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Work-in-Progress—Virtual Immersion: Bridging the Gap Between Construction Management and Civil Engineering Students' Learning and Performance in Structural Analysis

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Abstract. Virtual reality (VR) has emerged significantly as a powerful tool in immersive learning, contributing to effectively comprehending complex, theoretical concepts in education. This research examines the common foundations in structural analysis coursework between Building Science and Civil Engineering programs, specifically about learning about the physical properties and structural analysis of built structures. As these concepts are often theoretical and intangible, the current study aims to examine the effects of introducing an immersive VR scaffolding tool to enhance student learning experiences surrounding these abstract ideas. The VR intervention will provide a visual representation and interaction with structural analysis principles to determine if this augments conceptual understanding for beginning students in these disciplines compared to traditional instructional methods. This work-in-progress study focuses on leveraging the benefits of VR technology to concretize the unseen elements of structural analysis and evaluate the influence on student comprehension and performance.

Keywords: Virtual Reality, Immersive Learning, Structural Analysis.

1 Introduction

In design and education, virtual reality (VR) technology holds significant relevance for engineers and architects [1-2]. VR technology in the field of education is highly effective in enhancing learning outcomes [3]. Virtual environments allow users to experiment unlimitedly, by being able to interact with the virtual objects and receive real-time responses, which bridges the gap between theoretical knowledge and practical skills [4-5]. In the context of this study, VR technology was employed to deepen the understanding of construction mechanics. This can be achieved because of the capability to interact within a virtual environment that can closely simulate real-world conditions enabling an adequate comprehension of underlying concepts [3, 6].

Anecdotal review of several course catalogues indicates structural analysis is a fundamental concept in civil engineering (CE) and construction management (CM) curricula. It is essential to understand the impact of loads on physical structures and their components. Shear forces and bending momentum concepts are integral to Structural Analysis, aiding in structural design. They facilitate the calculation of shear force and bending moment values at specific points on structural elements, such as beams [7]. A shear force is defined as a force applied to a material in a direction perpendicular to its elongation [8]. This force is exemplified by the air pressure experienced along the front of an airplane wing. Shear forces typically induce shear strain. This phenomenon is also referred to as a shearing force. A bending moment arises as a response in a structural element when an external force or moment is applied, causing the element to bend [8]. Beams, common structural elements, are often subjected to bending moments. These beams may be configured with one end fixed and the other supported, varying the impact of bending moments. This study aims to observe a marked difference in learning outcomes between CE and CM disciplines. Utilizing VR technology, this research attempts to bridge the identified learning gap.

2 Literature Review

Many researchers have concentrated on the utilization and effectiveness of virtual reality (VR) technology in construction engineering education and training [9-12]. VR serious games can improve learning structural mechanics concepts by providing challenge, enjoyment, and mastery [9]. Furthermore, using VR games to teach structural mechanics has been shown to enhance learning by offering students the chance to consolidate and deepen their knowledge through experimental activities and the development of competencies [10]. Additionally, immersive VR has been identified as a potent tool for stimulating cognitive experiences in engineering students, particularly when integrated with generative learning strategies [11].

There have been studies that utilized VR technology to teach structural engineering focusing on various concepts such as safety on a construction site, construction health and safety considerations [2, 13]. In the study, [2], the virtual experience of a steel building under construction in a virtual environment provided students with a better understanding of concepts. However, since the study utilized only photographs in the virtual space, users preferred an active environment and interactivity. In the study conducted by [13], three models were developed, the construction defect learning model, the defect inspection game model, and the construction activity game model. These models are used to teach about defects in construction sites, identify defects in a virtual environment, and identify actions that may lead to defects respectively. This study can thus help in saving and using the resources effectively. Another study focused on creating a virtual construction site where users were prompted to arrive at different locations on the site and perform tasks as per the instructions. This prepares a student with no prior experience on a real-world construction site for forthcoming potential risks on the site. The study aims to build a VR environment to deepen the understanding of the concepts of building structures. The students can learn by not only visualizing the concepts of structural analysis but also interacting with the elements and observing the results in real time. This virtual training could provide insights on areas where traditional teaching might lack such as dynamic results for a user action.

3 Research Rationale

The Computer Science – Human-Computer Interaction (CSHCI) lab at Auburn University supported the design analysis and creation of a virtual reality application that will instruct students in learning the mechanics of how the building structures work. As mentioned above, students of CE and CM are identified as different disciplines by the building industry, but structural analysis concepts are the core concepts for both disciplines. Although common, students' learning and performance outcomes of structural analysis between these disciplines may differ based on the type of teaching method in different disciplines. Thus, it could result in different levels of understanding of the same concept. Therefore, this research study aims to bridge the learning and performance gap between the two disciplines by training the students on the mechanics of how building structures work using a virtual reality simulator.

4 Methodology

Since the goal of this research is to train students of both CE and CM disciplines on the concept of structural analysis in a virtual environment, a VR application is developed using Oculus Quest. Three different types of loads for the simple beam, ranging from light, medium, and heavy, were chosen to place on it to see the effects based on the connector types. The connectors used are fixed, hinged, and roller. Three concepts of structural analysis were used, axial forces, shear forces, and bending momentum using a simple beam and connectors. As previously defined, shear force is a reaction force that is in the direction perpendicular to the extension of the beam when applied to it. The bending moment is the reaction induced in a structural element when an external force or moment is applied to the element causing the element to bend.

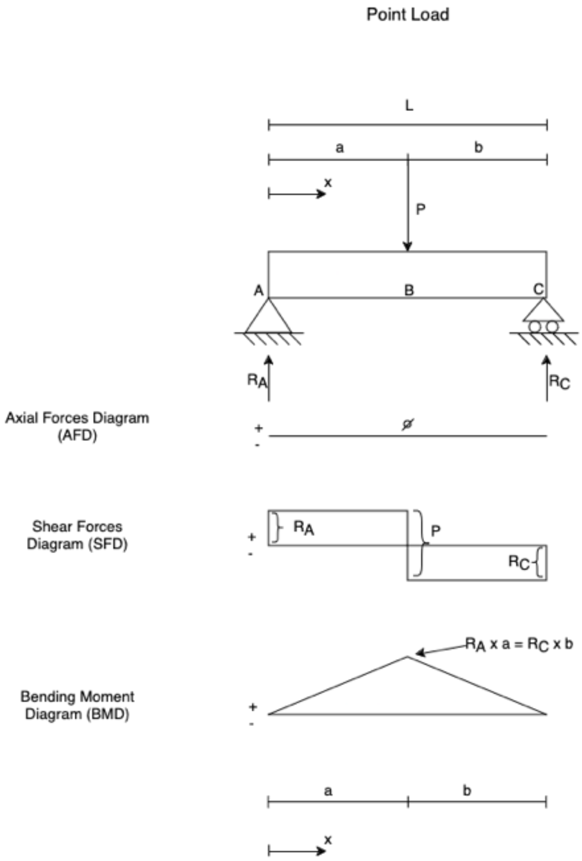

Fig. 1. Simply Supported Beam; L: length of the beam, P: Applied Load (weight), a: Horizontal distance between points A and B, b: Horizontal distance between points B and C, [L=a+b], RA: Reaction force in point A, RC: Reaction force in point C.

In Fig. 1, the load is assumed to be placed in the middle of the simply supported beam which consists of connectors on both sides (triangles shown in Fig. 1). The respective axial, shear forces, and bending momentum graphs are shown. In this study, users can place different loads on the simple beam along with different connectors on either side of it. This results in shear forces and bending moment graphs on the white canvas above the beam. This can be performed multiple times under different combinations of loads and connectors. In the testing room, shear forces and bending moment graphs are already presented to the user, suitable weight needs to be placed on the appropriate location of the beam with the correct connectors on either side of the beam. These are the basic concepts of structural analysis used can be applied to the real world. Experimenting in the virtual world gives the user dynamic results, making it easier to understand when compared to conventional methods of learning. It also allows the user to perform tasks that may be dangerous to the user or not possible in the real world. For example, a simple cannot have both connectors of type “roller”. The user is prompted when wrong choices are made. This way, the user can always go back and learn why it is not compatible.

Although the application was developed for undergraduate Auburn University (AU) students, pilot testing was performed with eight AU instructors to review and provide their expertise on the educational VR application. A short overview of the VR application was provided before getting started. Since instructors were of different backgrounds, the testing was not performed on the concepts learned but on their experience with VR for education and training, ease of use, and overall response to it. The goal of the study is to provide a common platform that can bridge the gap between the two disciplines in learning the same concepts. Because traditional methods would require the students to imagine the concepts and not view or interact with them, VR application has the potential to become a strong platform to provide better understanding. The next phase of testing will be with the AU students of CE and CM disciplines of larger samples.

5 Design

The design for this study consists of three rooms, (1) a learning room, (2) an experiment room, and (3) a test room. The overall flow of the game design is shown in Fig. 2.

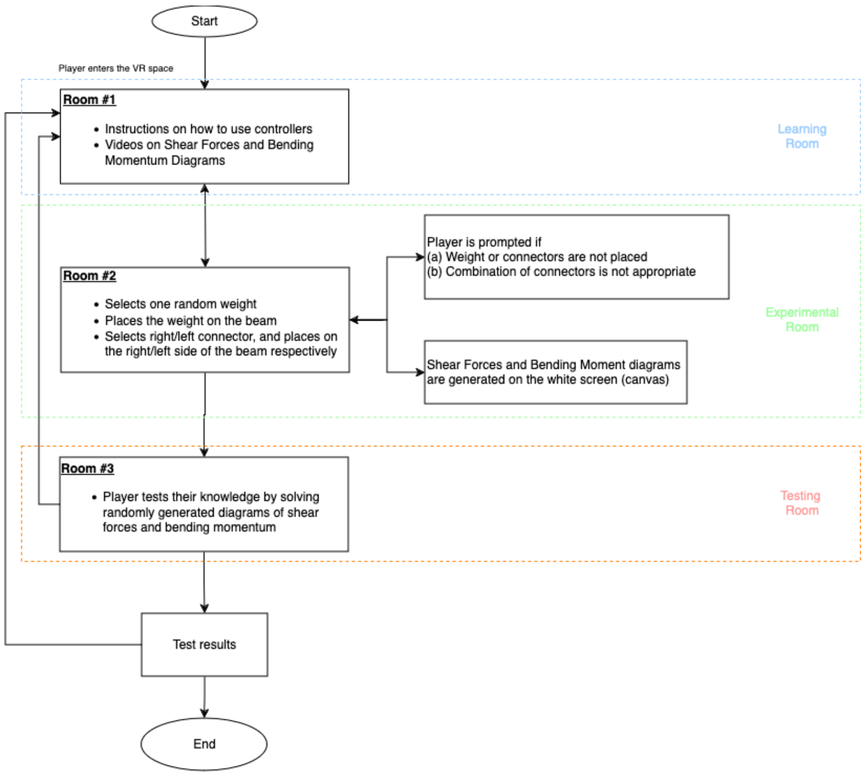

Fig. 2. An overview of the game design.

5.1 Learning Room

Upon loading the game, the player finds themselves in this room first. A three-dimensional model of the Oculus Quest controllers is displayed to help players learn how to use the controllers in the game (Fig. 3). Before moving to the next room, the user is taught about the concepts of shear forces and bending momentum through a video running in the virtual space (on the screens). The user can play, pause, rewind, and fast-forward videos that cover these concepts. By selecting the "Next Level" button, the user can proceed to the next room once he is comfortable with the concepts.

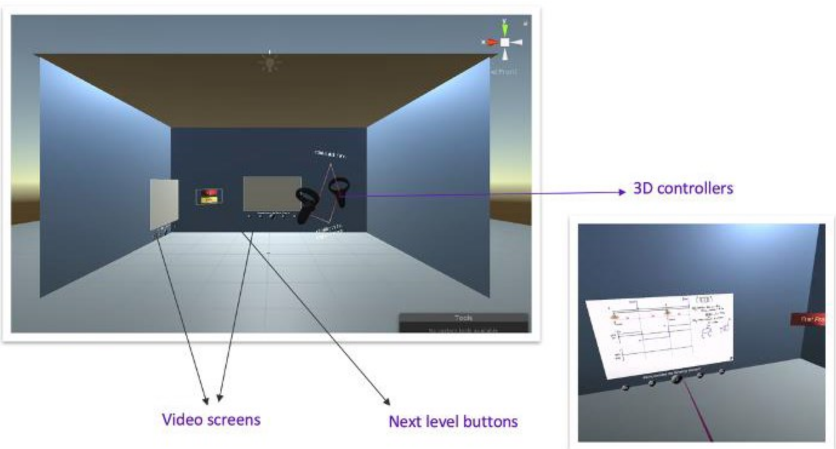

Fig. 3. VR Learning Room.

5.2 Experimentation Room

The second room the player enters is called the "experimentation room," where the user is encouraged to experiment with the objects provided with the concepts learned in the previous room. This room consists of three different loads ranging from lightweight to heavy. The lightest weight is gray, the medium is green, and the heaviest is red. Three types of connectors are used for this study, (i) Fixed connector (provides resistance in both vertical, horizontal, and moment), (ii) hinged connector (provides resistance in both vertical and horizontal directions), and (iii) roller connector (provides resistance in the vertical direction only). The user is positioned in the middle of the room with the weights behind him (along with an instruction board), connectors on either side, and a simple beam (with the canvas board for results over it), as shown in Fig. 4. The user can get a deeper understanding about shear forces and bending momentum concepts while placing various combinations of connectors and weights on the simple beam. However, the user is prompted if the weight is placed on the beam with no connectors attached and if the combination of the connectors is not compatible (ex, the beam cannot have roller connectors on both of its ends) Fig. 5.

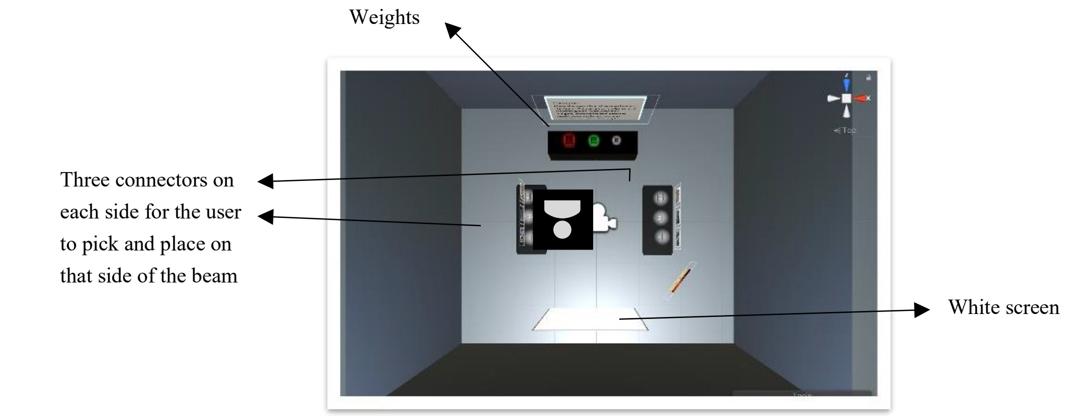

Fig. 4. VR Experimentation Room.

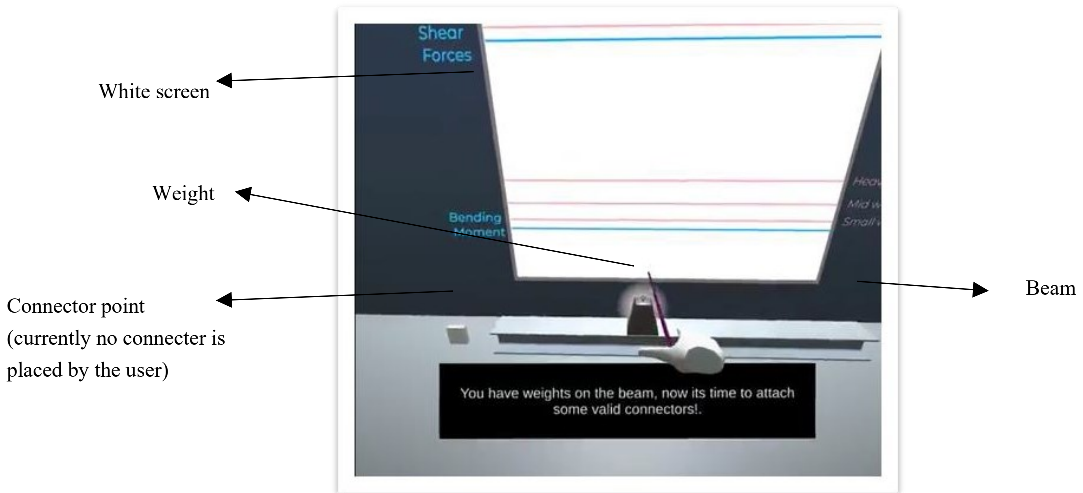

Fig. 5. User prompts.

A first-person view of the user interacting with the beam is shown in Fig. 5. The white screen shows the shear forces and bending momentum diagrams. In this figure, since the user has not connected the weights to the beam, no diagrams are shown. The prompt at the bottom guides the user on the next steps. After connecting the connectors to the beam, the user can view and analyze shear forces and bending momentum for the respective connectors. With each different combination of connectors, with different weights placed on the beam location, a unique set of graphs is generated. The user will be prompted if a combination of connectors is not compatible. Many combinations can be experimented with by the user in this room which helps in visualizing and understanding the concepts better.

5.3 Testing Room

This room allows the user to test their knowledge of Structural analysis. Random graphs are generated on the canvas board. The player must select the correct weight to be placed on the correct section of the beam with the correct combination of the connectors. The player is given up to three chances (each chance represented by a heart) to make wrong choices for five questions (Fig. 6). The player cannot go back to the previous room and can only restart the game from the first room.

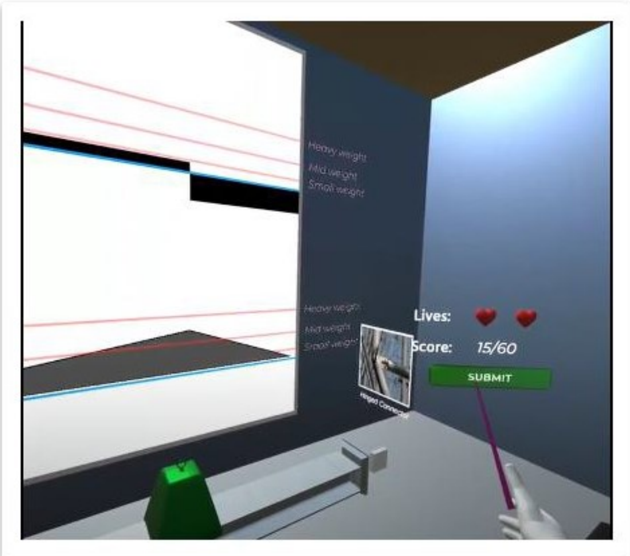

Fig. 6. VR Testing Room.

6 Development and Software Challenges

The application was developed using Unity and C-Sharp programming language on the Oculus Quest VR headset. Importing complexities with 3D SketchUp models were fixed by changing the internal model orientation. To reduce the motion sickness caused by the difference in speed between virtual and real-world scenes [5], Oculus Quest was used in this study since it has a body-tracking feature that can replicate users' body movements in the virtual space [14].

7 Discussion and Conclusion

A small alpha testing was performed by the CSHCI lab's development team with one professor from the building science department and one professor from the civil engineering department, improvements were made as per the suggestions. As the results of the initial phase are obtained from a small sample size of instructors, further testing is needed with a large sample of students from CE and CM disciplines. The next version of the VR application will include complex beam structures and connectors. A mobile platform will also be developed using Augmented Reality technology to reach out to as many students as possible. From the findings of the pilot study with the experts, the VR application appears to have the potential to provide a training platform irrespective of the users' VR experiences. Additionally, the tasks in the application were performed with ease leaving a positive experience. These results partially support the goal of this research, that is, providing a VR environment to deepen the understanding of the concepts of building structures. In the next testing phase with the students, the learning outcomes can be determined. The first limitation of this pilot study is that the sample size is small. The second limitation of the pilot study is that it was only tested with the experts (Auburn University faculty) to get their insights on the application which will be tested with the AU students in the next phase to understand its effect on learning.

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