Use of 3D Human-Computer Interaction for Teaching in the Architectural, Engineering and Construction Fields

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Abstract. In this paper, we outline the development of SKOPE VR, a system for immersive interaction within a 3-Dimensional Virtual Reality(VR) Environment designed to teach of architecture, engineering and construction (AEC) students. The paper presents the potential capacity of immersive and interactive tools for teaching and will discuss the key challenges for creating 3-D environments with embedded interactivity. Then, the solution proposed in the SKOPE-VR system will be discussed in terms of its rationale and its development process. Finally, some of the advantages of using immersive technologies for teaching future AEC professionals will be discussed.

Keywords: 3-D interaction · Virtual reality · Oculus Rift
Navigation in virtual environments · Virtual learning environments

1 Introduction

The use of visualization tools has been native to Architecture. For the past decades Architects have used 3D modeling and visual simulations as a main design vehicle to better understand building performance. More recently the use of VR has enabled architects to improve their designs by engaging clients or potential users in realistic walkthroughs of proposed buildings and alter the design according to their feedback [1].

In the past few years, the use of VR in construction and engineering has also become prevalent. VR-based training for creating safer construction sites, site analysis and planning, and visualizing construction scenarios for decision making are becoming increasingly widespread.

As virtual immersive environments become easier and cheaper to produce, more practical and useable, their educational use will follow. This paper discusses a project

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which develops a prototype VR environment to teach architecture, engineering and construction (AEC) students lessons on building sciences.

2 Benefits and Challenges of Immersive 3-D VR Navigation

The adoption of the new technologies that allow a user to be fully immersed in a 3-dimensional virtual world for the purpose of AEC education opens up a wide array of potential benefits, but it also presents with important challenges. In the following sections we will summarize the benefits and challenges most relevant to the application of BVR to AEC education.

2.1 Benefits

Virtual reality technology mainly draws its novel benefits from its robust and innovative human-computer interaction framework. Contemporary technology such as the Oculus Rift can provide developers and users with low latency 360-degree view of a virtual environment, as well as accurate and robust hand tracking and control. These features, verified in previous research, present a wide variety of benefits for education. Such as:

Immersion - Virtual reality's main feature is its ability to completely immerse users in a virtual environment, leading to a sustained period of focus [2]. Previous studies have shown that immersion plays a critical role in education, as a user focuses on interacting, absorbing and applying concepts presented in the virtual world [3, 4]. The result is a Virtual Learning Environment (VLE) that provides a focused space to analyze and explore concepts separate from the real world and its limitations.

Interaction - Virtual environment interaction is fundamental to VR design. Novel VR control and tracking systems have been recently introduced by devices such as Oculus Rift, HTC Vive and Windows Mixed Reality. Through these novel controls, users can physically interact with the virtual world as we can with the real world which provides a sense of familiarity [5]. Pan explains this interactive component of VLE's as "Active Action" which allow learners to act in their learning environment effectively [6].

Display of Information - While immersion and interaction are the most commonly attributed benefits in VLE's, the method and techniques we use to display information in these immersive worlds are just as important. Learning takes place in a structured environment where information is easily accessible and analyzed. Virtual Reality provides the benefit of a virtual 3-Dimensional world space to structure and organize information for learning [7]. The inherent and beneficial capability to represent concepts in 3D is well documented, as users can analyze a concept in a wider range of views [4]. In this paper the focus is on this benefit and the associated challenges that arise when we seek to apply VR/VLE's in education.

2.2 Challenges

Immersion and interaction are highly beneficial to the user in VR applications to education, however, our current methodology for displaying information and interacting with it in an immersive environment has limited the usability VLE's. While the display of concepts in a 3D space takes advantage of both immersion and interactivity, it also brings complexity [5]. Users now must take into consideration the extra dimension provided by VR, which with poor design, often leads to confusion and frustration. Simply put, users won't be able to access the immersive and interactive features of a VLE effectively.

When we consider the applications of VR for education, we must also consider the pedagogical approach we want to translate to a Virtual Environment [4]. As stated by Vassigh and Huang, understanding and defining a solid pedagogic framework is fundamental to the design of such virtual experience [8]. Effectively using such a framework brings complexity to a VLE's design, and presents its own set of challenges.

3 Rationale and Development of SKOPE VR

As discussed in the previous section, 3D brings an extra dimension of complexity to the design and use of a VLE. The placement of information (whether it be a 3D model or text) is critical to how the user experiences this information (i.e., absorb it, analyze it, etc.). Current VLE designs often overwhelm users with confusion, and degrade the immersive character of the VLE experience.

If we look closely, we see that while VLE's place users in a 3D space like the real world, we do not usually have standardized tools to help users interact with a virtual world's information in a concentrated and intuitive fashion [2]. What do we mean by this? In the real world, books and computers are examples of tools that help us understand the information around us in a "concentrated" fashion. VLE's lack these tools, and thus make it difficult for the user to experience the information in a VLE in an efficient and enjoyable way.

An example of a VR application that attempts to solve this issue is Google Tilt Brush. Tilt Brush presents the user with an open Virtual Environment in which they can draw in 3 Dimensions with a wide variety of colors, shaders and effects. While drawing might not seem like much, Google tilt brush supports all the functionality (or even more) that a program like MS Paint would provide. Google Tilt Brush successfully deals with complexity by creating a user tool that centralizes all user decisions and interaction with the virtual world. These tools are in the user's hands, which use VR's interaction benefits such as hand tracking and gesture control.

We believe that the philosophy utilized in Tilt Brush can be beneficial for a variety of VLEs. Using the same idea, we could possibly use VR's interaction benefits to create a centralized "Hub" tool of experiences and decision making in a VLE. This will improve a user's experience with the information around them, removing unnecessary complexity to the user. This is a step in the right direction; however the efficiency of the approach may depend significantly on the actual contents displayed in this "Hub" tool. In other words, what information should the concentrated "Hub" tool inherently display?

3.1 Pedagogical Framework

While most studies agree on the VLE's potential benefits in education, they all suggest the importance of building the VLEs on a solid pedagogical framework [4]. Pedagogical frameworks provide an in depth theoretical view of teaching and learning. By choosing a solid pedagogical framework, we could start building VLEs based on these frameworks and add structure to our experiences [8].

There are a variety of different pedagogical frameworks, but Constructivism is one of the most frequently frameworks used in similar research efforts [4, 8]. This is because Constructivism uses VLE benefits from immersion, interaction and display of information. For example, constructivism treats the user as an active learner who not only absorbs information, but also builds upon and connects previous knowledge to construct new knowledge through active interaction. Constructivism also encourages the construction of learning environments rather than instructional sequences to reinforce authentic knowledge in the user [4]. At its core, Constructivism promotes active experiences to construct knowledge in an immersive and interactive approach.

Through constructivism, we can introduce experiences that will be useful for our user in our theoretical experience "hub". We can also define how the user will interact with different concepts in our VLE through Constructivism to ensure a consistent and focused learning approach.

3.2 Development of SKOPE VR

In summary, the critical concepts that we kept under consideration as we planned the development of SKOPE VR were:

- Information vs. Experience
- VLE inherent Benefits: Immersion, Interaction, Display of Information.
- VLE inherent Challenges: 3D complexity and Pedagogical framework implementation.
- Information Perception and Centralization in a 3D Virtual Environment
- Constructivism pedagogical framework and Information Structure

Based on this information, we found a need for two tools that will separately handle experiences and information in the virtual environment. This will provide a user with a consistent set of controls to use in the VLE:

- Pointer
- Hub

3.3 Pointer (Information)

The pointer's focus is to enable user interaction with information in a VLE. As the name suggests, the user will use this virtual pointer tool to select information presented to the user and trigger some experience for the selected information (Fig. 1). This approach takes advantage of the VLE interaction benefit and reduces complexity in selecting information of interest. For example, access to a wide variety of experiences can be achieved by pointing and selecting environment buttons using the pointer.

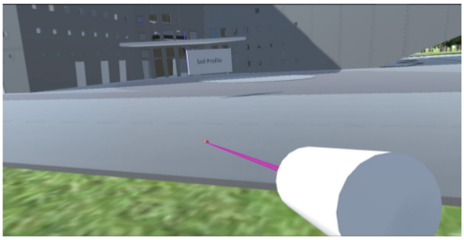
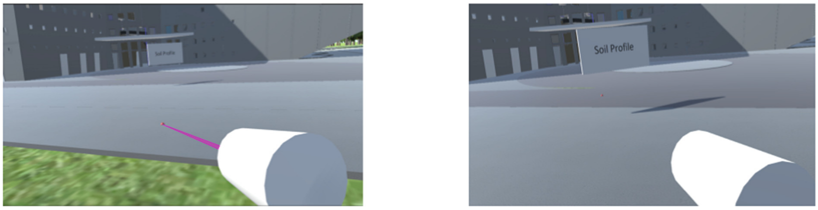


Fig. 1. Pointer

The Pointer also serves as a tool for locomotion around a VLE, as it can be used to point to the next desired location of the user in the virtual world and (upon pressing a button in the controls) “move” or “teleport” the user to that desired location. Figures 2a and b show this user translation mechanism. This facilitates efficient user access to information and the exploratory capabilities around a 3D world space. Mikropoulos suggests that navigation around a 3D world space can provide natural semantics for users, and avoid complicated and hard to remember symbolism and controls, further improving the user learning experience [2].



a. The pointer points to the next desired user location

b. Upon pressing a button the user is translated to the desired location

Fig. 2. Use of the pointer for changing the position (point of view) of the user within the virtual environment.

3.4 Hub (Experience)

The Hub (Fig. 3) is the centralized point of experience for the user. Its primary focus is to provide an appropriate experience for a selected piece of information by the Pointer. For example, let’s assume we want to find out more about a 3D cube in a virtual environment. Once selected by our pointer as information of interest, our hub will display relevant information to have the appropriate experiences about the selected object. In order to display an appropriate experience, the hub contains three separate panels each dedicated to a different aspect of the user experience in a VLE. These are:

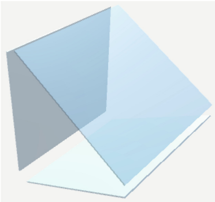


Fig. 3. Hub

Map Panel

The Map Panel in the hub is responsible for providing position feedback from the user's environment location, as well as providing the location of a VLE's experiences. Ultimately, the map panel aims at reducing the complexity of accessing information and experiences in the VLE alike. Furthermore, the map panel incentivizes user exploration around the virtual environment which improves a user's sense of immersion (Fig. 4).

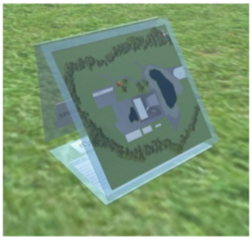


Fig. 4. Map panel

Options Panel

The Options Panel is responsible for displaying relevant options that are available to the user in a given experience. That is, information in a VLE might contain a set of options that will trigger a corresponding experience. Furthermore, the Options Panel takes advantage of the interaction and display of information benefits while reducing complexity and centralizing both areas. This allows the implementation of pedagogical frameworks like Constructivism, which demand active learning, in VLE's (Fig. 5).

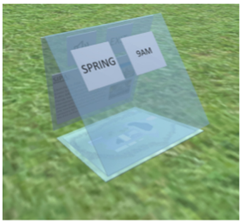


Fig. 5. Options panel

Info Panel

The Info Panel is used to provide relevant information in a given experience. This will enable a user to establish focus on a given experience while providing adequate background information. This is especially important when we adopt a Constructivism framework for the design and implementation of a VLE. Building new knowledge based on previous knowledge and experiences can be tricky in a virtual environment, so the Info Panel aims at reducing this inherent complexity while improving the user learning experience (Fig. 6).

Fig. 6. Info panel

3.5 SKOPE VR Implementation

The implementation of the form of interaction described above used the Oculus Rift (headset and touch controllers) and its most recent Software Development Kit (SDK). The virtual environment was developed using Unity 3D and Visual Studio 2017. The virtual world was rendered on a computer running Windows 10. 3D Studio Max was used for editing the models used in the project.

Figure 7 shows a user fitted with the Oculus Rift head set and both touch controllers in his hands. The headset provided the stereoscopic display of the virtual world and sensed the changes of orientation of the user's head to modify the stereoscopic display accordingly. The left hand controller was used to manipulate a selected hub. Its thumbstick provided the mechanism to rotate the selected hub on its x-axis, so that the desired panel would be presented to the user. The right hand controller was utilized to manipulate the pointer, using the "A button" to execute the teleport (move) operation, and the trigger as a general selection control.

Figure 8 illustrates the basic organization followed in the design of the system, outlining the interplay between the actual physical controls, the user interface element (the hub, with its three panels), and the user experiences. It is worthwhile noting the types of experiences developed for this particular architectural application: *Light-Changes*, *RemoveWalls*, *InspectMechanics*, etc.

Figure 9 shows some sample screenshots of user experiences. These correspond to two alternative views of the building housing the School of International and Public Affairs (SIPA) at Florida International University.

Fig. 7. User wearing the Oculus Rift and the touch (hand) controllers

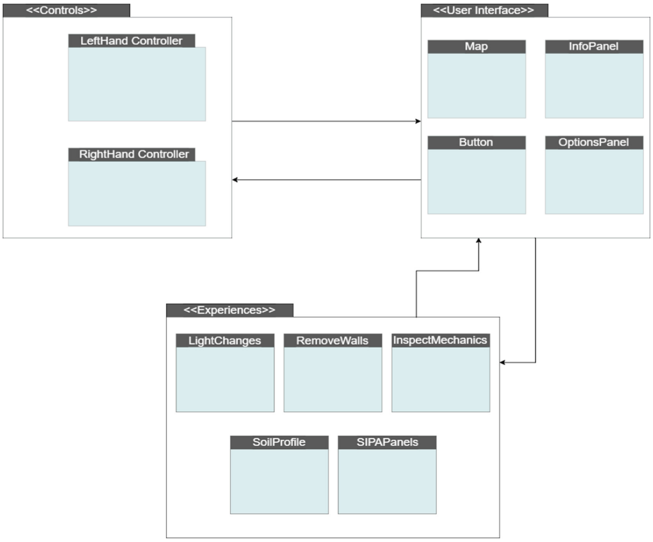


Fig. 8. System design

4 Advantages of Using Immersive Interaction for Teaching Building Sciences

VR has the potential to expand and transform learning in building sciences because of the two distinctive features described earlier. First, is its capacity to support interactivity. Steuer defines interactivity "as the extent to which users can participate in

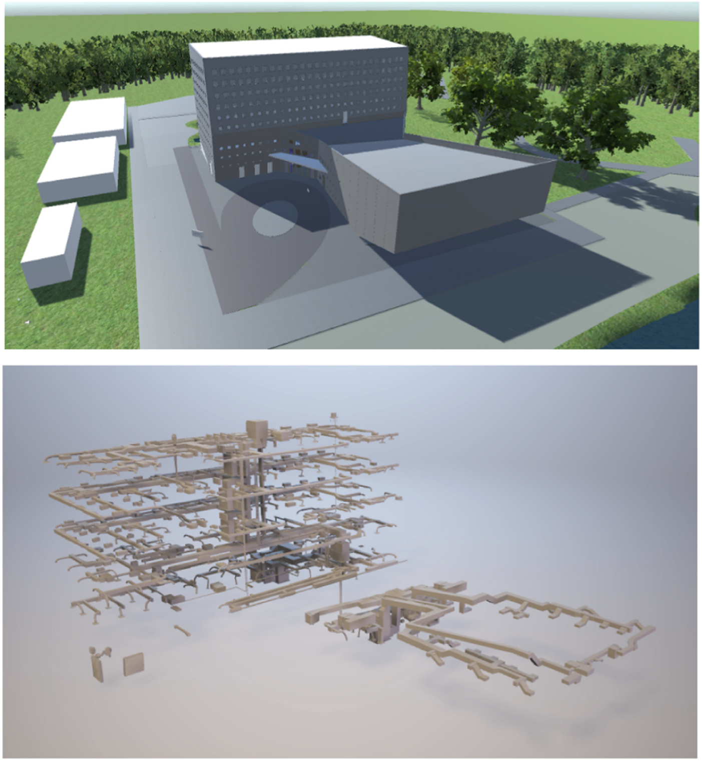


Fig. 9. Sample displays of user experiences viewing the FIU SIPA building: (a) (top) default view; (b) (bottom) *InspectMechanics* view.

modifying the form and content of a mediated environment in real time" [9]. Interacting with a responsive environment where the user can navigate and modify the learning context is a powerful aspect of VR technology. Interactive 3D environments can also produce game-like experiences that are truly engaging.

For teaching AEC students, interactivity could be used to enable students to change the parameters of their learning. While text, visuals, and animations can describe a building's performance, properties, structure, and construction details, the ability to change the existing parameters provides additional opportunities to better understand the content and be able to predict the behavior of the building.

Consider a student walking around a virtual building able to interact with objects within the environment. She can touch a wall and activate an animation showing its construction process, access metrics on the building envelope's thermal resistance, learn about the material properties used in its construction, and get information on the cost of its assembly.

VR environments could also recreate many processes that are not assessable in real-time. Example of this include building energy performance in various seasons, water collection and flow around the building site in various conditions, and structural materials' behavior. Using the interactivity features of the VR, students can change the season or the date to observe heat loss and heat gain through building walls, visually locate thermal breaks, and gauge natural lighting of the building interior in different time of the day.

Finally, interactivity affords another benefit. Hoffman and Vu describe that interactivity afforded by the VR environments reduces "cognitive overhead," allowing the users to focus attention on the content rather than the semantics of the computer interface [10]. VR offers a direct way of engaging the content.

Second feature of the VR is its immersive capacity. Bryson describes immersion as the sense that the "user's point of view or some parts of the user's body is contained within the computer generated-model [11]. Immersion can provide realistic experiences, where knowledge is produced through experience. By becoming part of a phenomenon learners gain direct experiential intuitions about how the various components of buildings work. Through using multisensory immersion in VR customized for students, complex and abstract scientific concept can be understood at an intuitive level [12].

In the context of building sciences, the experience of being inside a virtual building can provide a powerful way of learning. A virtual walkthrough of a building can equip the viewer with an almost x-ray vision, enabling her to see through the walls to examine the structural components, look through the ground plane to see the building foundation, and look through the ceiling to examine the building's mechanical systems.

5 Conclusion and Future Work

Virtual Learning Experiences (VLEs) show increasing promise to improve the educational experience for everyone, and hold a particularly strong promise for enhancing architecture, engineering and construction education. As with any new technology, VLEs possess inherent benefits, challenges and complexity that must be handled accordingly to implement them in an effective manner. Through the theoretical examination of information perception/centralization and appropriate pedagogical frameworks, we presented a novel user interaction approach to tackle VLEs challenges and complexities in hope to improve the user learning experience.

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