

Use of *Immersive Navigation in Virtual ENvironment (INVEN)* to Improve Students' Understanding of Building Components and Materials

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To improve student learning, construction educators are using virtual reality. The improvement of the technology and economic feasibility of the devices have increased their use in the recent years. This study looked into the potential of Immersive Navigation in Virtual ENvironment (INVEN) to complement traditional teaching practices to provide immersive learning about building components and materials to the construction students. A survey was conducted among a group of undergraduate students by allowing them to explore INVEN created as a pilot. The survey was conducted to capture the students' learning engagement, understanding of 3D spatial layout, user experience, and perceptions of educational effectiveness. The preliminary results show positive feedback on the usability of INVEN and suggest the possibility of developing the technology as a self-paced learning tool with embedded information.

Keywords: Virtual environment, virtual reality, building material, construction education, experiential learning, immersive learning

Introduction

The modern construction professionals require a variety of knowledge and skill sets that will allow them to navigate through the complex construction industry effectively. In turn, construction programs must prepare graduates with the practical and theoretical skills required by the industry. The need for hands-on practical experience in the field is obvious and employed by most universities at the undergraduate and graduate level programs. "Traditional hands-on learning, site visits, and practical work experience is viewed as a very powerful experiential learning tool for construction management students" (Lucas 2017). If we further explore the success of experiential learning, it becomes obvious how heavily dependent the acquisition of knowledge is on visualization. Context plays a key role in constructing the perception of environment. The stronger the perception of environment is for the students, the more easily they will be able to apply abstract concepts and processes. The closer the students come to actually participating in the activity, the more understanding they will have of the environment. The ability to visualize the built environment and understand building construction processes is critical for students in the architecture, engineering, and construction disciplines. Students are often challenged to visualize three-dimensional structures and understand the complex spatial and temporal relationships related to building these structures (Nikolic 2009). Experimental learning activities carry many unavoidable constraints, such as limited resources, material costs, as well as space and time concerns. Consequently, construction programs are forced to find new methods to complement the traditional lecture-based educational delivery method. Interestingly, we are seeing a push to integrate data rich virtual environments into the construction curricula, which in turn, fulfils the visualization component of experiential learning.

Currently, research is gaining speed and breadth concerning virtual reality (VR). Research reveals VR can take a variety of forms including: Building Information Model (BIM), game constructs, immersive environments (Oculus Rift), interactive augmented realities, and telepresence. The most common form of VR being studied in construction education is BIM. It is ubiquitous in the commercial construction industry and research suggests a positive potential for education. However, BIM is extremely rigorous and requires extensive training to operate most BIM programs at a basic level. This research will focus on the virtual environment, specifically, the 360-degree navigable technology commonly used in real estate.

Many first and second-year construction students lack a fundamental understanding of basic building components. These gaps in understanding must be filled prior to acquisition of higher-level concepts. Commonly, during lecture, instructors spend a brief period reviewing these fundamentals before moving into new material. There is little time to ensure all students have grasped these fundamental concepts, but understanding certain fundamentals is vital to the success of the students. Navigable virtual environment may offer a unique tool for students to view and interact with building components and materials. The objective of this study is to determine if a navigable virtual environment will complement the traditional classroom lecture to allow students to fill gaps in fundamental knowledge and better understand the more advanced concepts within the construction curriculum.

The study will focus on the current junior class of a construction program in the Midwest. Quantitative and qualitative measures were drawn to explore the students' feedback on the efficacy of the virtual environment to complement traditional lecture-based delivery method used in construction education. This study is limited to the preliminary phases of fact finding and will not address a number of variables that could affect the outcome of the study. However, this study will hopefully point to the value of visualization of the built environment for the construction students.

Hands on, practical experience is widely considered to be one of the most effective teaching methods for construction programs. "However, this approach is often hindered by logistics and is insufficient in duration for students to gain exposure to the various construction stages and gain a deeper understanding of the multiple facets of a building project" (Nikolic 2009). These constraints do not excuse educators from attempting to create the hands-on learning experience for their students. Technology is allowing educators to recreate the built environment in different ways. Creating an interactive 360-degree virtual environment will allow students to explore the built environment to fulfill many of the essential components of experiential learning. The technology allows students to access this tool almost anywhere, and in turn solves many of the constraints common to experientially learning. This paper presents a review of pertinent literature related to the use of virtual reality in construction education, followed by details of the technology adopted by the authors, and presenting the feedback of the students on the efficacy of the technology to offer experienatial learning to complement traditional lecture-based delivery method.

Literature Review

"Humans learn by having experiences, by interacting with their environment and using their senses to derive information from the world. Virtual reality is a technology that replaces sensory input derived from the real world with sensory input created by computer simulation." (Christou 2010). The challenge for many educators is creating the setting and situations to allow students to have these experiences. As early as the 1990s, educators have recognized the potential virtual reality could offer. "Virtual reality has the potential to move education from its reliance on textbook abstraction to experiential learning in naturalistic settings" (Helsel 1992). This prophetic statement encapsulates the current state of education and technology. Although textbooks are still a valuable and utilized resource, modern education is migrating away from the lecture and text based traditional education, to differentiated instructional styles based on student needs. VR allows instructors to deliver content in a personalized and immersive way. A review of the current research has revealed the ubiquitous use of VR in education. From early childhood education to medical school, VR has infiltrated all levels, disciplines, and modes of education. This literature review will attempt to validate the use of VR in construction education by exploring several examples in various educational disciplines. We will then address the current use in construction education, followed by the apparent benefits and inherent challenges of VR in construction education.

Medicine as an educational discipline has a unique challenge. The complexity of the medical field demands an educational rigor unlike any other academic disciplines. "It involves mastery of competencies that enable the individual to effectively perform occupational activities to the standards expected in the professional environment" (Kamphuis 2014). Medical education must provide ample opportunity for students to train in a workplace environment. Experiential learning is a priority for medical schools, but patient safety is a priority for medicine. Allowing students unfettered access to patients is not only dangerous, but in most cases illegal. This is where VR has begun to play an important role. One example is the use of augmented reality in human anatomy education.

Miracle, nicknamed the magic mirror, is an augmented reality system which allows students to explore the human anatomical structure of a participant. The volunteer stands behind a high definition screen and Miracle displays the selected anatomical structures while mimicking the volunteer's movements. “It [Miracle] provides a meaningful context (the whole human body) compared with textbook descriptions and stand-alone graphical presentations of anatomical structures (e.g. pictures, plasticized models). And it uses real-life material which can be applied in similar ways as in the professional context. This implementation of augmented reality technology is promising because of its strong visualization and manipulation features. But, it does not yet do justice to the full potential of augmented reality technology” (2014). This example of VR use illustrates the problem-solution dynamic. Many institutions cannot afford to buy human anatomy sections and cannot maintain or house human cadavers. Consequently, the lack of experiential learning within those human anatomy classes presents an obvious problem. VR is seeking to bridge the gap by offering a low cost, interactive, and effective solution to these constraints.

Engineering education has always been at the forefront of innovation concerning curriculum and instructional technique. The industry demand for more capable graduates is pushing higher education to continually develop new techniques and innovative training tools. Higher education is also tasked with ensuring student safety, controlling costs, and remaining timely. VR offers significant solutions to these challenges. “Virtual reality provides an innovative educational instrument for science that enables students to assess the value of their solutions requiring them to apply relevant knowledge and understanding to a particular real-life complex problem. The interactive 3D environment also provides a suitable tool to break a complex problem into secondary ones and establish relationships between them to create a unique, realistic and practical solution” (Abulrub 2011). Abulrub (2011) describes the use of VR integrated into the training and review of vehicle prototypes. The New Product Introduction process (NPI) utilizes virtual images of prototypes created by a variety of 3D programs, to allow students to review and analyze digital models. Working with these models boosts the confidence of students when making decisions during the modeling phase. Students are then able to create prototypes with a certainty which would otherwise be absent. Engineering education is continuing to evolve to produce capable and innovative graduates. VR is simply a tool that resourceful schools are leveraging to create these graduates.

The growing complexity and scope of the construction industry is creating a demand for capable graduates with a variety of skill sets. Construction programs are responding to this demand in a variety of ways. As has been previously stated, many construction programs utilize hands on experiential learning to convert theoretical knowledge into practical knowledge and skill. However, the experiential learning model comes with inherent constraints. Research into construction education exposes the use of technology, specifically VR, is allowing institutions to give students virtual experiential learning. One of the most immersive examples is found on the Penn State campus. The ICon lab leverages BIM models to allow student exploration of building process and construction in the virtual environment. “Virtual reality (VR) has become an increasingly valued technology that offers students the opportunity to visualize and explore 3D information and data in a dynamic, real-time environment. At Penn State, our students are encouraged to engage in exploration of design and construction processes in the Immersive Construction (ICon) Lab on a large three-screen stereoscopic display to facilitate better visualization of building design and construction processes” Nikoli (2011). According to Lee et al. (2014), since 2006, three different Virtual Construction Simulators have been designed and tested using the ICon Lab, which have shown promising results.

Another VR contribution to construction education is the Interactive Building Anatomy Modeling system or IBAM. IBAM was modeled after the gross human anatomy education which utilized human cadavers to give students physical access to the human body. In comparison “the IBAM concept is comprised of an anatomy approach and construction approach, along with a hierarchical breakdown structure, which classifies building objects according to element, space and work result criteria” (Park et. al. 2016). Essentially, IBAM is a tool for educators to dissect a BIM model into appropriate phases for teaching. The 3D model is taken apart so as a student can observe a building by its parts. For example, a foundation can be deconstructed into its individual parts, a 3D model of the dissection is then rendered, and the student then observes the concept of a foundation as parts of a whole.

Park et al. (2015) could study the effect of the VR technology on 30 undergraduate architectural engineering students. Park et al. (2015) concluded that IBAM is more effective than the traditional method. In other words, students participating in the class using IBAM had higher score than those joining the traditional class based on whiteboard lectures. This objective evaluation partially demonstrates that IBAM can improve the construction education process and help learners to acquire construction knowledge." Illustrated by the previous two examples, VR has a wide range of benefits for construction education.

The growing body of evidence for the benefits of VR in all disciplines of education is pushing academia to develop new and exciting VR systems. VR does not come without its own inherent challenges. VR systems can be very expensive to create and maintain. "Recently, VR has been extensively applied to enable the experiential perception of simulated environments and elements. To solve aforementioned problems in construction education, several studies have adopted VR; however, these have predominantly been of a state-of-art of visualization nature, solely focusing on what VR tools can offer technically" (Park et. al. 2015). As Park et al. (2015) pointed out, the state-of-the-art technology comes with a price tag many universities cannot or will not pay. Money is not the only challenge universities face. The technical aspects of VR may require extensive and time-consuming training. Much of the current literature regarding VR in construction education focuses on BIM. BIM is by nature very complex and intricate. Experienced users have to develop skill sets over many years and require extensive training. Faculty, who are already over committed, may not have the time or desire to learn not only BIM programs, but then in turn a VR system. Additionally, student learning exercises that require knowledge of BIM automatically limit student participation to those students who have had formal BIM training. However, the benefits of VR within construction education are undeniable. The motivation of this research comes from this undeniability and the lack of less technically demanding VR systems.

Developing this navigable virtual environment is necessary because of the clear benefits VR offers construction education, but also because it is a simple, user friendly way to offer students a hands-on, interactive learning experience. Traditional lecture-based methods lack the experiential component needed for meaningful learning, while the true hands-on practical construction learning experience is fraught with constraints. It is our hope that these virtual environments will help entry level students fill gaps in prerequisite knowledge and allow educators a technically simple way to utilize VR. Immersive reality is simply more involved. The interface eliminates all sources of distraction and allows the user to explore and interact with the environment as though they are physically present.

Motivation

This study was initiated from the need felt by the authors in enhancing the traditional teaching approach adopted in most of the construction programs comprising of lectures, site visits, building mock-ups, and sharing photos and videos. Students coming with some knowledge or background in construction feel more at ease in visualizing the building components and materials in comparison to students who have minimal or no background in construction. While making frequent site visits can be an option to resolve this disparity of knowledge in the students, but sometimes site visits can prove to be time consuming and a logistical hassle. This led to the search of other options of bringing similar immersive experience comparable to a site visit to the students. At the time of creating the Immersive Navigation in Virtual ENvironment (INVEN) on a pilot basis, the authors envisioned building a library of virtual environments focusing on components pertinent to various CSI divisions to serve as a key piece of the construction curriculum.

The capability of the virtual environments to offer an immersive experience without the need for a physical mock-up is one of the motivations for the authors. The link to the virtual environments can be shared with the students without any additional expense. With no need for any additional lab space or other necessary resources for building physical mock-ups, the virtual environments can provide the same information. The students can enhance their experience in the immersive learning by using Google Cardboard to navigate through these virtual environments.

Methods

Development of Virtual Environments

The process of creating the navigable virtual environments involved capturing 3D scanned images of the spaces followed by converting them to point cloud models. If needed, the point cloud models can be overlaid with BIM models. However, for the present study, the authors did not investigate that functionality of the models. The scanner used for the purpose (Figure 1), mounts to a tripod and needs to be leveled to allow the scanner to properly capture and align the data from the scan. Once the scanner is properly set up and adjusted, it must be connected to the manufacturer's proprietary application via an iPad. The scanner will automatically connect to the application and when activated rotates 360 degrees capturing everything in its surrounding field of vision. The scanner can be moved between eight and ten paces from one scan location to the next and placed/adjusted as was done previously. This process is repeated several times depending on the size of the space and how rich the user would like the data. More scans provide dense point cloud and higher clarity in the image, which in turn offers several features that we will discuss later in this section. After completing the appropriate number of scans the images are uploaded to the manufacturer's proprietary application. It is important to note here that scanning in outdoor environments is challenging due to the interference of the sunlight with the scanner and difficulty in defining the boundaries of the space.

Figure 1: 3D scanner used and a screen capture of the virtual environment

The manufacturer's proprietary application allowed the authors to add information about the building components visible in the virtual environment (Figure 2). The information added can be in the form of a pop-up text box or any linked videos. In order to embed these information, the point cloud model has to be dense that can be achieved by taking multiple scans. As the user navigates through the virtual environment, they can examine the components and at the same time get information from these text boxes and the videos.

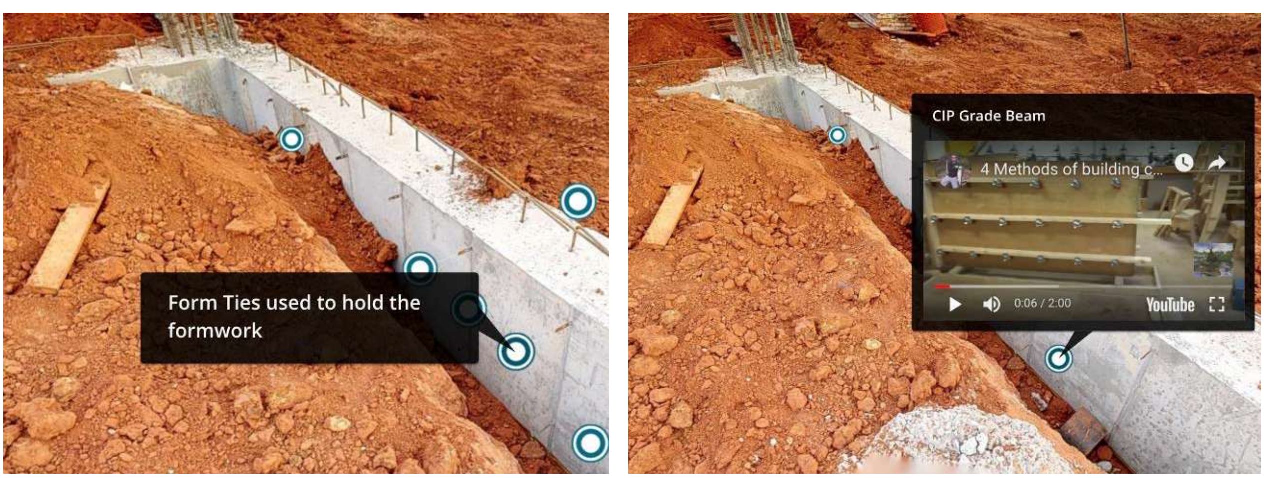

Figure 2: Pop-up text boxes and videos added to the virtual space

A construction site which was undergoing gypsum board installation was selected for the pilot. Due to the irregular shape of the space, scans at eight different locations were taken and uploaded to the manufacturer's application to be stitched together to create the model of the virtual space. The application allowed to create a web link that was shared with the students for navigation and exploration.

The students could navigate through the virtual environment using their laptops as well as using affordable headsets such as Google Cardboard (Figure 3). Upon activating the simulation, the user is placed inside the model and gets the feeling as if he/she is viewing the space from where the scanner was physically placed while capturing the scans. The user navigates through the space by changing his/her location from one scanner position to the next. The simulation creates a floor plan of the scanned space showing the different locations where the scanner was placed while capturing the scans. The simulation provides the users option to select their location of choice and also to switch between the locations.

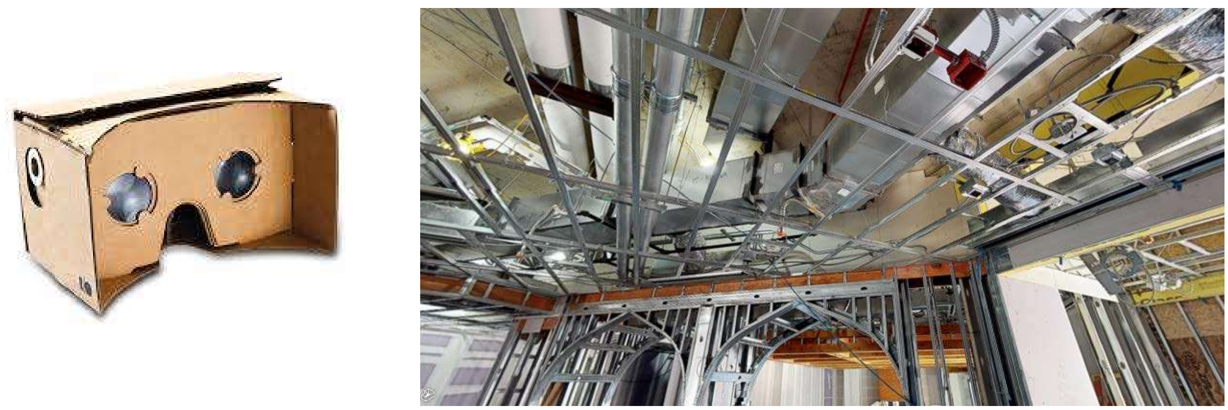

Figure 3: Google Cardboard and screen capture of the navigable virtual environment

Data Collection & Analysis

After sharing the web link to the virtual environment with the students of a construction program, a survey was conducted to gather information related to students' learning engagement, understanding of 3D spatial layout, user experience, and perceptions of educational effectiveness. The group of students included in the survey comprised of those in their junior standing and graduate students. This group of students was selected as the group took the Print Reading/Quantity Surveying course with the first author in the previous semester. The author followed traditional lecture-based approach to teach the afore mentioned course. Thus, this group was deemed most fitting to compare the benefits of using the navigable virtual environment for construction education in comparison to the traditional teaching practices.

After allowing time to the students to navigate through the virtual environment, they were invited to complete an online survey. A total of 48 students were invited to complete the survey on a voluntary basis and the authors received 46 completed responses. The survey questionnaire was divided into 4 categories using five point Likert-type scale questions (5 = strongly agree; 1 = strongly disagree). They were also asked two open ended questions as part of the survey. The results of the survey are presented below in Table 1.

A high level of learning engagement was evident from the survey responses. One of the purposes of the study was to see how INVEN could increase the engagement of the students. While the responses to the questions related to learning engagement showed wide ranges (of 1 – 5), the students showed positive engagement with mode of 5 for active participation and finding value in the activity. The engagement of the students was gauged from their responses to the questions: "I surfed the internet, checked social media, or did something else instead of doing the activity," and "I rushed through the activity." In response to those questions, most of the students selected "strongly disagree" indicated by a modal value of 1. The authors are encouraged from these responses as the long-term vision is to create a library of INVEN focusing on different CSI divisions as supplemental materials to be provided to students.

The survey asked questions about the efficacy of INVEN in helping the students understand the three-dimensional spatial layout of the space. One of the purpose of this study was to see how students' perception of space, ability to visualize the building components and materials of construction were facilitated by the navigable virtual environment. Though the authors did not do any pre-test or post-test to measure the efficacy of INVEN, the students' perceptions about INVEN in this regard were high with modal value of their responses equal to 5 (which is equivalent to "strongly agree"). The authors are specifically interested on this aspect as historically many first and second-year construction students lack the fundamental understanding of basic building components and cannot visualize them.

Overall, INVEN was identified as easy to find ways around and of excellent image clarity with a tight range (of 4-5) and mode of 5 (strongly agree). The other questions related to user experience received highly favorable ratings from the students with mode of 5 (strongly agree). The virtual space provided to the student for the pilot was purposefully complex to see if the students find the user experience favorable or not. This is a promising result as the authors believe the user experience, if not favorable, might be a distraction for the users from focusing on the building components and the materials in the virtual space.

Table 1: Summary of the students' responses

Questions	**Range**	**Mode**	**Mean**	**Std. Dev**
	5 = strongly agree; 1 = strongly disagree			
LEARNING ENGAGEMENT				
I participated actively (or attempted to)	3 – 5	5	4.6	0.57
I saw the value in the activity	1 – 5	5	4.5	0.88
I felt the time used for the activity was beneficial	2 – 5	5	4.5	0.75
I enjoyed the activity	2 – 5	5	4.5	0.74
I surfed the internet, checked social media, or did something else instead of doing the activity	1 – 5	1	1.6	1.10
I rushed through the activity	1- 5	2	2.1	1.15
UNDERSTANDING OF 3D SPATIAL LAYOUT				
I developed a sense of space in the 3D virtual space	2 - 5	5	4.5	0.69
I could visualize the building components through the virtual space	2 - 5	5	4.7	0.68
The virtual space conveyed information about the materials used and components of the building	3 - 5	5	4.6	0.56
USER EXPERIENCE				
The navigation application was user friendly	3 - 5	5	4.6	0.57
I could easily find my way around in the application	4 - 5	5	4.7	0.48
The visual clarity of the space was excellent	4 - 5	5	4.8	0.39
There was minimal movement lag in the simulation experience	3 - 5	5	4.5	0.64
EDUCATIONAL EFFECTIVENESS				
You are satisfied of the learning through the 3D virtual space	4 - 5	5	4.6	0.56
The 3D virtual space will be favorable for learning construction materials and methods	3 - 5	5	4.8	0.59
Your knowledge on construction materials and methods will increase if we use similar virtual 3D spaces during instruction	3 - 5	5	4.6	0.56

Conclusion

This paper presented the process of development of a virtual environment to allow the students to navigate through the environment and observe the various building components and materials. A construction site which was undergoing gypsum board installation was selected for the pilot. A web link to the virtual environment was created and shared with the students to get their feedback on the usability of INVEN to complement traditional lecture-based teaching approach in construction curriculum. The students were surveyed using five point Likert type scale questions to measure four constructs: learning engagement, understanding of 3D spatial layout, user experience, and educational effectiveness.

The preliminary results show increase in learning engagement of the students with most of them finding benefit and value in the technology as a teaching tool and participated actively. The most benefit identified was understanding the building components and materials. This was resonated in the responses of the open-ended questions where majority of the students identified materials & methods, print reading/quantity surveying, estimating, and scheduling as probable courses where INVEN can be used effectively and be most beneficial to students. As expected, several students mentioned the technology will be very helpful for students who do not have much of construction background. The students responded very positively about the ease of navigation in the virtual environment and the clarity of the images.

Overall, the responses of the students based on the pilot were positive and provided impetus that INVEN can be developed to complement the traditional lecture-based teaching approach in construction curricula. The capability of the virtual environments to offer an immersive experience without the need for a physical mock-up taking up resource and space will be advantageous to any program. Further efforts will be put to explore how INVEN can be developed as self-paced learning tool with embedded information in the form of texts and videos. The future goal of the authors is to develop a library of virtual environments focusing on components pertinent to various CSI divisions to serve as a key piece of the construction curriculum. With the initial investment on the scanner, the rest of the process can be conceived as cost effective. The added feature of navigating through the virtual environments using affordable headsets can make this technology more appealing to the students.

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