An Augmented Reality Application and User Study for Understanding and Learning Architectural Representations

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Abstract

Advances in computational technology provide opportunities to explore new methods to improve spatial abilities and the understanding of buildings in architecture education. The research employed BIMxAR, a Building Information Modeling-enabled AR educational tool with novel visualization features to support learning and understanding construction systems, materials configuration, and 3D section views of complex building structures. We validated the research through a test case based on a quasi-experimental research design, in which BIMxAR was used as an intervention. Two study groups were employed – non-AR and AR. The learning gain differences within and between the groups were not statistically significant, however, the AR group perceived significantly less workload and higher performance compared to the non-AR group. These findings suggest that the AR version is an easy, useful, and convenient learning tool.

Keywords: Augmented Reality, BIM, Cross-Section.

Index Terms: Computer Uses in Education; User Interfaces

1 Introduction

The ability to translate virtual information and relate it to the physical world is a crucial skill in the domain of architecture as well as Science, Technology, Engineering, and Math (STEM). Researchers anticipate that students experience cognitive mental loads during the process of translating and relating components of a 2D or 3D drawing to their locations in the physical world due to the differences in views, perspective angles, and scales [1]. The mental effort required to process multiple sources of information that are distant from each other may increase the extraneous cognitive load [2]. Augmented Reality (AR) has been used in architecture education to train students to produce orthographic projections and understand building components [3]. However, there is scant research investigating the utilization of AR in facilitating learning and the creation of building cross-sections, which are important in building design, construction, and modeling. Additionally, the limited examples of BIM-enabled AR in the literature lack the level of interaction needed for building components inspection. Thus, further investigation in these particular areas is required. This research seeks to explore the AR effects on assisting students to comprehend and reproduce architectural section views by utilizing AR – augmenting physical buildings by virtual building models. The research approach was validated through a test case based on a quasi-experimental research design, in which a BIM-enabled AR tool (BIMxAR) was used as an intervention.

2 Prototype

The current research utilized our BIM-enabled AR tool, BIMxAR, which was developed to support architectural students' comprehension of building construction systems, material assemblies and configurations, and architectural representations. BIMxAR enables highly accurate physical-virtual overlay to facilitate spatial learning using existing physical buildings and their BIM project files [4]. BIMxAR supports the visualization of hidden information in buildings and allows users to retrieve BIM metadata of building objects. Moreover, BIMxAR enables users to spatially slice the building to create architectural section views. It allows users to freely control the sectional plane location and orientation, allowing them to inspect the building from different views, supported by other advanced visualization features (e.g., mixed mode). The mixed mode is a novel visualization method that integrates real and virtual worlds (mixed reality) by revealing the spaces behind the physical objects being sliced in a section view for a better understanding of the spatial relationships in a building, as shown in Figure 1.

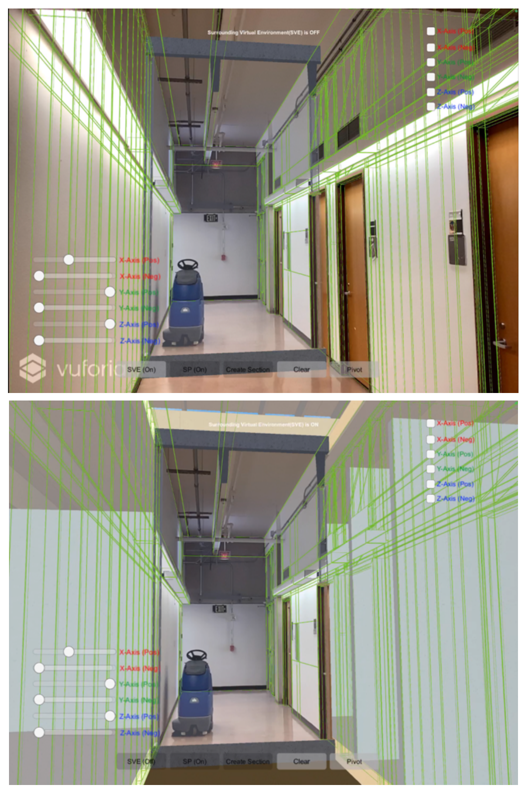

Figure 1: Section views spatially mapped on the physical building. Top: A section view (mixed mode disabled). Bottom: A section view (mixed mode enabled) rendering/revealing the spaces and objects behind the physical walls that are virtually sliced.

Additionally, inside the section mode, BIMxAR enables BIM metadata retrieval of hidden elements behind wall finish through section poches. This feature is beneficial, especially, when the sliced objects consist of multiple layers, as shown in Figure 2.

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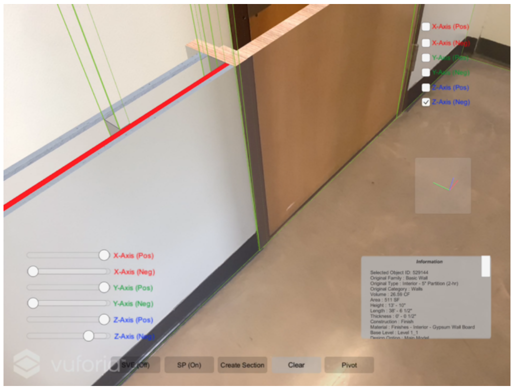

Figure 2: Drywall and door section views and BIM metadata retrieval of internal layers in BIMxAR.

3 Test Case

The recruited participants were 16 students from the Department of Architecture and the Department of Construction Science in the College of Architecture at Texas A&M University. Two study groups were employed – experimental (n = 8) and control (n = 8) groups. For the purpose of a comparative study, the research developed a non-AR version of BIMxAR, identical to the AR version in terms of the BIM example project and capabilities, except for missing the AR registration function. The control group used the non-AR version of BIMxAR, and the experimental group used the AR-version of BIMxAR, both running on iPads. The test case utilizes a longitudinal study approach as a data collection strategy, i.e., pretest phase–learning phase–posttest phase. In the pretest and posttest phases, we utilized Santa Barbara Solids Test (SBST), and our developed Architectural Representations Test (ART) (Figure 3). The learning gain is defined as the difference between the participant scores in the pretest and posttest. During the learning phase, which lasted less than or equal to 25 minutes, the participants were closely observed and their devices' screens were video recorded. Participants were asked to use BIMxAR to learn how to create and observe section views using the physical building. At the end of the study, the participants were asked to respond to the NASA Task Load Index (TLX) questionnaire.

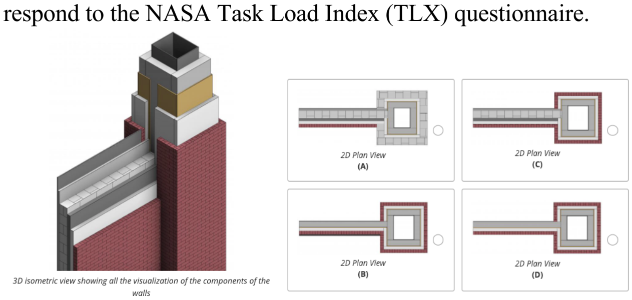

Figure 3: Sample question of ART – based on 3D view of a building component (left) choosing the correct 2D section view (right).

4 Analysis and Results

Due to the small sample sizes, non-parametrical statistical analyses and descriptive statistics were the primary means for our assessment. Most participants in both groups have improved for the SBST and ART. In the non-AR group, the mean scores for the SBST ($mean_{pretest}$ = 74.58, $mean_{posttest}$ = 80.83) have an 8.38% improvement. In the AR group, the mean scores for the SBST ($mean_{pretest}$ = 80.83, $mean_{posttest}$ = 85.42) have a 5.67% improvement. In the non-AR group, the mean scores for the ART ($mean_{pretest}$ = 67.86, $mean_{posttest}$ = 76.79) have a 13.16% improvement. In the AR group, the mean scores for the ART ($mean_{pretest}$ = 72.32, $mean_{posttest}$ = 82.14) have a 13.58% improvement. Wilcoxon matched-pairs signed-rank tests show no significant difference in the SBST and ART scores between posttest and pretest sessions in both groups.

As for the NASA TLX, the mental demand adjusted rating mean in the non-AR group (mean = 19.83 out of 33.3) was higher than the AR group (mean = 13.92). The physical demand adjusted rating mean in the non-AR group (mean = 1.33) was lower than the AR group (mean = 2.25). The temporal demand adjusted rating mean in the non-AR group (mean = 3.33) was lower than the AR group (mean = 6.50). The effort adjusted rating mean in the non-AR group (mean = 11.42) was higher than the AR group (mean = 7.67). The frustration adjusted rating mean in the non-AR group (mean = 3.08) was higher than the AR group (mean = 2.08). The negated performance adjusted rating mean in the non-AR group (mean = 10.92) was higher than the AR group (mean = 3.17). The overall workload in the non-AR group (mean = 49.92 out of 100) was higher than the AR group (mean = 35.58). While statistical tests show no significant difference between the groups for the mental demand, physical demand, temporal demand, effort, and frustration, Wilcoxon rank-sums tests show a significant difference between the groups for the performance (higher performance perceived by AR participants) and the overall workload (lower workload with AR).

5 Observations and Conclusion

Observations and screen recordings show that BIMxAR (AR version) was easier to use since participants did not spend any effort in matching the orientation of the BIM virtual model with the physical building. Moreover, while inspecting the section views, participants favoured the novel visualization mode in AR – the rendering of the surrounding environment in front of and around the section cutting plane, otherwise the environment is hidden by physical surfaces. The test case results and observations were promising, considering the small number of samples and the short learning period. The results reveal that the AR group in the ART performed better than the non-AR group, but this difference was not statistically significant. However, based on the observations and the significant difference in favour of the AR group in the performance and the overall workload, we may consider BIMxAR (AR version) as an easy and convenient learning tool. For future work, the user study will be improved by increased samples with extended training sessions that span throughout a semester.

Acknowledgments

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