Comparing 360° Virtual Reality Learning Configurations for Construction Education

J Kim
Auburn University, Auburn, Alabama, United States

Abstract. Virtual reality is rapidly becoming an effective tool for training in construction. Hazardous environments can be simulated and used for training purposes without endangering students. Furthermore, these virtual environments can be saved and re-used, on-demand, allowing students to observe temporal changes to an environment that would normally require multiple visits to a real project site to achieve. While the virtual construction site visit should not be considered a replacement for the real thing, some site visits get passed over because they are costly and logistically difficult to coordinate. Having options would be desirable. Virtual reality construction site visits using 360° photographs are a novel approach toward substituting for the real thing – yet they can be ineffective. Therefore, considering this media as a replacement for the real experience is not advisable – without some additional upgrades. This research documents a between-groups experiment that compared student’s self-reported learning performance when using 360° photographs that were annotated versus 360° photographs that were not annotated. The annotations included pop-ups, visual cues, audio clips, video clips, and quizzes to direct the learning when viewing the 360° photographs. Results indicated increased performance with the students that used the annotated 360° photographs. This study anticipated a difference in performance between the two groups and therefore used eye tracking technology with the students that used the non-annotated 360° photographs to obtain a better understanding of why their achievement differed.

1. Introduction
Instructors of construction management programs recognize the uniqueness and importance of the construction field trip that is used to augment the passive teaching that occurs in the classroom [1]. The construction management student gains valuable experience from a field trip in much the same way as a medical student that visit a hospital. However, there are many challenges in managing a successful field trip [2] and these challenges often become excuses for not incorporating the field trip in the curriculum. Therefore, it is imperative that we find ways that broaden the student’s experience base and makes the task of incorporating these experiences less burdensome for the instructors. With this need in mind, this paper focuses on the betterment of the virtual construction site field trip.

2. Background and Research Rationale
There is an ever-growing collection of research studies that examine the use of virtual reality (VR) for training and general education. To begin this examination, there needs to be a distinction made about the various realities that are available and the content used to create them. Furthermore, there needs to be an understanding how the cognitive ability of humans are affected when using technology tools to increase learning performance.
2.1. A Perspective of Virtual Reality

It is not uncommon nowadays to confuse the various types of virtual and augmented realities that are available. In their seminal study on classifying the “continuum” of “reality-to-virtuality”, Milgram et al. [3] put forth a concept that is used in nearly all VR research to define how reality is experienced when using different technologies. Their spectrum defines everything from absolute reality to fully simulated reality. Considering the technologies involved in making reality virtual, it is generally understood that VR devices tend toward fully simulated reality – the computer mimics almost all of what the user experiences. Albeit there is also a spectrum of how much reality is simulated in a virtual environment and Kim et al. [2] examined the immersion of VR devices. Figure 1 illustrates the most common types of modalities of VR used and aligns them based on their level of immersion [4], presence [5], and telepresence [6].

![Figure 1](image)

**Figure 1.** Comparison of Immersion, Presence, and Telepresence (I.P.T.) in various modalities with today’s VR technology [2]

From their figure, the reality is more engrossing when devices on the right side of the spectrum are used. Therefore, devices that fully replace the user’s view, such as the head mounted VR device, will render the most immersive experience that also gives a sense of truly being in the simulated environment, thus increasing the realism of the experience.

2.2. An Educational Challenge for Virtual Reality

VR can be an effective educational tool as has been indicated in the research [6]-[9], yet there are others that have suggested that for the VR to properly enhance learning, there are some key relationships between people and their environment (i.e. the difference between the real environment and the virtual environment) that may lead to “counter-intuitive” findings for supporting VR as and effective training tool [10]. Li et al. conducted a systematic literature review concerning mixed realities used to train construction safety and identified the following challenges faced when using VR:

- Hardware and software limitations
- Insufficient connectivity
- Complications due to hybridized training (some virtual and some non-virtual)
- Symptomatic effects (motion sickness)

These are significant factors for a technology that is viewed as technical and difficult to implement [2]. Therefore, there remains much work that can be done to research where VR can be used most effectively in the training and educational process.

2.3. Technology and Cognitive Load

The factors enumerated in the previous section are significant, yet one must also consider that people can become cognitively “overloaded” or distracted [11] as they incorporate the use of technology in their learning experience. The cognitive load can be so overwhelming that it prohibits the student from storing newly obtained information from their learning experience [11]. Despite this undesirable outcome when using technology in the classroom, if applied properly, it has the potential to augment the learning experience. As Kim et al. [12] found in their research using augmented reality, they observed that while students exhibited some learning improvement when using extended reality (XR)
tools to assist in their understanding of spatial skills they also discovered that the student’s perceived a favorable outcome in their learning performance. In their study they indirectly measured cognitive overload by using tools that allowed students to self-report perceived effort when using the technology tools during the experiment. This method represents a novel way to measure cognitive overload and could be used in preliminary studies that seek to address the conundrum of cognitive overload.

2.4. Virtual Reality Content
The virtual environment is mostly digital, in the sense that it replaces the viewer’s perception of the world around them. Many sensory replacements can be mimicked, such as sounds, touch, motion, temperature, and smell. Everything within the virtual environment is said to be symbolic of something within reality. VR is intended to act on the viewer’s perceptions in such a way as to cause experiences and potentially feelings to encourage behavior [13]. Despite the literature that supports, or casts doubt on VR, there is an underlying notion that the content is what truly differentiates the VR experience [9], [5, (p.1249)], and has effect on the learning experience. Instead of merely creating a virtual environment and testing if the outcome had a benefit or not, there needs to be a more thoughtful approach toward measuring the content that is represented and its impact on the VR learning experience, currently the research is lacking in this attribute of the technology’s use.

2.5. Research Rationale and Objective
VR, among other XR technologies, is finding new opportunities as a useful tool for enhancing the learning process. Using VR in the classroom encourages active learning pedagogies that liven the learning experience for students [14]. There are tangible incentives proven from past research that encourages more research in the use of VR in the classroom [7]–[9]. Therefore, aligning a need to increase experiential learning with a method that makes it more available for the student would be prudent.

The objective for this research study was to ascertain the effectiveness of using 360° photographs as a supplement to the construction site field trip. Because content has been demonstrated to be an important element in the success of VR in the classroom, this study will undertake a between groups examination of content that contains annotated features (pop-ups, visual cues, audio clips, video clips, and quizzes) versus content that is not annotated. The researcher anticipates that the annotated content will result in higher self-perceived performance and so a further examination the students using the non-annotated 360° photographs would elicit a better understanding of why their achievement may differ.

3. Methodology

3.1. Demographics
This research included, for convenience, students from a 4-year construction management program in the Southeastern United States. Students that graduate from this program are sought for employment in the commercial construction sector of the US. Table 1 below summarizes the characteristics of the population for this study.

| Characteristics       | TEST GROUP VR Experience Included Annotations (n=64) | CONTROL GROUP VR Experience DID NOT Include Annotations (n=17) |
|-----------------------|--------------------------------------------------------|---------------------------------------------------------------|
| Age Group             |                                                       |                                                               |
| Younger than 19       | 1 (1.6%)                                               | -                                                             |

Table 1. Student Demographics


|                | 20 – 25 years | 26 – 30 years | 62 (96.9%) | 1 (1.6%) | 16 (94.1%) | 1 (5.9%) |
|----------------|---------------|---------------|------------|----------|------------|----------|
| Gender         |               |               |            |          |            |          |
| Female         | 4 (6.3%)      | 60 (93.8%)    |            |          |            |          |
| Male           |               |               |            |          |            |          |
|                |               |               |            |          |            |          |
| Academic Year  |               |               |            |          |            |          |
| Postsecondary  |               |               |            |          |            |          |
| Junior (3rd)   | 49 (76.6%)    | 15 (23.4%)    |            |          |            |          |
| Senior (4th)   |               |               |            |          |            |          |
|                |               |               |            |          |            |          |
| Experience     |               |               |            |          |            |          |
| Working in the |               |               |            |          |            |          |
| Construction   |               |               |            |          |            |          |
| Industry       |               |               |            |          |            |          |
| Yes            | 44 (68.8%)    | 9 (52.9%)     |            |          |            |          |
| No             | 20 (31.3%)    | 8 (47.1%)     |            |          |            |          |
| Have You Ever  |               |               |            |          |            |          |
| User VR in the |               |               |            |          |            |          |
| Classroom?     |               |               |            |          |            |          |
| Yes            | 44 (68.8%)    |               |            |          | 11 (64.7%) |          |
| No             | 20 (31.3%)    |               |            |          | 6 (35.3%)  |          |

3.2. Controlled Experiment
A controlled between-groups experiment was arranged so that the students from each group were divided and separated from one another to prevent either group from knowing what type of VR experience they would encounter. The test group (TEST) viewed a 360° photograph that included annotations (annotations are described in the next section of this paper). The control group (CONTROL) viewed a non-annotated 360° photograph. Both groups were given a head mounted VR headset (Oculus Quest with hand controllers) and asked to view the 360° photograph (see Figure 3a). The students were allowed up to ten minutes viewing time and upon completing their viewing were asked to self-report their performance in understanding what they observed. Figure 2 illustrates the experiment workflow.

3.3. 360° Photographs and VR Annotations
This section will describe the elements included in the TEST environment and constitutes the independent variable of the study. The elements described here were viewed by the students in the TEST group by using the head mounted VR device mentioned in the previous section of this paper.

3.3.1. The 360° Photograph
The same 360° photograph was used for both the TEST and CONTROL groups (see Fig. 3a). The subject of the photograph was a music auditorium project that was currently under construction. A student could change their viewing perspective by rotating their head. The VR headset would respond by displaying a different perspective of the 360° photograph. The effect of the simulation mimics a person viewing their surroundings as if they were at the actual construction project site. For the purposes of this study, the photograph was a static image that did not contain any motion or audio, aside from the video
annotation (see section 3.3.2. Annotations) included in the TEST group’s viewing. Fig. 3 illustrates the 360° photograph and how it was viewed by the students.

**Figure 3.** The 360° Photograph (a) and Students Viewing by way of a VR Headset (b)

### 3.3.2. Annotations

The TEST group’s VR experience included various annotations that were part of their VR environment. The annotations appeared as graphical notations in the 360° photograph that the students could interact with using a hand controller. The following annotations were used in this experiment and are depicted in Figure 4.

- **Textual Annotations** – these annotations were staged as visual pop-up text boxes that students could read and obtain more information about what they were currently viewing.
- **Video Annotation** – these annotations were designed to play a short video of a construction topic that also included an audio track.
- **Quiz Annotation** – this annotation was used to assess a student on some element of the VR experience – they interacted with the quiz with their hand controller and were given immediate scoring feedback from their response.

**Figure 4.** Annotations used with the TEST group

(a) Textual Annotations, (b) Video Annotations, and (c) Quiz Annotations
4. Results
After viewing the 360° photograph in the VR headset, all the students (TEST and CONTROL) were asked to self-report learning performance. Figure 5 summarizes the self-reported learning performance on nine subscales using a 5-point Likert scale.

![Figure 5. Self-Reported Learning Performance on Nine Subscales](image)

5. Analysis and Discussion
The student’s self-reported scores shown in Fig.5 demonstrates a higher perceived learning performance by the TEST students in all but one category. It is presumed that Q8 (Rate the quality of color and texture) was ranked lower because the students may have been rating the annotations and not the 360° photograph. The CONTROL group did not have annotations and their responses would have been directed only at the quality of the 360° photograph. The annotations did appear to use a lower resolution graphics, due in part to a technical issue when converting the annotation images from a 2D layer to a simulated 3D layer of the 360° photograph. While this self-reporting survey was not statistically compared, it does represent a tendency, from the student’s experience, that the tool was configured in such a way to enhance their perceived learning experience. As previously mentioned, this was not unexpected. Therefore, the researcher chose to further investigate the CONTROL group’s VR experience.

5.1. Eye Tracking Analysis of the CONTROL Group’s Experience
Half of the participants from the CONTROL group were asked to participate in a follow up examination using head motion tracking sensors and eye tracking sensors that were attached to a different VR headset (HTC Vive). The same 360° photograph (see Figure 3a) was presented to the students again and they were asked to freely observe their surroundings – as they did before. The gathered motion and eye tracking data were compiled into heat maps so that the researchers could observe areas of interest to the students. It was anticipated from this follow up examination that the researcher could identify regions of the 360° photograph that the students seemed more interested in and thereby inform where annotation elements could be placed to better suit the student’s interests and in-turn their perceived learning performance. An example image included in Figure 6 illustrates regions of ductwork in the project that
students seemed most interested in by indication of their gaze in the eye tracking VR headset. The area of the heat map colored in red indicated the highest viewing intensity and diminished from there to yellow then to green which indicated some viewing, but less than yellow and red. These areas represented focus areas for content authors to add more annotations that could further educate the students about what they are looking at when presented with a 360° photograph.

![Figure 6. Areas of Interest Heat Map of a 360° Photograph](image)

Some limitations in this study existed and should be considered if this study were to be expanded.
- This experiment was conducted during the height of the world-wide COVID epidemic (from 2020 March to 2020 May). This required the researcher to enhance measures requiring social distancing and limiting personal contact. In doing so, the population pool was relatively small and severely unbalanced (TEST n=64 and CONTROL n=17). While not tested, this imbalance may yield different results if the population were to be expanded and the groups were more evenly balanced.
- The results from the eye tracking study were not reincorporated into the original study and re-tested to determine if the eye tracking data could be useful in determining where annotations should be placed in the 360° photographs. This is a recommendation for further research and could validate the effectiveness of the workflow presented in this paper.

6. Conclusion
The objective of this research study was to examine a supplement to the construction project field trip that students commonly take to augment their classroom learning. These field trips can be costly, time consuming, and unsafe for students [1] but we should not discontinue them altogether. We need to find solutions that supplement the classroom field trip. This research study examined the use of 360° photographs that were annotated and non-annotated and compared the perceived learning experience from their use. Overall, the annotated 360° photographs provided a better perceived learning experience, and the data suggests that the non-annotated versions were also significant as a learning tool. As this result was somewhat expected the researchers sought to understand if a method could be employed to close the gap between the two different VR experiences (annotated versus non-annotated). It was determined that using head motion and eye tracking software on non-annotated viewing users while they were observing 360° photographs could be a useful workflow to add annotations to a 360° photograph.
Again, the overall intent of this research study is not to advocate for the replacement of the construction site field trips. Those experiences offer intangible learning opportunities despite their difficulties in being coordinated and executed [1]. However, it is because of these shortcomings that alternatives for the construction site field trip must be sought out. Within this study, the researchers considered the content of a VR experience as a significant element of the learning experience and in so doing advocate that the comprehensiveness of the content is also a significant contributor to the learning experience. Furthermore, the researchers advocate a workflow like the one designed in this study as a method for testing the content in a VR experience that can improve a student’s perceived learning outcome.

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