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Using Augmented Reality to Enhance Collaboration in Online Education

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This study evaluated the impact of Augmented Reality (AR) on collaboration and problem-solving in online construction management education. The research was conducted with 60 students, and AR's effectiveness was compared with traditional visualization methods such as 2D and 3D models. The study utilized iPad and HoloLens for AR implementations. Using different visualization tools, participants worked in pairs and completed various construction-related tasks, including preconstruction, construction, and post-construction. The main focus was on measuring collaboration efficiency, task completion time, and accuracy, particularly emphasizing how AR can enhance online collaborative skills. The results of the ANOVA with repeated measures indicate that AR, primarily through the use of HoloLens, significantly improves collaboration compared to traditional methods. Although task completion accuracy remained the same across all methods, AR notably reduced the time required to complete tasks. These findings suggest that AR has the potential to significantly benefit online construction management education, offering a more interactive and practical learning experience. However, the study acknowledges certain limitations, such as excluding other visualization technologies and using AR devices in experiments. The research highlights the potential of AR to improve spatial and temporal understanding and collaboration in educational settings, especially in the field of construction management.

Key Words: Collaboration, Online Education, Augmented Reality, Construction

Introduction and Background

In the past three decades, the computer industry has experienced major improvements. Large computers changed in form factor and computational power and transformed into laptops, mobile devices, and wearable technologies. With the advancement of the fourth industrial revolution, machines have become smarter due to the use of more sensors and processing capabilities (Due 2014). While these impending changes hold great promise for future prosperity, the construction industry has always shown a slow adoption rate of new technologies. Because of the complex nature of the

Architecture, Engineering, Construction, and Operations (AECO) industry, it is of utmost importance to benefit from technological advancements and tailor them to facilitate the evaluation and communication of information on construction projects.

Information systems have been used in the form of maps to preserve and transmit geographic data by means of visual representation. More recently, maps have evolved into more robust platforms with the introduction of Geographic Information System (GIS) mapping, allowing users to better visualize and analyze data. Construction information systems evolved from 2D drawings to computer-aided design (CAD) drawings, and in the 21st century, to building information models (BIM). BIM technology is mainly centered on buildings and indoor environments and provides a rich data source on all building components (architectural, structural, and mechanical) that can be used throughout the project lifecycle. GIS, on the other hand, focuses on outdoor environments and provides insights on urban and logistics planning. Integrating BIM and GIS extends the benefits of building models to outdoor environments (Karan et al. 2015).

Contrarily to Virtual Reality (VR) where the user is completely immersed in the virtual world, Augmented Reality (AR) blends real-world objects with digital content, allowing computer-generated data to be fed into the user's view of a real scene in real-time and interactively. AR helps users efficiently interpret digital and physical content and the relations between them and gives the illusion of holograms that can be interacted with using gestures, gaze, and voice commands.

With all the new technological advancements in the construction industry, construction management education is facing parallel challenges and opportunities at the frontier of preparing the next-generation construction workforce. As one of the new technological innovations, AR has gained the attention of many construction professionals to revolutionize construction education and on-job training (Bosche et al. 2016; Wu et al. 2019). The idea of using AR in the construction industry is not novel; many research projects have discussed the benefits of using this technology to interact with prototypes, visualize planned improvements (Thomas et al. 2000), and document construction processes (Zollmann et al. 2014). In addition, AR has the potential to enhance construction education by introducing job-like spatial and temporal constraints to enhance the understanding of complex situations (Shanbari et al. 2016). In addition to the visualization benefits afforded through AR, this technology can offer motivation to students to learn new content (Ayer et al. 2016). By bringing content into context, AR helps students visualize virtual information from BIM and GIS models in the context of its physical space. The educational values of AR do not rely solely on the use of the technology but also on how AR is integrated into formal and informal learning settings (Wu et al. 2013).

The main limitation that is driving the scope of this research is the lack of studies discussing the benefits of AR applications in online construction management education. Given the discussed benefits of AR and its different technological and pedagogical benefits, this research aims at evaluating the use of AR in online construction education and its effect on collaboration between students in online courses and degrees. In this user-centered experiment, recruited construction management students were asked to rely on different visualization methods (i.e., 2D drawings and 3D models, AR on iPad, AR on HoloLens) to complete a series of tasks in groups of two, and report on the effect of AR on their collaboration experience. This study evaluates the effectiveness of AR technology in virtual learning environments for construction management education, providing insights into enhancing collaboration and spatial understanding.

Methodology

Description of the Experimental Study

The main purpose of the user-centered experimental study is to analyze the impact of visualizing integrated BIM-GIS data using AR on online students' collaboration skills. The entire study took place virtually where one student was located on site and used the different visualizing techniques, and the other students were collaborating virtually by receiving live feed from the site. Three visualizing techniques were used in this study: (1) traditional methods, including 2D drawings and 3D models (see figure 1), (2) AR on iPad (see figure 2), and (3) AR on HoloLens (see figure 3). Students had to solve a series of tasks using each of the visualization methods and share their assessment on the effect each method had on their collaborative problem-solving. Specifically, in the first method, students visualized BIM-GIS data of the site by navigating models on traditional non-3D computer monitors, including Revit models, 2D drawings, photos and videos of the location, and virtual walkthroughs. In the second method, one team member walked through the building holding an iPad Pro to broadcast the BIM-GIS data on top of the real images captured by the iPad's camera to the other team member joining virtually. Autodesk© Revit, Autodesk© Infraworks, and VisualLive© were used in this process. Similarly, in the third method, one student walked through the building wearing a Microsoft© HoloLens, and the AR visualization was broadcasted to remote participants. The independent variable in the experiment is the method used by each group of participants to visualize the BIM-GIS data. A within-subject design was adopted since the study is assessing a utility theory, with all participants exposed to all three conditions.

The experiment's main dependent variable was the collaboration skills of students. The collaboration among students using the different visualization method reflects the students' abilities to establish common norms and goals, communicate, coordinate, make collaborative decisions, and take collaborative action. These dependent variables were evaluated by the study's participants. This dependent variable was first self-evaluated by each student by answering the following questions on 5-point Likert scale ranging from "None at all" to "A great deal":

- To what extent did each of the methods used help you communicate your ideas?
- To what extent did each of the methods used help you complete the task?

In addition to the dependent variable evaluated by students, the researcher evaluated two additional dependent variables, i.e., the time needed for a group of students to complete a task and the number of correctly completed tasks. The time was recorded from the moment students started solving the problem until they affirmed that they were done. This time did not include any time that was needed to go over the experiment and the different tools. For each task that the students had to complete, there was only one correct answer. After the students completed the task, the researcher checked whether they reached the correct answer.

At the beginning of the experiment, each group of two students were presented with the different tools to be used throughout the different tasks to be completed. Each group had to complete three tasks, one related to preconstruction, one related to construction, and one to post-construction. Each task was completed using the three visualization methods. It is important to note that slightly modified models were used for each visualization method in order to have independent observations. The following list includes examples of the tasks that the students had to solve using each visualization method,

- Preconstruction task: The owner decided to add an extension to the existing building in the parking lot. Evaluate this addition and point out the main problem you notice.

- Construction task: Due to the extension to be added, the engineer needs to add a 14-in pipe on Main Street above the existing pipe. Does it fit properly?
- Post-construction task: One of the sprinklers of the Hall of Fame garden is not working. You investigate, and you realize that water is not reaching it. Where should you excavate to fix the damaged irrigation pipe?

Data Collection and Analysis

A total of 60 students (30 groups of two) participated in this study. The sample size was chosen based on a priori power analysis. A priori power analysis involves estimating the sample size required for a study based on predetermined maximum tolerable Type I and II error rates and the minimum effect size that would be clinically, practically, or theoretically meaningful. This analysis considered three categorical groups, corresponding to the three visualization methods, an alpha value of 0.05, a medium effect size of 0.35, a power of 0.9 based on a tolerance of 0.1 for Type II error which represents the probability of failing to reject the null hypothesis when it is actually false. The null hypothesis postulates that the mean composite score collected from participants is the same irrespective of the visualization method used. Also, the analysis assumed the sphericity of the data which must be met to conduct the ANOVA with repeated measures. The choice of the values for each variable was based on similar studies related to AR and on conservative suggestion for studies concerned with behavioral sciences and utility theories (Cohen 1988; Tang et al. 2003; Faul et al. 2007; Bademosi et al. 2019; Yen et al. 2013). These assumptions match the purpose of this study which focuses on a behavioral aspect of the participants who were tasked to assess three different tools and their effect collaboration skills. The calculated sample size was 33.

The data collection can be divided into three main parts. The first part consisted of a survey conducted to collect demographic data related to the participants' education and industry experience levels. In addition, the participants were asked to assess their knowledge level in the following topics on a 5-point Likert scale ranging from "Not knowledgeable at all" to "Extremely knowledgeable": plan reading, construction coordination, BIM, GIS, AR using iPad, AR using HoloLens. The second part of the data collection was a survey filled out by each participant, as they were completing the tasks at hand, to answer the two self-evaluation questions previously presented in this paper. The third part of the data collection was the data collected by the researchers, i.e. time needed to complete each task and the number of correct tasks completed.

Since the study followed a within-subject design, where each participant was exposed to three different visualization methods, the data analysis was conducted in IBM© SPSS using an ANOVA with repeated measures test (IBM 2020). Each participant completed three collaborative tasks. After each task, each participant answered the two self-evaluation questions. Therefore, a total of six responses per participant were averaged and used as a composite score for the first visualization method. The same process was repeated for each visualization method. When using ANOVA with repeated measures, the null hypothesis assumes that the mean (composite score) is the same among all groups (visualization methods). In the case of the researcher-collected data, the null hypothesis assumes that the average time needed to complete a task is the same among all groups. Post hoc tests for pairwise comparisons, i.e., multiple paired t-tests with a Bonferroni correction, were also conducted when the omnibus test showed a statistically significant difference between the three visualization methods. The number of correct answers, being ordinal data, is discussed using descriptive statistics.

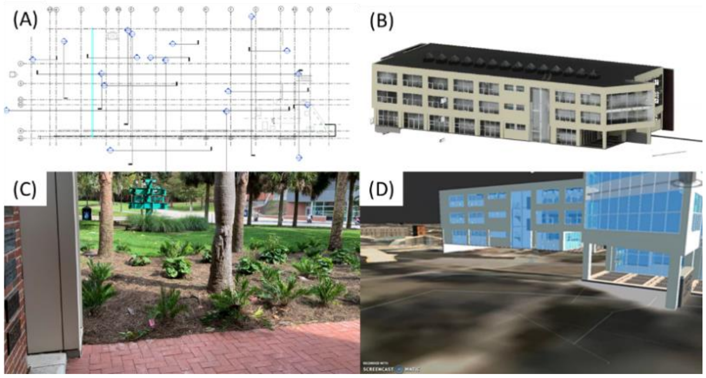

Figure 1. Examples of traditional visualization (A) 2D drawings (B) Revit model (C) Site image (D) Infraworks models

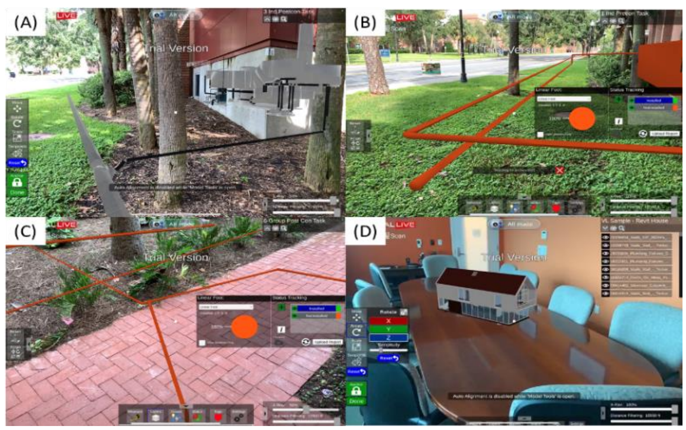

Figure 2. Examples from the visualization on iPad (A) Mechanical room (B) Underground pipes (C) Underground pipes (D) Tabletop sample model

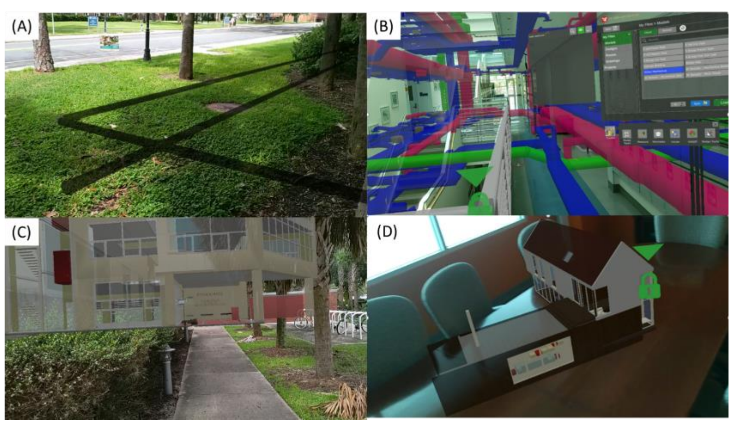

Figure 3. Examples from the visualization on HoloLens (A) Underground pipes (B) Building mechanical systems (C) Hall exterior (D) Tabletop sample model

Results and Discussion

Demographics Data

Sixty construction management and engineering students participated in the study. Their education level ranged from junior to Ph.D. students. Moreover, they all had some level of industry experience which ranged from at least two months to two years with an average of seven months. The participants indicated their level of knowledge in the technologies used in the experiment on the following 5-point Likert scale: (1) Not knowledgeable at all, (2) Slightly knowledgeable, (3) Moderately knowledgeable, (4) Very knowledgeable, (5) Extremely knowledgeable. The results, shown in figure 4, indicate that all participants were very or extremely knowledgeable in plan reading, construction coordination, and BIM. Most students (83%) indicated that they were slightly or moderately knowledgeable in the use of AR with iPad. Finally, 65% of students indicated that they were not knowledgeable at all with the use of AR on Microsoft© HoloLens.

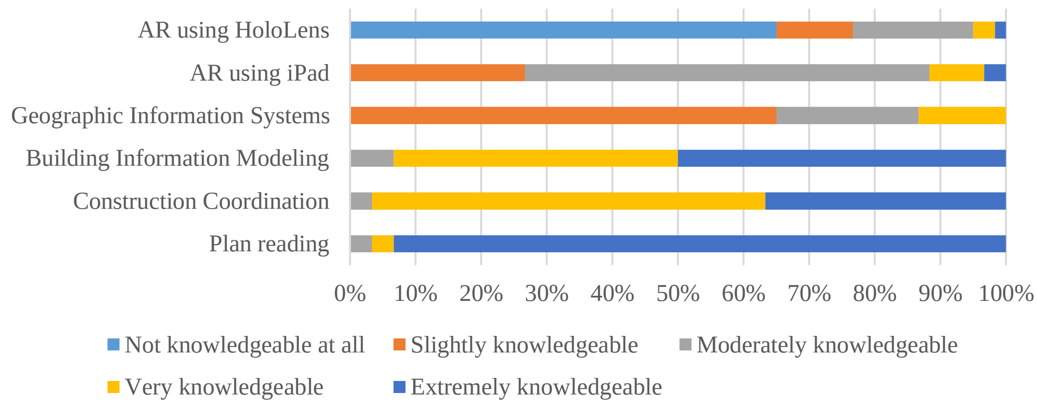

Figure 4. Level of knowledge of participants in experiment topics

Collaborative Problem Solving

The dependent variable analyzed in this experimental study was the collaboration skills of students. A composite score was calculated based on the students' responses to the survey questions. The score reflected the extent to which students believed each visualization method helped them better collaborate and communicate with their teammate to complete the task at hand. The null hypothesis assumes that the mean composite score is equal between the three groups (each representing one visualization method).

An ANOVA test with repeated measures was used to test this hypothesis. Since sphericity was assumed, the first row in Table 1 was used. This table shows a significance very close to zero which is smaller than 0.05. The null hypothesis is rejected, i.e., the mean composite scores obtained from students to evaluate their collaboration were significantly different among the three groups. Tayeh et al. (2021) explained the reasoning behind adopting the ANOVA test and subsequent statistical tests.

Table 1

Tests of within-subjects effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Visualization Method	Sphericity Assumed	12.680	2	6.340	64.490	0.000
	Greenhouse-Geisser	12.680	1.920	6.605	64.490	0.000
	Huynh-Feldt	12.680	1.983	6.394	64.490	0.000
	Lower-bound	12.680	1.000	12.680	64.490	0.000

The results in Table 1 show an overall significant difference in means. A post hoc Tukey test was conducted for pairwise comparisons to discover which specific means differed. The results in Table 2 show a p-value close to zero for pairwise comparisons including AR on HoloLens. This shows that there was a significant difference in the reported scores between AR on HoloLens and computer models and between AR on HoloLens and AR on iPad. A p-value greater than 0.05 was obtained when comparing computer models and AR using iPad. The difference in mean score in the latter two groups was not statistically significant.

Table 2

Results of pairwise comparisons

(I) Visualization Tool	(J) Visualization Tool	Mean Difference (I-J)	Std. Error	p-value	95% Confidence Interval	
					Lower Bound	Upper Bound
Computer models	AR using iPad	0.007	0.052	1.000	-0.120	0.134
	AR using HoloLens	-0.559	0.058	0.000	-0.702	-0.417
AR using iPad	Computer models	-0.007	0.052	1.000	-0.134	0.120
	AR using HoloLens	-0.566	0.062	0.000	-0.719	-0.414
AR using HoloLens	Computer models	0.559	0.058	0.000	0.417	0.702
	AR using iPad	0.567	0.062	0.000	0.414	0.719

The results of the repeated measures ANOVA determined that the mean score reflecting the students' evaluation of their collaboration skills differed statistically between the three visualization methods. The post hoc test showed that the mean score was also statistically different when comparing AR on HoloLens to the other two visualization methods. A comparison between AR on iPad and computer models did not lead to any significant difference in the group means. Based on their feedback, the student participants perceived that AR on HoloLens has the potential of improving their collaboration skills during online education.

Effect of AR on the Time Needed to Complete a Task

The time each participant took to solve a task starting from the moment they started solving the task until the moment they affirmed they completed it was recorded. In addition, the number of correct answers obtained by the participants was tracked. A repeated measures ANOVA determined that the time needed to complete a task differed statistically between the three visualization methods (p=0.001). The post hoc test showed that the average time was also statistically different when comparing AR on either tool to computer models. A comparison between AR on iPad and AR on HoloLens did not lead to any statistically significant difference (p>0.05). Therefore, it can be assumed that AR can be a helpful tool to assist users complete pre-construction, construction, and post-construction tasks in online environments.

The researchers recorded the number of correct answers obtained by each participant on the individual tasks as a function of the visualization tool. Each task had only one possible solution. Figure 5 shows an approximately similar number of correct answers obtained irrespectively of the visualization method used. On average, only 2% of the participants had zero correct answers, 17% had one correct answer, 42% had two correct answers, and 39% had three correct answers. These percentages were roughly the same among all three visualization tools. Considering that the time it took participants to complete the tasks was significantly different among visualization methods, and the average number of correct answers is roughly the same among visualization methods, it can be assumed that using AR in an online environment has the potential of facilitating the process of solving construction tasks.

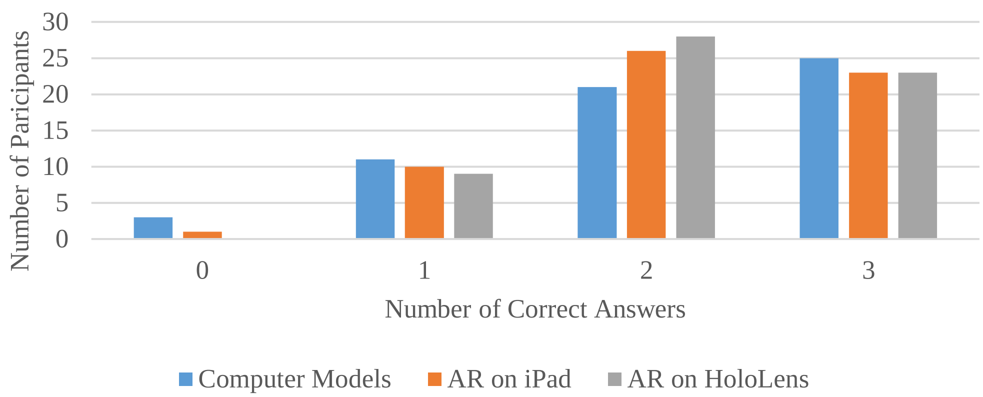

Figure 5. Distribution of number of correct answers based on the visualization tool

Conclusion

This study explored the applications of AR for remote instructions in construction management education. The main purpose of this study was to evaluate the effect of AR on the collaboration between students in online education. Based on the results of the repeated measures ANOVA and the corresponding post hoc tests, students believed that using AR in online environments has the potential to improve their spatio-temporal understanding and collaboration skills in comparison to other methods, including models, photos, and videos. In addition, by using AR technologies, students were able obtain a similar number of correct answers in significantly less time. Given the results that were presented in this paper, AR is hypothesized to help students enrolled in online classrooms better understand the space and collaborate on solving construction tasks, even if they were not physically using AR technologies. These benefits can also be hypothesized to apply on construction sites when stakeholders cannot be all physically geolocated.

It is important to note some of the limitations of this study. The experimental study did not consider other visualization methods, such as VR, 360 images, and educational games. Another limitation to this research is the fact that only one person was using the AR or AR equipment during the online experiment. Future research will focus on addressing these limitations by including more AR headsets to evaluate the effects of AR on collaboration and communication. Furthermore, future projects will include industry professionals in the pool of participants to further generalize the results of this study to real-world construction projects.

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