Assisting Construction Plan Comprehension Through the Use of Augmented Reality Technology

Jeffrey Kim
Auburn University, United States, https://orcid.org/0000-0001-7048-2402

Yilidaer Yilifeina
Auburn University, United States

Abstract: This research aimed to explore the effectiveness of using augmented reality (AR) technology to enhance construction management students' understanding of construction plans. Specifically, the study employed a controlled experimental approach, utilizing pre-assessment and post-assessment measures to evaluate the impact that the AR tool had on students' comprehension of construction plans. The methodology for this study was developed following an analysis of previous similar studies and by recognizing that the construction industry is in the early stages of utilizing AR technologies to scaffold comprehension of construction details with constituents that are often not adept at this process. The controlled experiment demonstrated a positive impact on the students' spatial skills, with improved accuracy and proficiency at interpreting construction plans. Additionally, student feedback revealed a high level of satisfaction with the use of AR technology as a learning tool in construction management education. Lastly, this research contributes to the existing body of knowledge by highlighting the potential of AR technology to improve the comprehension of construction details which is a necessary skill for the construction industry.

Keywords: Augmented Reality, Construction Industry, Construction Details, Spatial Skills, Visualization

Citation: Kim, J. & Yilifeina, Y. (2023**).** Assisting Construction Plan Comprehension through the use of Augmented Reality Technology. In M. Shelley, V. Akerson, & M. Unal (Eds.), *Proceedings of IConSES 2023-- International Conference on Social and Education Sciences* (pp. 448-457), Las Vegas, NV, USA. ISTES Organization

Introduction

With accelerated urbanization and a rapidly developing world-wide economy, the construction industry is experiencing unprecedented opportunities for advancement. Yet, this positive outlook comes at the expense of a workforce that is struggling to keep pace with the industry's growth. The construction industry has been notoriously slow at adopting new technology (JBKnowledge, 2020). Historically, the construction industry has been hesitant to embrace new technology, often due to intense competition resulting in narrow profit margins. Moreover, the prevailing ethos in the industry has been to stick with traditional methods that have historically led to success.

The industry's seasoned workforce is steadily retiring in vast numbers (Hildebrandt, 2014) and is being replenished with a younger, less experienced workforce. The positive aspect of this generational shift is that the younger workforce is more open to the benefits of technology. This is encouraging for educators who play a crucial role in shaping the careers of these new practitioners. Educators must advance knowledge and instill the idea that there are often more effective ways of doing things. This research seeks to address contemporary challenges in the construction industry, particularly in educating the new generation, through an experimental approach.

As the demand for construction practitioners continues to rise, the rapid education and training of this workforce becomes paramount. Unfortunately, like many industries, construction skills are primarily honed through practical experience rather than classroom instruction. One of the most critical skills for a construction worker is the ability to read and interpret construction plans, which are typically two-dimensional (2D) representations of building projects. Interpreting these plans requires individuals to read 2D lines on paper and mentally transform them into three-dimensional (3D) interpretations, enabling the actual construction of the project. As construction projects become more complex, the need for precise plan interpretation becomes even more crucial. Currently, this primary training occurs in traditional classrooms, with limited support systems to enhance the learning process (Sweller, 2011).

Augmented reality (AR) has been effectively used in classrooms as a scaffolding tool for learning experiences. In this study, AR is employed as a scaffold for construction management students to assist them with reading and interpreting construction plans. The primary aim of this research is to determine whether AR is an effective scaffold (Sweller, 2011) for improving construction management students' ability to accurately interpret construction plans.

Literature Review

AR technology is increasingly being used to enhance student learning experiences in various educational settings (Kim & Irizarry, 2020). These applications span multiple industries, often serving to compensate for the absence of real-world experience in a classroom environment. AR technology can be deployed through user-worn headsets or commonly available mobile devices. It operates by overlaying virtual objects onto the real-world environment, as explained by Azuma et al. (2001). AR technology operates by superimposing virtual objects onto the real-world environment. Figure 1 illustrates the use of AR to see additional virtual objects when the camera of a mobile device observes a special paper document known as a *marker*.

Figure 1 demonstrates how AR offers a new perspective by overlaying virtual objects on the real-world view displayed on a mobile device's screen. The subsequent sections of the literature review explore AR's applications in education, its role in aiding students learning to interpret construction plans, and the impact of cognitive load on the learning experience, all of which contribute to the foundation of this research.

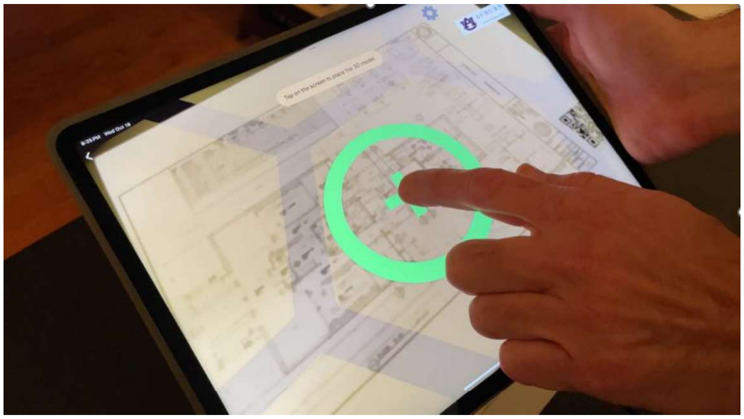

Figure 1. Sample AR being used to show students a 3D representation of a 2D object (Kim & Irizarry, 2020)

Augmented Reality Used in the Classroom

AR is most effective when it seamlessly integrates with the real world, creating a unified experience where users are unaware of the distinction between the virtual and physical worlds (Azuma et al., 2001), often referred to as *connectedness*. Consequently, many educational studies utilize markers to enhance the user's AR experience (Shirazi et al., 2014). These markers can take the form of pages in a book (Shirazi et al., 2014) or printed documents with special QR codes (Kim & Irizarry, 2017). Present-day students are visually inclined and media-savvy (Moskal et al., 2004), making them well-suited to technology-enhanced learning experiences. Students are often familiar with AR and have ideas about how it can be incorporated into their education, requiring instructors to bridge the gap between technology and practical applications in their teaching (Shirazi et al., 2014). For instance, in construction management education, it is reasonable to employ devices that students are already comfortable with to harness the potential of AR during their lessons.

Understanding and Interpreting Construction Plans

Interpreting construction plans is a critical skill in the construction industry, as these plans provide essential information about building design and construction. Accurate interpretation of construction plans is imperative for successful project execution, as emphasized by Clough et al. (2015). The significance of education and training in enhancing workers' understanding of construction plans is highlighted by Wang et al. (2021) and emphasizes the role of engineering plans in conveying critical structural information, and Clevenger et al. (2014) discuss the importance of shop drawings (plans) in guiding the fabrication and installation of building components. These sources collectively support the notion that a comprehensive understanding of construction plans is an essential skill for anyone in the construction industry.

Distractions to Student Learning

A significant problem to consider when using technology in the classroom is how it may distract students from the intended learning objectives. Therefore, the deployment of technology during a scaffolded learning experience must be measured to determine if there was increased cognitive load during the experience (Sweller, 2011).). This increase in cognitive load, if not checked, could negate the possible benefits of using the AR tool.

There are a variety of ways to measure this cognitive load and one such method uses the NASA TLX self-perceived load index (Human Performance Research Group, 1986). This self-reported survey measures perceived effort on six subscales, mental effort, physical effort, temporal effort, performance, overall effort, and frustration. When used, this tool can identify potential extraneous loads that may be detrimental to the learning process.

Rationale

It is reasoned from the literature that using AR in the proper manner has the potential to affect the student's learning. This effect could be positive if the tool used does not overload their cognitive abilities. A measured and controlled experiment would be able to assess the short-term student's learning while a survey tool could be used to measure their perceived effort during the study. The outcome of this study will demonstrate the capability of AR as a scaffolding tool and identify considerations for how to use it in a classroom environment.

Methodology

This research adopted a mixed-methods approach to investigate the effectiveness of AR technology for enhancing the understanding of construction plans among construction management students. By combining quantitative and qualitative research methods, this study aimed to provide a comprehensive and multifaceted understanding of the research topic. A quantitative research method was employed to measure and quantify the impact of AR technology on students' spatial skills. Pre-assessment and post-assessment tests were used to evaluate the improvement in students' understanding of construction plans after using the AR tools.

The quantitative data collected allowed for statistical analysis and objective conclusions regarding the effectiveness of AR technology in enhancing spatial skills. A qualitative research method was utilized to explore students' perceptions, experiences, and attitudes towards the use of AR technology as a learning tool and to indirectly measure cognitive load. Interviews, observations, and student feedback provide rich and in-depth insights into the subjective aspects of using AR in construction management education. The qualitative data collected allowed for a deeper understanding of the students' perspectives and sheds light on the utility and potential challenges of AR technology in this context.

Research Design

The proposed research aimed to investigate the effectiveness of using AR technology to help construction management students understand construction plans. The research utilized a single-blind experiment design, with a pre-test and post-test survey, to compare the effectiveness of using AR technology versus traditional methods of interpreting construction plans. Figure 2 illustrates the workflow of the experiment that was conducted.

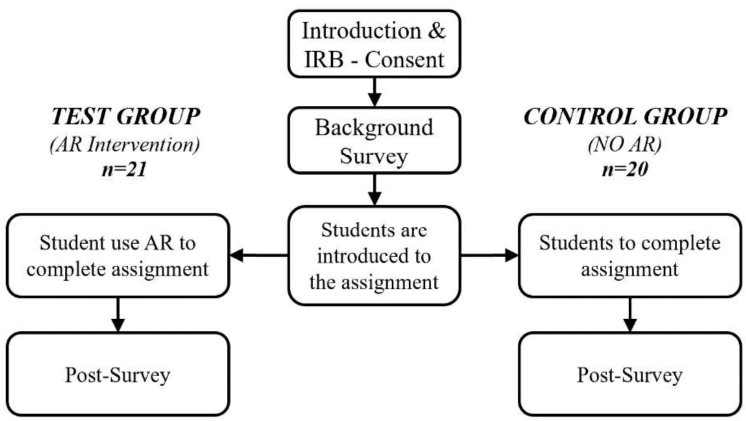

Figure 2. The Experiment Workflow

The Single-Blind Experiment

The experiment involved administering a background survey to the participants before dividing them into two groups: a control group that received traditional 2D construction plans and a test group that received the same plans but with the additional AR technology to scaffold their learning experience. The data collected from the background survey was analyzed to investigate whether any demographic or experiential factors were associated with participants' understanding of construction plans and the effectiveness of the AR technology. The participants were then assigned specific tasks, which included identifying key components, determining spatial relationships, and interpreting dimensions and materials from the construction plans. These tasks required the participants to analyze and comprehend the plans accurately. The participants' performance in these tasks was measured and compared between the control and test groups to assess the impact of AR technology on their understanding of construction plans. By specifically evaluating the participants' performance in these tasks, the experiment aimed to provide more detailed insights into the effectiveness of AR technology for supporting their interpretation and comprehension of construction plans.

The participants were then divided into two groups: the control group and the test group. The control group worked with traditional 2D construction plans, while the test group worked with the same plans but with additional AR technology. The AR technology provided the participants with a 3D visualization of the construction project, allowing them to interact with the project in a more immersive way. The participants then completed a series of tasks related to understanding the construction plans, including identifying key components, determining spatial relationships, and interpreting dimensions and materials from the construction plans.

Pre-test and Post-test Measuring Tools

To assess the effectiveness of using AR technology in helping students understand construction plans, participants completed a pre-test and post-test survey consisting of multiple-choice questions. The multiple-choice questions assessed the participants' knowledge of construction plans, including their ability to interpret symbols and annotations commonly used in construction plans. These questions provided a quantitative measure of participants' knowledge and were scored based on the number of correct answers.

The Augmented Reality Intervention (Independent Variable)

The AR software used in this study was Augment (http://www.augment.com); a commercially available mobile software package used to scan a *marker* (fiducial) and render a 3D model on the screen of a mobile device. A student, along with a mobile device and the AR software, would scan the paper-form of the marker using the AR software. Once the image was recognized and matched with the inventory of stored marker images from the server, the mobile device's AR software would call the corresponding 3D model from the server and would combine it along with the image of the marker being captured by the mobile device's back-facing camera. The combined image on the mobile device would show the marker with a 3D AR model displayed on it as shown in Figure 3.

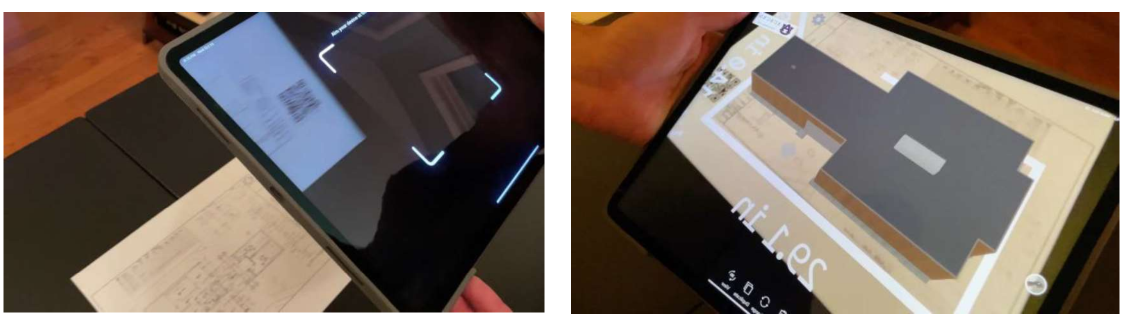

Figure 3. Scanning for AR Image Used by the Test Group
(Scan Process on the Left and AR Image on the Right)

Lastly, the 3D model that would display on the mobile device's screen would be superimposed over, and attached to, a live image of the marker that is being displayed by using the mobile device's back facing camera. The students could then interact by moving the mobile device or the paper-form marker.

The NASA Task Load Index (Human Performance Research Group, 1986) is a reliable measuring tool for self-perceived effort and has been used in academic research to indirectly measure cognitive load. It was included as part of the post-test survey to measure student's workload and cognitive effort. By incorporating the NASA TLX, this research aimed to capture participants' subjective experiences regarding the mental demands, physical demands, and overall perceived workload associated with the tasks performed during the experiment.

Results & Discussion

Demographics

The students that participated in this study were selected from a four-year post-secondary construction management program in the Southeastern United States. The characteristics of these students are somewhat predictable in that they commonly possess practiced skills in reading and interpreting construction plans. In addition, these experiences may also come from past work experiences or from having close relatives that work in the industry. These factors were collected by having the students complete a background survey at the start of the experiment. The results of this survey are enumerated in Table 1. The results indicate that the issues concerning the student's background and experiences were somewhat evenly distributed between the control and the test group. This distribution would allow for results that were not biased by the student's prior histories on the subject.

Table 1. Student Background Demographics

CHARACTERISTICS	TEST GROUP N = 21	CONTROL GROUP N = 20
GENDER		
Male	18 (86%)	18 (90%)
Female	3 (14%)	2 (10%)
PRIOR CONSTRUCTION EXPERIENCE		
None	9 (43%)	10 (50%)
Some	9 (43%)	9 (45%)
Extensive	3 (14%)	1 (5%)
FAMILY BACKGROUND in CONSTRUCTION		
Yes	16 (76%)	14 (70%)
No	5 (24%)	6 (30%)

Testing Results

Before the intervention, a pre-test was administered to both groups to assess their baseline spatial skills. In terms of accuracy, the control group scored an average of 62.75 correct points while the test group scored an average of 61.19 correct points. These close scores indicate that the two groups were statistically equal in terms of their initial spatial skills aptitudes. After the students in both groups completed their respective work assignments (the test group was assisted by using AR and the control group was not), a post-test was given to measure the effectiveness of the work assignment at improving their spatial skills. The control group scored an average of 63.75 correct points while the test group scored an average of 68.10 correct points. Both groups scored better in their post-test; the control group improved by +13.3% and the test group improved by +1.6%. Therefore, the test group improved their accuracy by +11.7% more than the control group. While this numerical difference appears to be an improvement, a two-tailed t-test with a confidence interval of 95% (*CI*=95%) where $t_{(22)} = -1.36459$ resulted in $p = 0.180205$ (p is not less than 0.05) indicates that the improvement was not statistically different.

Furthermore, a more qualitative measure was used to measure the student's self-perceived performance and effort while completing the assignment prior to the post-test. The NASA TLX survey was administered to collect this feedback and the results have been enumerated in Table 2.

Table 2. NASA TLX Perceived Workload

Sub-Scale	TEST GROUP		CONTROL GROUP		Variance
	Mean	SD	Mean	SD	Δ = CONTROL - TEST
Mental	0.2	5.4	1.5	5.2	1.3
Physical	-8.7	2.7	-7.7	5.2	1.0
Temporal	-5.3	3.5	-5.8	5.0	-0.5
Performance	6.3	2.8	4.4	5.6	-1.9
Effort	1.6	6.1	0.8	4.0	-0.8
Frustration	-7.2	3.4	-7.5	3.0	-0.3

Variable Range is -10.0 through +10.0

The students in both groups roughly perceived similar levels of effort for temporal (-0.5), overall effort (-0.8), and frustration (-0.3). However, for mental (1.3), physical (1.0), and overall performance (-1.9), the test group indicated less self-perceived effort for these sub-scales while using the AR tool to scaffold their learning.

It has been suggested that a certain measure of applied technology in the classroom can have an interfering effect on the learning experience (Cristia et al., 2012). When deploying new technology in the classroom, will its use equate to a better and more active learning experience (Shirazi et al., 2014)? Less effort in the NASA TLX results means that the scaffolding works as an intervention and does not distract students from their learning despite it not proving to be a significant intervention in terms of direct assessment scores.

Conclusion

AR research in education is maturing and we are seeing more research that supports its use in the classroom. Across many disciplines, AR is used as a visualization tool to improve known processes. In this research study the aim was to explore if there was a benefit to using AR in the construction management classroom to help post-secondary students learn how to interpret 2D plans into a mental 3D representation. It was identified that this is a critical skill for practitioners in this industry.

The research found that while the accuracy could not be determined to be significant, there was no interference to the student's learning experience. In fact, their results indicated that the students perceived an increased level of performance while expending less mental effort. Arguably this is a positive finding for using this in the CM classroom. It is presumed through this research that improvement in technology will encourage others to continue this research as the technology begins to address some of the shortcomings found in this study.

While the researchers sought to control as many variables as possible, there were some limitations that the authors would like to share. Due to budgetary constraints, the researchers allowed the students to use their own mobile devices. These devices were not consistently of the same manufacture, size, or quality. This ultimately resulted in some inconsistent experience for some of the students. In the future, providing devices to the students would eliminate this concern. Lastly, due to time constraints, the students were not assessed for long-term retention. In future studies, measurement of longer-term retention may provide alternative insights in how the AR tool affects the student's learning. Lastly, student learning when the attention is spatial skills is a difficult skill to improve if not conducted in an active learning environment. This study attempted to add that element through the use of AR technology which encourages the students to ask the all-important *why* questions.

References

Azuma, R. T., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent Advances in Augmented Reality. *IEEE Computer Graphics & Applications*, 21(6), 34. https://doi.org/10.1109/38.963459

Clevenger, C. M., & Khan, R. (2014). Impact of BIM-enabled design-to-fabrication on building delivery. *Practice Periodical on Structural Design and Construction*, 19(1), 122-128.

Clough, R. H., Sears, G. A., Sears, S. K., Segner, R. O., & Rounds, J. L. (2015). Construction contracting: A practical guide to company management. John Wiley & Sons.

Cristia, J., Ibarrarán, P., Santiago, C., Santiago, A., & Severin, E. (2012). Technology and Child Development : Evidence from the One Laptop per Child Program. IZA Discussion Paper No. 6401, 6401. https://doi.org/10.2139/ssrn.2032444

Hildebrandt K. (2014) Age Safe : How an Aging Workforce Impacts the Construction Industry. *Constructor: The magazine of the Associated General Contractors of America 2014*. Accessed on 2023-10-26: http://www.naylornetwork.com/ngc-constructor/articles/?aid=253843&issueID=31705

JBKnowledge. (2020). The 9th Annual Construction Technology Report 2020. Accessed on 2023-10-26: https://jbknowledge.com/2020-construction-technology-report-survey

Sweller, J. (2011). Cognitive Load Theory. *Psychology of Learning and Motivation*, (pp. 37–76, 55).

https://doi.org/10.1016/B978-0-12-387691-1.00002-8

Kim, J., & Irizarry, J. (2020). Evaluating the Use of Augmented Reality Technology to Improve Construction Management Student's Spatial Skills. *International Journal of Construction Education and Research*. https://doi.org/10.1080/15578771.2020.1717680

Kim, J., & Javier Irizarry. (2017). Assessing the Effectiveness of Augmented Reality on the Spatial Skills of Postsecondary Construction Management Students in the. *34th International Symposium on Automation and Robotics in Construction* (ISARC 2017).

Moskal, B., Lurie, D., & Cooper, S. (2004). Evaluating the effectiveness of a new instructional approach. *ACM SIGCSE Bulletin*, 36(1), 75–79.

Human Performance Research Group. (1986). NASA Task Load Index User Manual v. 1.0 (p. 19).

Shirazi, A., & Behzadan, A. H. (2014). Design and Assessment of a Mobile Augmented Reality-Based Information Delivery Tool for Construction and Civil Engineering Curriculum. *Journal of Professional Issues in Engineering Education and Practice*, 4014012. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000229

Wang, T., Abdallah, M., Clevenger, C., & Monghasemi, S. (2021). Time–cost–quality trade-off analysis for planning construction projects. *Engineering, Construction and Architectural Management*, 28(1), 82-100.