IMPACT OF MIXED REALITY TECHNOLOGY ON TEACHING AND LEARNING IN STRUCTURAL ENGINEERING

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Abstract- This study investigates the impact of Mixed Reality (MR) technology on teaching and learning outcomes in structural engineering education. Specifically, it examines how MR enhances students' comprehension, engagement, and efficiency when learning about complex structural assemblies compared to traditional pedagogies based on 2D drawings. Participants were divided into two groups: one used conventional 2D drawings, while the other interacted with MR models via Microsoft® HoloLens 1.0. Both groups completed identical assessments measuring understanding and task completion time. Although the average quiz scores were similar (61%), the MR group completed tasks 17% faster and demonstrated more consistent performance. Qualitative feedback revealed that students valued MR's immersive and interactive experience, which helped them visualize and understand structural relationships more effectively. However, concerns were noted regarding device cost and physical discomfort. Overall, the findings highlight MR's potential to improve structural engineering instruction by enhancing spatial comprehension and learner engagement, suggesting promising directions for future integration into engineering curricula.

Keywords- Building Structures, Structural Engineering Education, Learning Efficiency, Mixed Reality

1 Introduction

Mixed Reality (MR) is a technology that merges computer-generated objects with the existing real-world environment to create an ideal platform for 3D visualization. Unlike virtual reality (VR), which transports users into a fully digital environment, or augmented reality (AR) which simply overlays digital information onto the real world, MR blends the digital and physical worlds as shown in Figure 1. One of the key advantages of MR is occlusion, which is a special ability that AR cannot achieve [1]. This feature allows MR to line up virtual objects correctly in a 3D landscape, enabling objects to appear more realistic in the interaction between real-time environments and virtual images. MR belongs to the broader category of Extended Reality (XR), which encompasses all immersive technologies including VR, AR, and MR. In this framework, the 'X' represents a variable that can accommodate any current or future spatial computing technologies.

Traditional teaching methods in structural engineering, particularly the use of 2D drawings, present several pedagogical limitations when it comes to conveying spatially complex systems. Structural assemblies often involve multiple components intersecting in three-dimensional space, including beams, columns, connections, reinforcements, and material transitions. Understanding how these components relate spatially to one another is critical for students, yet flat 2D drawings reduce three-dimensional complexity into abstract representations that demand high levels of spatial cognition [2]. Mixed Reality directly mitigates the above challenges by merging real and digital environments, offering an interactive 3D visualization experience that enhances spatial understanding. Students using Mixed Reality (MR) devices such as the Microsoft HoloLens can observe, manipulate, and walk around full-scale 3D models of structural assemblies as if they are physically present, allowing for intuitive exploration of spatial relationships that traditional 2D methods cannot provide. This immersion enables the viewer to naturally perceive depth, orientation, and component relationships without relying on mental reconstruction from abstract 2D information [2,3].

With the advancement of technology and release of Microsoft HoloLens second edition, MR has become more accessible to professionals across various fields. In the design and construction context, MR enables the placement of construction assembly models directly in front of students, seemingly "inside" the classroom or at non-operational jobsites. This makes mixed reality especially useful for sharing 3D content, like BIM models, in ways that could help students better grasp design and construction concepts [3].

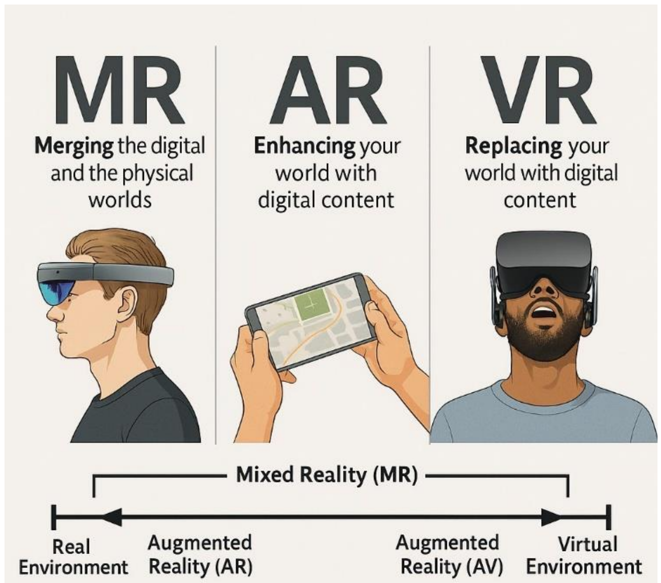


Figure 1. Key differences between MR, AR, and VR environments (Image created in Sora-OpenAI™)

This study explores how well students understand building structures when mixed reality tools are used in their learning. The objectives of this research are: (i) to identify the difference in students' performance scores and time for reading structural drawings using 3D MR view as compared to traditional 2D drawings, and (ii) to assess factors influencing students' comprehension performance using MR applications.

2 Literature Review

Previous research has demonstrated the significant utility of Mixed Reality (MR) technology in construction education [4, 5]. MR effectively creates realistic design and construction jobsite scenarios, giving students the chance to explore jobsite planning, organization, safety, and risk management without having to visit a real construction site [3, 4].

A notable study examined a first-year architectural design classroom, investigating the impact of various visualization technologies including traditional methods and both non-mobile and mobile MR approaches [6]. In this study, researchers implemented two distinct cases: familiar and unfamiliar design cases. For the "familiar design" case, students were provided with five different visualization methods of a campus building: (i) 2D orthographic and photographic renders, (ii) VR using HTC VIVE with a PC, (iii) Mobile VR using Samsung S8 smartphone with Google Cardboard, (iv) AR using Microsoft HoloLens, and (v) The actual physical built environment on campus. For the "unfamiliar design" case, students worked with only four visualization methods, as the physical building had not yet been constructed. Post-test questionnaire results revealed that students strongly valued MR visualizations' ability to strip away layers and visualize complex components. They also acknowledged the continued importance of physical models in the learning process.

Moreover, many construction management curricula typically incorporate field trips or internships to overcome limitations in teaching spatial-temporal concepts and contextual conditions. However, research indicates that AR technology, particularly in the form of head-mounted displays, offers significant benefits in situations involving safety risks, such as when workers' hands are occupied during assembly tasks [7]. Student safety during jobsite visits and practical curriculum activities remains paramount. AR/MR systems can create safe, clean, and accessible jobsite environments for construction students. One experimental research developed a 6-degree-of-freedom head pose tracking system that enabled trainees to safely experience different working conditions at height, thereby helping them develop readiness for situations they might encounter in actual construction project environments [8].

Another study by Ogunseiju et al. [8] looked at how MR can make construction education more engaging by giving students hands-on experiences without needing to step onto a real job site. Using tools like eye-tracking and student feedback, the research evaluated how well an MR setup helped students learn about sensing technologies used in the field. Students found the experience more effective when the virtual environment included realistic animations, easy-to-use features, and clear access to information. Overall, the study shows that thoughtfully designed MR tools can help close the gap between classroom learning and what's needed on actual construction projects [9].

Finaly, a study by Tan et al. [10] introduced a new way to teach civil engineering students about steel reinforcement bars using AR/MR environments. Instead of relying on traditional 2D drawings, students used AR/MR headsets to explore and interact with 3D models. The results showed that this hands-on, immersive approach helped students understand the material better, remember it longer, and feel more engaged in the learning process.

Most previous research on mixed reality (MR) in structural engineering and construction education has focused on straightforward, low-complexity examples such as illustrating steel reinforcement techniques or demonstrating basic sensing technologies. While these efforts have provided helpful insights, they often fall short of reflecting the complexity found in real-world construction. In this research, we applied MR technology to more advanced and integrated scenarios, like visualizing how complex structural joint assemblies function within framed buildings. This shift offers students a more immersive, realistic, and engaging learning experience that better mirrors the challenges they'll face in professional practice. This paper highlights one part of a larger research project, while the rest of the findings have been shared in another published paper [11].

3 Research Methodology

The methodology of this research was designed to evaluate the effectiveness of MR technologies compared to traditional 2D drawings in construction education. Figure 2 shows the overall methodology used in this study.

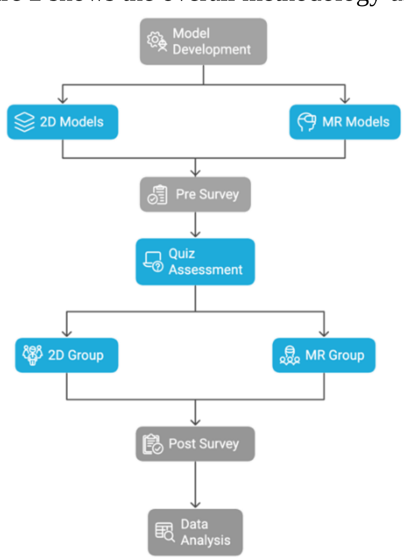
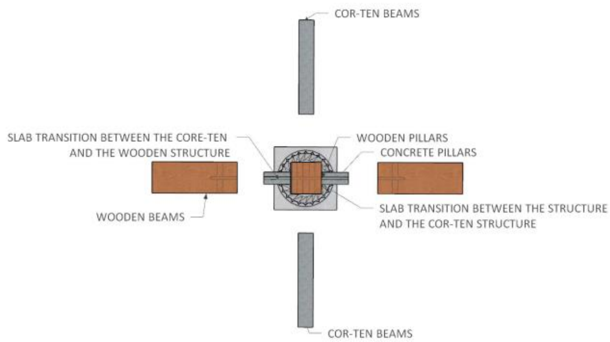
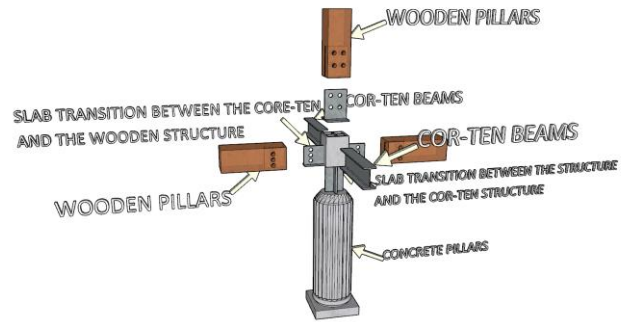


Figure 2. Research Methdology Overview

First, 2D and 3D models were developed for traditional and MR-supported teaching, respectively. To compare comprehension levels across different topics in an undergraduate building structures design course, eight structural detailing models were developed that were presented to students in two formats: (1) traditional 2D drawings and (2) 3D MR models viewed through Microsoft HoloLens version 1.0. All 3D models were developed using Sketchup Pro. Figure 3 illustrates the comparison of a 2D drawing of a composite wood-steel connection along with its 3D model developed in Sketchup-Pro software.



A steel-wood connection in 2D view



3D model development in Sketchup Pro

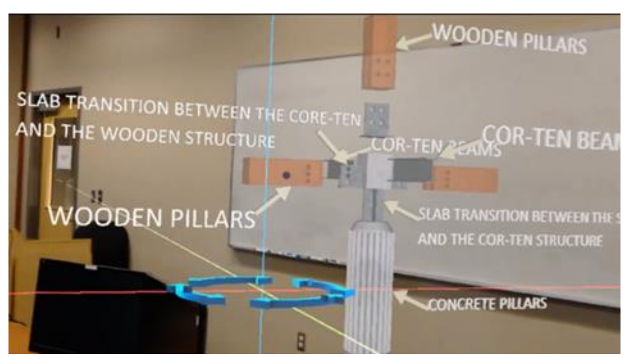
Figure 3: A comparison of a 2D drawing and 3D model of a steel-wood composite joint

3.1 Data Collection and Analysis

This study focused on how students understand building structure components. The research involved third-year undergraduate students from Auburn University's Building Science and Architecture programs. Participants were selected from the Structures of Buildings-II course, ensuring they had enough background to assess structural components effectively. Data were collected through surveys (pre- and post-experiment) distributed via Qualtrics®, along with quiz assessments hosted on Canvas®.

The pre-experiment survey was designed to assess students' familiarity with mixed reality (MR) and their understanding of topics covered in the Structures of Buildings-II course. Students also shared their expectations about how MR technology might help them interpret drawings compared to traditional 2D formats. Based on their survey responses and academic performance in the course, participants were divided into two groups: the control group (Group 1) and the MR group (Group 2). The control group had 14 students, while the MR group had 13. Both groups were carefully balanced to include a mix of academic performance levels and varying experience with MR technology.

(a) Viewing the 3D MR model using Microsoft HoloLens



(b) 3D model as seen through the HoloLens headset

Figure 4: 3D MR model viewed using Microsoft HoloLens, with a perspective shown as seen through the headset

On the quiz day, participants received a 45-minute lecture on structural assemblies, with the control group learning from traditional 2D drawings and the MR group through pre-loaded MR models. Figure 4 illustrates the 3D model viewing via Microsoft HoloLens. Following the lectures, all students completed an 18-question multiple-choice quiz on Canvas, with each structural assembly covered by 2-3 specific questions. Both completion times and scores were documented for each participant.

After finishing the assessment in their assigned format, students were shown all presentation formats for comparison for the post-experiment survey. The control group additionally received a demonstration of the MR system following their quiz, introducing them to its capabilities and operation. Finally, an online follow-up survey was conducted to gather students' perspectives on using MR technology for understanding building structures, complementing the quantitative performance data with qualitative feedback on the experience.

Finally, the collected data was examined using both quantitative and qualitative approaches. Descriptive statistics helped provide a clear overview of the numbers, while content analysis of the qualitative data offered deeper insights into emerging themes and patterns. The following section summarizes the analysis process and highlights the key findings that emerged from the study.

4 Results

4.1 Pre-Experiment Survey Results: Descriptive Analytics

The study involved a group of 27 third-year undergraduate students enrolled in the BSCI 3440: Structures of Buildings II course. Among them, 15 were Building Science majors (56%), while the remaining 12 were Architecture majors (44%). Although 11 students (41%) had some prior experience using augmented reality (AR) on personal devices, none had used mixed reality (MR) or the HoloLens before participating in this study. Before the MR experience, students were asked to rate their own understanding of the course content on a 10-point scale, where 1 meant "Least Knowledgeable" and 10 meant "Very Knowledgeable." As shown in Table 1, the average self-rating score was 6.74, suggesting that most students felt they had a moderately strong grasp of the subject going into the activity.

Table 1 Results of participants' level of comprehension in the Structures of Buildings class

Minimum	Maximum	Mean	Median	Std Deviation	Variance	Count
3	9	6.74	7	1.51	2.27	27

Regarding participants' preferred method of viewing structural models, a three-option choice was presented with results distributed as shown in Table 2. Participants were encouraged to provide explanatory comments for their selection in an accompanying text box. After reviewing all comments, a comprehensive list of reasons associated with method preferences was compiled and ranked according to repetition frequency.

Table 2 Participants' reasons for preferring 2D drawings or mixed reality (MR) models prior to the testing phase

2D drawings		Mixed reality (MR) model	
Reason	**Count**	**Reason**	**Count**
More prior experience	7	Better visualization	6
Simple and easy to use	5	Manipulate model (turn or move)	3
Less training required	3	Easier and more portable	2
Less disturbance	2		
Rich and detailed content	2		

The analysis showed that traditional 2D drawings were the preferred option, chosen by 18 participants (64%), more than MR or AR models. For most of these students, the main reason was familiarity; 7 out of the 18 shared that they were simply more comfortable with this conventional format. Three others appreciated the clarity and simplicity of 2D drawings, pointing out that they required little to no extra training to understand these drawings. Some also noted specific advantages, like being able to see finer details more easily, focus on individual sections without distraction, and examine one element at a time. Overall, previous experience with 2D drawings played the biggest role in shaping their preferences.

On the other hand, 9 (36%) participants favored the MR experience using HoloLens. Of these, 7 said they found it to be the most helpful method because it allowed them to view the structures as if they were physically present. One participant specifically highlighted that the ability to interact with digital objects in a lifelike way was the key reason they chose MR.

4.2 Quiz Assessment

Comparing the assessment results between students who used traditional 2D drawings and those who worked with mixed reality (MR) models reveals some encouraging benefits of MR in construction education. Although both groups ended up with the same average and median scores, 61% and 65%, respectively—the MR group showed clear advantages in other areas. Most notably, students using MR completed their assessments significantly faster, taking just 19 minutes and 22 seconds on average, compared to 23 minutes and 26 seconds for those using 2D drawings, a time savings of about 17%. This suggests that MR helped students interpret and process complex structural information more efficiently. On top of that, performance among the MR group was more consistent, with a smaller standard deviation of 9.1% compared to 11.60% in the 2D group. This tighter range hints that MR might help level the playing field, supporting a more uniform understanding across different learning styles. A summary of these results is presented in Table 3.

Table 1 Quiz score and completion time comparison

Group	Mean	Median	Standard Deviation	Mean Time
2D Drawings	61%	65%	11.60%	23:26
MR	61%	65%	9.1%	19:22

These results are particularly encouraging considering that MR represents a relatively novel technology for most students compared to the familiar 2D drawings. The fact that MR users matched the comprehension accuracy of traditional methods while significantly improving speed and consistency highlights MR's potential as an effective educational tool in building science. This efficiency advantage could prove especially valuable in professional settings where rapid, yet accurate interpretation of structural elements is essential.

4.3 Post-experience survey

After the quiz assessment, the student answered the post-experience survey. Table 4 summarizes students' experience with MR in terms of sentimental analysis. Overall, out of 27 respondents, a majority (15) recommended incorporating MR into future building structures courses.

Table 2 Semantic analysis of student experience with MR-supported learning

Attitude	Key Words	Frequency	Total
Positive	Immersive and interactive experience	9	15
	Present the way how structure elements are put together	4	
	Learn to read drawings in a different way	2	
Negative	Not cost-wise	4	7
	Motion sickness	2	
	Technology immature - insensitive movement	1	
Neutral	Too little experience to judge	3	5
	Depend on different students and class materials	2	

The primary reason, cited by 9 of these students, was that MR's immersive and interactive experience provided a real-life perspective leading to superior 3D visualization compared to traditional 2D drawings. They noted that hands-on experience with HoloLens would allow them to personally manipulate structural models. Four respondents specifically highlighted MR's effectiveness in demonstrating how structural elements interconnect. Similar to opinions about AR

[11], two participants appreciated the opportunity to learn drawing interpretation through multiple modalities, adding that HoloLens created an engaging learning environment that enhanced student interest.

That said, 7 students were hesitant to recommend MR technology, mainly due to concerns about the high cost of HoloLens devices, sensitivity to movement, and instances of motion sickness. While they recognized the potential of MR as a powerful learning tool, they felt that physical discomfort and technical limitations could make it challenging to use effectively in a typical classroom setting. Some also pointed out that simply watching recorded MR sessions wasn't nearly as impactful as actually interacting with the technology firsthand. The idea of providing individual devices for all students was seen as impractical given the cost.

Meanwhile, 5 participants took a more neutral stance. They felt they didn't have enough hands-on experience to form a solid opinion. Their responses reflected an awareness that people respond differently to new technologies and that the learning curve for MR could vary depending on the course content and how the technology is applied.

Students were invited to share their final impressions of the MR technology, and many expressed strong appreciation for its immersive capabilities. One student remarked that it "felt like being inside the structure," underscoring how the technology brought the model to life in a way traditional methods could not. Another noted, "Seeing how all the components connect in 3D made everything click instantly," highlighting MR's effectiveness in clarifying complex relationships. A third student shared, "This was the first time I truly understood how the structural components fit together—2D drawings never gave me that clarity," reinforcing MR's potential to significantly enhance spatial comprehension.

5 Discussion and Conclusion

The integration of Mixed Reality technology in structural engineering and construction education demonstrates promising potential despite certain limitations. MR's primary strength lies in its ability to provide immersive and interactive experiences that help students visualize complex structural relationships, having a capability that traditional 2D drawings cannot offer. The results of this study revealed that, despite equal performance scores between the MR and 2D groups, MR's advantage in time efficiency and consistency suggests that this technology can enhance the learning experience without compromising comprehension.

It is important to recognize that such innovative methods typically require time for full adoption into learning environments, which may explain why immediate grade improvements were not observed in this study. It also appears in the neutral comments, indicating that some students felt they had insufficient experience to form definitive opinions, while others recognized that the effectiveness of MR might vary depending on individual learning styles and specific course materials. This contextual perspective is important as it acknowledges that MR may not be universally superior but rather offers complementary benefits to traditional methods. Educational technologies often face an implementation curve where their full benefits are realized only after students and instructors have developed familiarity with the tools and adapted their learning strategies accordingly. The time efficiency advantage demonstrated by MR users despite their relative inexperience with the technology indicates that with greater exposure and adaptation, MR could potentially lead to improved comprehension and performance outcomes in the future. As students become more comfortable with MR interfaces and develop cognitive frameworks for processing information in this format, the technology's impact on educational outcomes may become more pronounced.

The findings reveal that students most strongly agreed on MR's immersive and interactive experience. Students also valued MR's ability to present structural assembly relationships and offer alternative approaches to drawing interpretation. This aligns with previous research suggesting that spatial visualization technologies can enhance understanding of complex 3D relationships that are difficult to convey in 2D formats [3]. However, cost concerns emerged as the primary barrier to MR adoption, appearing in 5 negative comments. This practical limitation reflects the current reality of MR technology's accessibility in educational settings. Additionally, physical discomfort in the form of motion sickness was noted by multiple students, which could potentially limit extended use of MR in educational contexts. Accordingly, the implementation of MR in educational settings must address several challenges, particularly cost concerns and physiological discomfort experienced by some users. As the technology matures, these issues may diminish, but they currently represent significant barriers to widespread adoption. Future research should focus on developing more affordable MR solutions and refining the user experience to minimize motion sickness.

This research contributes to the field in several important ways. First, the study offers valuable insights into the time efficiency advantages of MR technology, which has significant implications for both educational settings and professional practice where rapid interpretation of complex structures is essential. Secondly, the detailed analysis of student attitudes toward MR reveals both opportunities and challenges for implementation, providing educators with practical considerations for integrating this technology into their curricula.

Like any study, this research comes with a few limitations that are important to acknowledge. First, the sample size was relatively small, which means the findings should be interpreted with some caution. While the insights gathered offer meaningful direction, they may not fully represent the broader population of students in construction and architecture programs. A larger and more diverse group of participants could provide a more comprehensive understanding of how different learners respond to MR technology.

Secondly, the time allocated for students to engage with MR experience was quite limited. Participants only had a short window to interact with the technology, which may have restricted their ability to fully explore its features or develop deeper comfort and familiarity. As a result, their feedback and performance might reflect an early, surface-level interaction rather than the richer experience that could emerge with repeated or extended use. Future studies with longer exposure periods and more opportunities for hands-on practice would likely offer more nuanced insights into MR's long-term educational benefits.

Future research will focus on evaluating the long-term retention of structural concepts following MR-based instruction, as well as assessing how effectively students apply this knowledge in real-world or simulated construction tasks. Such studies could offer a deeper understanding of MR's lasting educational impact beyond immediate comprehension and engagement.

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