunity to test the VRE as well. The study finally provided a survey to the panellists to gather information about their background and opinions towards learning with VR. The whole process is illustrated in Fig. 3.

The aim of this study is to assess whether the VRE provides a better learning experience and outcome than the traditional way of learning about construction details. To assess this, we compare the exam-score with the score for pre-existing knowledge (PEK) s_{PEK}. The exam-score measures the participant's exam performance, where s_{exam} is calculated by:

$$s_{\mathrm{exam}} = \frac{n_{\mathrm{ex,correct}} - 0.5 \cdot n_{\mathrm{ex,total}}}{0.5 \cdot n_{\mathrm{ex,total}}} \tag{1}$$

with $n_{\mathrm{ex,correct}}$ is the number of correctly answered exam questions and $n_{\mathrm{ex,total}}$ is the total number of question in the exam. Half of the maximum score is deducted from the actual score to account for the bias mentioned above. Since the exam questions possess a binary answer space (true/false), filling it at random would on average lead to 50% of the possible points. Therefore, the exam score is mapped accordingly by half of the maximum score. The pre-existing knowledge is assessed by eighth questions with a score between 0 (no preexisting knowledge) to 1 (good knowledge). The pre-existing knowledge score s_{PEK} is computed as the mean of the obtained answers. Measuring the pre-existing knowledge enables then to account for the prior knowledge bias for the learning increment.

To define a measure for the learning increment $\partial_{\mathrm{knowledge}}$, the pre-existing knowledge score s_{PEK} is compared to the achieved exam score s_{exam} by:

$$\partial_{\mathrm{knowledge}} = 0.5 \cdot \frac{1 + s_{\mathrm{exam}}}{1 + s_{\mathrm{PEK}}} \tag{2}$$

This measure, equal s_{PEK} and s_{exam} yield a $\partial_{knowledge}$ of 0.5 (i.e. the person did not learn anything). For $s_{exam} > s_{PEK}$, the result are in the interval from 0.5 to 1, indicating the person to have learned something. Otherwise, $\partial_{knowledge}$ lies in the interval between 0.25 and 0.5, indicating that the person's pre-existing knowledge was higher than they performed in the exam.

Table 1: Mean values for the most relevant variables

	All	**Test**	**Control**	**Test Professional**	**Control Professional**	**Test Other**	**Control Other**
$N_{participants}$	41	22	19	11	12	11	7
s_{exam} [-]	0.726	0.734	0.715	0.769	0.820	0.699	0.551
s_{PEK} [-]	0.471	0.384	0.572	0.622	0.727	0.145	0.308
$\partial_{Knowledge}$	0.485	0.519	0.445	0.454	0.450	0.584	0.436
VR Quiz Score [-]	0.666	0.619	0.740	0.659	0.750	0.591	0.722
VR PEK [-]	0.372	0.466	0.263	0.420	0.271	0.511	0.250

4 Results

The panel consisted of mostly students or recently graduated professionals. 23 persons had a AEC background ("professionals"), while the remaining 18 persons came from various fields ("Other"). Division into test and control group happened at random. The results for the most important variables are shown in Tab. 1, where a conditioning w.r.t. the background as well as being in test and control group is made.

Tab. 1 reveals, that test and control group performed very similarly on the exam, however when conditioning w.r.t. to professional background performed better on the exam. The exam score amongst professionals is surprisingly higher in the control group than in the test group, but the prior knowledge score is also higher in the control group amongst professionals. While $\partial_{Knowledge}$ is similar for the groups amongst professionals, for participants from other backgrounds the values differ significantly. The control group scored higher on the VR quiz, which is not surprising as they learned the detail on paper and filled out an exam before taking the VR quiz. The VRE user experience and the liking of the VRE and whether VR was deemed useful for education were all rated similarly amongst the different groups. The time spent in the VRE was slightly higher for the test group.

Considering the average score achieved by each participant during the exam, it can be observed, that these values lie above 0.5 for all participants. As pointed out earlier, this can be expected as filling out the exam at random would still achieve 0.5 points on average. Therefore s_{exam} is calculated acc. to Eq. 2. Further investigation of $\partial_{Knowledge}$, as provided graphically in Fig. 4, delivers a mean amongst the test group at 0.52 and 0.44 for the control group. Non-professional participants of this study achieve a clearly higher mean of $\partial_{Knowledge}$ in the test group.

In addition to the quantitative evaluation of the knowledge increase, participants were surveyed towards the usefulness of functionalities of the app and enjoyment of the VRE. The highest rated features are those related to the model and corresponding labels. Both professionals and others rated features similarly in most cases. Most users gave a high overall rating towards their enjoyment of the VRE.

5 Discussion and Conclusions

This study elaborated a workflow for augmenting existing construction lectures with VR content to deepen students' learning. The effect of the VR in gained knowledge $\partial_{\text{Knowledge}}$ about the construction detail was statistically investigated. From the results of the tests we can conclude, that the learning effect is pronounced for non-professionals but not significant for the professional group. However, the scores for professionals are more widely distributed (cf. Fig. 4) in the control group. The data furthermore indicate that although on average they did not learn more with VR, their performance became more streamlined. From this it can be deduced, that prior knowledge did not play much of a role in the test group than in the control group. Furthermore a larger learning effect occurred for professionals in the test group compared to the control group.

In total, the study proved VRE to support learning more significantly for participants with limited to no prior knowledge, which is especially the case for students and laypersons. Therefore the VRE is a suitable medium for augmenting teaching of AEC students about construction details in their early studies. Through conversations after the VR experience, we observed, that most participants see clear advantages in learning with VR. However, when asked whether the VRE would be useful as the main means of teaching without an accompanying lecture series, some strongly disagreed and on average the answer was somewhere between neutral and agreement. Furthermore, the participants on average agreed that VR is a better means than 2D drawings for displaying construction details. Surprisingly the participants had a different view when asked whether VR was better for learning than 2D drawings as the average response was between neutral and agreement. Interestingly, professionals did not learn better in the VRE than on paper, which we mainly reason given their significant prior knowledge about construction details and reading 2D drawings. Regardless of the learning outcome, the users might prefer VR technology for learning as it is more entertaining and engaging. Combined with technological advancement in XR and sinking costs for implementing VR technology, this will lead to the introduction and application of VR into more areas within education in general and AEC education in particular. However in our perspective, any XR method will rather augment the teaching than completely replace it.

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