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FIELD KNOWLEDGE TRANSFER VIA IMMERSIVE VIRTUAL FIELD TRIPS IN ARCHITECTURE, ENGINEERING, AND CONSTRUCTION EDUCATION

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Abstract

Field trips to actual project sites offer students in architecture, engineering, and construction (AEC) disciplines valuable exposure to real-world experience. However, traditional field trips often face logistical challenges and geographical limitations. This paper presents the findings of the research team's follow-up study on immersive virtual field trips (VFTs). The proposed VFTs are distributed via an online virtual reality (VR) platform. Learning assessments were conducted in multiple engineering and construction classes. Results indicate the proposed VFT helped students develop a critical understanding of professional practices and gain insights into workplace-specific knowledge and skills.

Introduction

VFTs are becoming increasingly popular in AEC education as a cost-effective, safe, and logistically feasible alternative to traditional field trips. They can be used in conjunction with in-class lectures, field trips, lab activities, and problem-based learning to develop essential technical skills and the ability to identify problems, evaluate information, and create viable solutions. Moreover, students can experience real-world construction projects and processes from the comfort of their own environment, making it a convenient and effective learning experience.

This research paper builds upon a previous pilot study to further explore the use of VFTs in AEC education, examine their impact on student learning outcomes, and identify the factors that influence their effectiveness.

Literature Review

Tuthill and Klemm (2002) discussed five types of pre-made VFTs for educational purposes in the early days. They are still widely practiced today, including "***travel brochures***" (where a web-based tour is assigned to students prior to an actual trip to the site), "***multi-school partnerships***" (where a "host" class gathers data of a local site and presents it to one or more "remote" classes), "***collaboration***" (where students and faculty at universities around the world create and share multimedia curriculum materials via one website), "***professionally produced multi-media VFTs***" (which "combines synchronous with asynchronous activities and provides extensive background resources" via multimedia), and "***threaded VFTs***" (where educators select VFT contents and arrange them in a thread built into their learning management system).

Recent technological advancements have also opened up opportunities for incorporating advanced features in the creation of VFTs. Wen and Gheisari (2020) conducted a thorough review of the technologies used in current construction-related VFTs and classified them into two categories: ***captured-reality technology*** and ***VR technology***.

The captured-reality technology employs either regular or 360-degree photos or videos of actual projects. For example, Pham et al. (2018) built VFTs using 360-degree panorama rendering of construction site activities for mobile construction safety education. Quinn et al. (2019) developed interactive VFTs as supplemental materials for online courses. They utilized 360-degree images of construction site with the added dimension of "time", as well as embedded 2D images and videos.

The VR technology utilizes computer-generated simulations, which can be accomplished through the use of 3D modeling software such as Revit and SketchUp, or game engines like Unity and Unreal. Zhang et al. (2019) developed a fire safety inspection prototype using 360-degree images and BIM models, enhanced with an indoor real-time localization system. Castronovo, et al. (2019) created a VR educational game in Unity 3D, allowing students to practice evaluating and reviewing design models of residential buildings.

VFTs also have their limitations. Despite many students find the virtual environment to be engaging and realistic, some may struggle with the limited interactivity in a self-guided VFT, which can lead to a lack of engagement. The technology used by VFTs may not always be available or reliable. Content creation can be costly and time consuming. In addition, some VFTs may require lab accommodations and/or tech assistance.

Nevertheless, VFTs are believed to have several notable advantages over traditional field trips if properly designed and implemented: They provide flexibility and cost-effectiveness in production and updates. They support student accessibility at different scales. They can also replace or enhance background lecturing/information transmission and allow students to explore specific issues in a more 'inquiry-based' manner both in the field and on campus (Stainfield et al., 2000).

Simulation and/or Experiment

Beginning in the fall of 2019, Luo and Wu led a team to develop VFT prototypes featuring location-based learning with immersive VR technology to facilitate construction field knowledge transfer in VR learning environments (Luo, et al., 2022).

In an earlier prototype, the VFT was designed to demonstrate a virtual tour of a completed building with limited media types (mostly 2D and 360-degree photos). However, the team's latest prototype, which is the subject of this paper, takes the concept further. It offers learners the opportunity to track the progress of an ongoing construction project and incorporates a wider range of media types to enhance the learning experience.

Research Design and Implementation

The research design consisted of three phases. The first phase involved the selection of a suitable VR platform. The second phase entailed the design of VFTs and the collection of relevant data. Lastly, the third phase involved conducting a usability test and learning assessments to evaluate the effectiveness of the VFT.

1. VR Platform Selection

After evaluating several popular VR platforms, including Unity, Second Life, Sansar, Cupix, and OpenSpace, the team selected HoloBuilder as the web-based VR platform for their research. HoloBuilder is a versatile platform that enables users to create immersive views of a construction site, and has been widely used in the construction industry for jobsite progress management. The platform offers seamless web browsing on any device, and is compatible with several mainstream VR headsets. In addition, it integrates with project design and management tools commonly used in the construction industry, such as Autodesk Revit, Autodesk Navisworks, PlanGrid, Bluebeam, and Google Drive. This integration facilitates seamless collaboration between the different stakeholders involved in a construction project, and provides learners with a comprehensive and immersive learning experience.

2. VFT Design and Project Data Collection

The First VFT Prototype

The first VFT prototype aimed to provide AEC students with a self-guided virtual tour of a completed building project, while covering topics related to architectural/structural design and facilities management. The tour was designed using a combination of field-captured 360-degree images, regular 2D images, quick text, and PDFs. The team captured the building using a 360-degree camera during two site visits. Although this prototype showed promising results, its potential was somewhat limited by the lack of variety in the multimedia types used.

The Second VFT Prototype

For the second VFT prototype, the team embarked on a four-month project to document selected field activities on an active construction site, using a 360-degree camera and a GoPro camera (for video recording). Over the course of fifteen site visits, the team aimed to create a self-guided virtual tour of the construction site, highlighting the procedures of common field practices such as excavation, concrete pouring, and steel framing, as well as the necessary safety precautions during these practices. While traditional field trips that cover similar topics are common for students in lower division AEC courses, they often require multiple visits to observe the activities at various stages of construction. The second VFT prototype offers a more efficient and accessible alternative, enabling students to gain a comprehensive understanding of these field activities in a self-guided virtual environment.

In response to student feedback on the first VFT prototype, the team incorporated a wider range of multimedia types into the second iteration. The new prototype features 3D models, field-captured 2D and 360-degree photos, as well as audio and video recordings of field production and installation processes. The addition of these new multimedia types provides a more comprehensive and immersive learning experience for users. The VFT also includes quick text and PDFs for additional information and reference. Users can navigate the virtual site and access the various multimedia content via interactive action objects. These objects are designed to trigger special actions, such as displaying additional information or initiating animations, when clicked or hovered over by the user.

The team also explored the potential of advanced features on HoloBuilder, including the measuring tool and SplitScreen. SplitScreen enables the comparison of two 360-degree images side-by-side within the browser window. These two images are linked to the same location in the floor plan and can be rotated independently or synchronously. This feature has immense potential in VFT development and creates new opportunities for AEC students to compare designs (3D models) with reality (field images) and monitor project progress over time - something which can be challenging with traditional field trips. As shown in Figure 1, a SplitScreen view displays a 3D model scene and an active construction site scene side-by-side, with a floor plan and a group of small circles (called "waypoints") displayed in the top left corner. Each waypoint is linked to a 360-degree image, and the highlighted waypoint indicates the current location.

Figure 1: A HoloBuilder SplitScreen view displaying a 3D model scene and an active construction site scene

3. Usability Test and Learning Assessments

The First VFT Prototype

This study employed a mixed-methods approach to evaluate the impact of VFTs on student learning and to explore their perceptions of the new learning experience. The assessment for the first VFT prototype mainly served as a usability test, which involved 33 participants from two introductory construction management courses. The students were tasked with identifying various building elements and systems, examine project documentation, and complete a post-test survey that included both quantitative and qualitative assessments.

The Second VFT Prototype

To evaluate the effectiveness of the second VFT prototype, student participants were recruited from five different courses, including two upper-division courses in construction management and civil engineering (CM180B and CE133), and three lower-division courses in construction management (CM1, CM7S, and CM20). The assessments included a pre-test and a post-test (available upon request) with eight technical questions covering the three main topics addressed in the VFT: concrete placement, steel erection, and safety. Additionally, the post-test contained four perceptional questions that solicited feedback on tour highlights/takeaways, ease of navigation, overall experience, and recommendations for future improvements. The mixed-method approach allowed for both objective and subjective data to be collected and analyzed, providing a more comprehensive understanding of the effectiveness of VFTs in AEC education.

The VFT assignment was made available to all students through Canvas, the university's learning management system, along with detailed instructions explaining the various features of the tour. Students were able to access the tour on a PC or any mobile device and were given one attempt on the pre-test and up to three attempts on the post-test. The recruited participants were drawn from a diverse range of courses, allowing the study to obtain a broad range of feedback from students with different levels of expertise and experience in the field of AEC.

Result Analysis

The First VFT Prototype

The initial assessment results from the 33 student participants in the first VFT prototype suggest that the VR-enhanced VFT can lead to better learning outcomes than traditional field trips, as students have the ability to revisit the virtual job site and interact repeatedly with learning objects, which is not possible with traditional field trips. A significant finding was that a majority of student participants engaged with the virtual tour multiple times and retook the assessment quiz several times to improve their learning outcome, providing direct evidence of increased student engagement and improved learning outcomes.

The Second VFT Prototype

A total of 99 students participated in the study, with the following distribution among five CE and CM courses: CE133 (36), CM180B (26), CM1 (13), CM7S (7), and CM20 (17).

1. Technical Learning Assessment

The initial step in reviewing the learning assessment data was to analyze each class individually. Figure 2 presents the class average grades for the eight technical questions (1 point per question) in CM20. Upon comparing the pre- and post-test grades for these questions, a consistent improvement in learning was observed across all five participating classes. Notably, the questions that displayed the highest improvement in grades for all classes were those related to (1) equipment and tools used in concrete pouring, (2) fall protection, and (3) the purpose of slump tests.

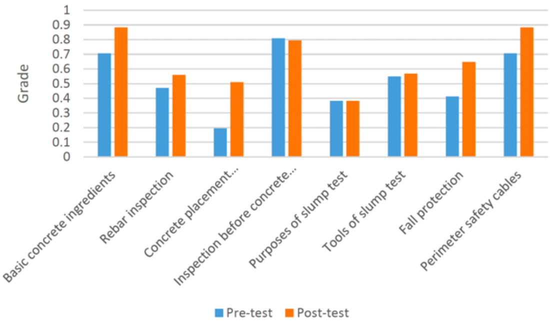

Figure 2: Pre- and post-test scores by question in CM20

Figure 3 showcases the average grades (out of 8 points) for the pre- and post-tests of each class, providing additional insights into the performance of each class.

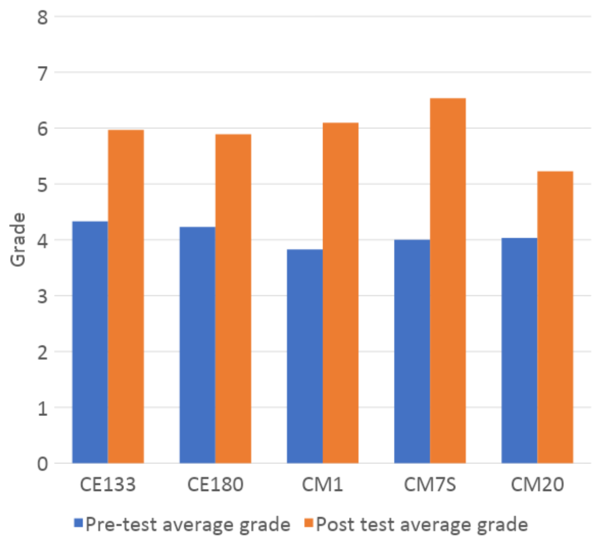

Figure 3: Pre- and post-tests' average grades by class

A paired t-test was conducted to evaluate the impact of the VFT on students' technical knowledge learning. The results are presented in Figure 4, and the P-value was found to be significantly lower than the alpha level (0.05), indicating rejection of the null hypothesis. These findings demonstrate that the VFT can effectively facilitate the acquisition of construction technical knowledge among learners.

	Pre	Post
Mean	4.155	5.8
Variance	1.423	2.2
Observations	99	99
Pearson Correlation	-0.213	
Hypothesized Mean Difference	0	
df	98	
t Stat	-7.756	
P(T<=t) one-tail	4E-12	
t Critical one-tail	1.661	

Figure 4: T-test results

A single-factor ANOVA F-test was used to determine if there was a significant difference between the ratios of post-test grades to pre-test grades among different classes. Figure 5 provides a statistical summary of the post-test grade to pre-test grade ratios for each class. The results of the test are presented in Figure 6, which shows that the calculated p-value is greater than the chosen alpha value of 0.05. Based on this result, we can conclude that there is no significant difference between the ratios of the different classes, suggesting that the VFT helped all students in the same way regardless of their class.

Class	Groups	Count	Sum	Average	Variance
CE180B	1	26	38.71	1.49	0.28
CE133	2	36	54.53	1.51	0.42
CM1	3	13	22.51	1.73	0.36
CM7S	4	7	10.88	1.55	0.7
CM20	5	17	27.4	1.61	1.48

Figure 5. Statistical summary of post-test grade to pre-test grade ratios

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.63	4	0.16	0.28	0.89	2.47
Within Groups	53.7	94	0.57			
Total	54.3	98				

Figure 6. Single-factor ANOVA F-test results

A cumulative frequency analysis was also performed. Figure 7 displays the distribution of final grades from pre- and post-tests in relation to cumulative percentage, with the green vertical line marking the target grade 5.8 (i.e., 70% of the total grade). Based on the data, it appears that a significant improvement in grades occurred after the VFT intervention: 62% of students achieved the target grade in the post-test, compared to only 13% in the pre-test. Notably, the black arrow on the graph highlights a distinct increase in grades among medium-level students, suggesting that they benefited more from the VFT intervention than other groups. This observation indicates that the VFT may be particularly effective for improving the performance of medium-level students.

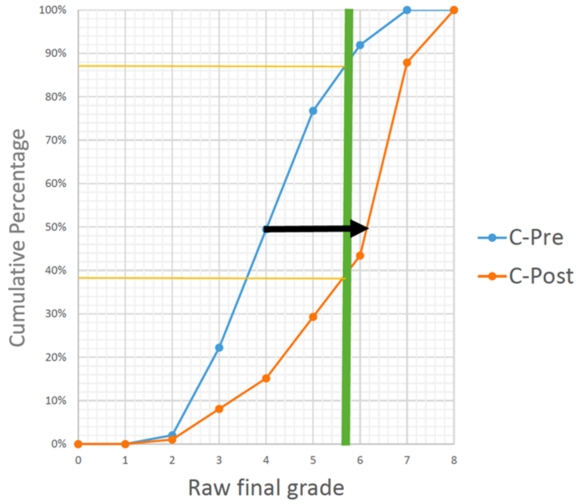

Figure 7. Cumulative percentage vs final grades in pre- and post-tests

2. Student Perceptions

Tour Highlights:

Both CE and CM students expressed their appreciation for the various construction activities they were able to learn about. Several students specifically highlighted the immersive experience provided by the 360-degree views, which made them feel as if they were actually on the construction site. This heightened sense of realism, in turn, motivated and excited them.

Ease of Navigation:

Most CE and CM students found the VFT easy to navigate, but a minority encountered lagging issues that caused delays in loading content. On average, it took CE students 26 minutes to complete the VFT, while CM students took an average of 32 minutes. Figure 8 displays the navigation times for each class.

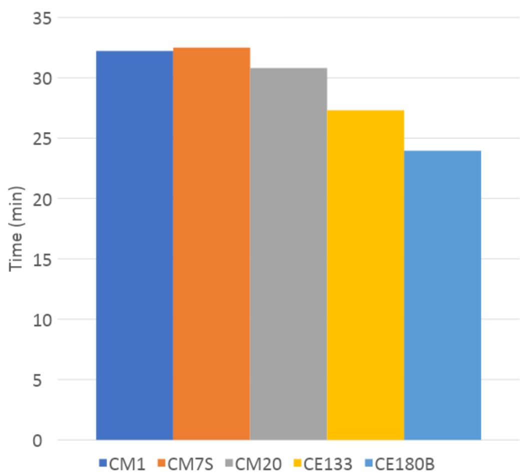

Figure 8: VFT navigation time by class

Additionally, a few students admitted to experiencing confusion during the tour, which they attributed to overlooking the instructions and being unfamiliar with the action objects.

Overall Experience:

Most students found the immersive VFT experience interesting, innovative, and informative. The features they particularly enjoyed include:

1. The tour captured field activities from different stages of construction and allowed students to navigate through them within a reasonable amount of time.
2. Users could select different dates and times from a drop-down list to view the project progress at a specific location on the site with SplitScreen.
3. The highlighted "waypoint" on the floor plan made it easy to locate where you were on the project.
4. The 360-degree images enhanced the users' ability to visualize the actual construction site. The supplementary 2D images and videos were also highly informative.
5. The action objects and the robotic voice of the tour narrator gave the VFT a futuristic feel.

Recommendations for Future Improvements:

In their feedback, students suggested that future VFTs could be improved by incorporating additional 360-degree field images, including images of the finished project. Some students also recommended including a checklist in the tour to help users ensure they don't miss any important scenes or project information.

Discussion and Conclusions

As technology continues to advance, VFTs are set to become an increasingly important tool in AEC education for promoting hands-on learning and addressing a wide range of knowledge and skills essential to AEC professionals, such as 3D spatial exploration and reasoning, design review and communication, code compliance, construction planning, safety management, field inspection, sustainability, and more. In contrast to traditional field trips that only offer a snapshot of a site at the time of the visit, VFTs can provide project documentation over an extended period, and release the information to learners in a controlled manner, offering a more comprehensive and flexible learning experience.

This paper reports on a follow-up study conducted to evaluate the effectiveness of immersive VFTs in promoting construction field knowledge transfer. Compared to the previous prototype, the current VFT delivers content through a broader range of media types and shows site activities happening at different stages. The assessment results demonstrated that the proposed VFT was highly effective in facilitating technical knowledge acquisition among the students. Furthermore, the results indicated that the VFT was particularly beneficial for medium-level students in enhancing their performance.

Despite the many promising benefits, it is worth noting that the delivery of information through various media types in a VFT can be a complex and potentially overwhelming experience for users. To mitigate this issue, incorporating a checklist feature into the VFT is recommended. This feature can serve as a guide to help users keep track of essential project information, ensuring that they do not miss any critical details or tasks. The checklist should be designed to be user-friendly and easily accessible, allowing users to refer to it at any point during the tour. Additionally, future VFT development should also consider incorporating other interactive features, such as quizzes or interactive simulations, to enhance the engagement and learning assessment of the users. With thoughtful curriculum design, VFTs can be seamlessly integrated into AEC courses and linked to specific learning outcomes.

Lastly, for VFTs to be most effective, project-specific content is vital. In the long term, creating a shared VFT database could be a valuable resource center for AEC education. Such an effort would provide students, faculty, and industry professionals from various institutions and organizations with collaboration opportunities, promoting authentic cross-disciplinary learning experiences. The availability of a centralized VFT database would also reduce redundant development efforts and facilitate more widespread adoption of VFTs.

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