VR-BASED TEACHING AND LEARNING TOOL FOR BUILDING DESIGN AND CONSTRUCITON

C. ZHANG[1], AND B. CHEN[2]

[1] Department of Civil Engineering, Xi'an Jiaotong-Liverpool University
111 Ren'ai Road, Suzhou 215123, China
cheng.zhang@xjtlu.edu.cn

[2] Department of Urban Planning and Design, Xi'an Jiaotong-Liverpool University
111 Ren'ai Road, Suzhou 215123, China
bing.chen@xjtlu.edu.cn

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Abstract. A Virtual Reality (VR) based teaching and learning tool is proposed in the present paper. A virtual 3D environment is built for students to conceive their design ideas, plan the layout, design the structure, construct the products (buildings, communities, infrastructures, etc.), and to directly interact with the products they designed. The aim of the research is to strengthen the learning-by-doing approach. The objectives are: (1) to build a VR design environment for students to experience corresponding impact from different scenarios, which will help the student understand and investigate different design theories and schemes; (2) to build a VR construction environment for students to investigate how the building is built and what are the safety issues should be noted when visiting a construction site; and (3) to provide an collaborative environment for students in the Built Environment domain for better communication through a complete building project featuring active and experiential learning. Students with different majors in the cluster can work together in a design project using the VR platform so as to enable collaboration work, which is a common working situation in reality. A game was developed to guide the students to explore a virtual construction site by answering technical questions and carrying on tasks resolving safety hazards on site. Unity is used as the game engine to develop the package. VR software package, VIVE, is used to realize the interaction between the virtual environment and the user interactively and immersively. Students from the Civil Engineering were invited to play the game and give feedbacks using a questionnaire. Positive comments were given by the students showing that they were very interested in playing such a technical game. Most of the students were willing to spend more time in finding answers after playing that game. In this way, the benefits of the research could be: (1) Enhancing the understanding of conceptual design ideas and how to make better designs in urban planning, architecture, and civil engineering domains; (2) Better accessibility to more realistic structural products in a large scale; and (3) Improving professional skills such as teamwork and communication in the VR-aided learning-by-doing process.

1 INTRODUCTION

The Civil Engineering department aims to incorporate "active learning" into all its modules, which means students engaging with teaching materials instead of passively listening. Among them, a CDIO concept is introduced based on a commonly shared premise that engineering graduates should be able to: Conceive – Design — Implement — Operate, which is complex value-added engineering system in a modern team-based engineering environment to create systems and products. A good example in the department is CEN101 - Design for Engineers, where the students design and construct cardboard bridges by "hand-on" activities. Students learn the structural design through material strength testing, using structural analysis software packages, and testing their final product with designed load. Students enjoyed and learned more. However, the scale covered through that module is limited to small truss bridges only. Large scale design activities should be provided to the students and a diversity of design projects should be incorporated into this module.

In addition, Civil Engineering students need to collaborate with other built environment related professionals in their career path, such as urban planner and architects. It is essential for the students to learn in an early stage how to efficiently cooperate with students from other disciplines, especially within the built environment cluster.

In the department of Urban Planning and Design (UPD) and Architecture (ARCH), design-related issues (e.g. scale, 3D perception, etc.) are usually taught in a studio-based environment. However, it is very difficult to allow students to challenge (or even fully understand) some design principles (e.g. how to create a pedestrian friendly working environment? And more importantly, why should it be designed like that? etc.) in the given learning environment. A range of tools have been developed and applied in order to solve this problem. These include Computer-Aided Design tools (e.g. CAD/SketchUp models), physical models, case studies of best practice, etc. Yet their effectiveness is still questionable, especially to beginners such as junior UPD or ARCH students.

Based on above mentioned experience in the built environment cluster, we would like to propose a Virtual Reality (VR) based teaching and learning tool, which can efficiently improve students' active learning capability by allowing students interact with their designed 'virtual built environment' directly and immersively. By doing so, it can inspire students' imagination and support their design thinking. At the same time, structural design practice will be integrated to allow students to do simplified structural analysis but for a real product (e.g. building, bridge, etc.) in full scale. The structural analysis results may need a revision of architectural design to meet the stability and safety purposes. During the cycle, students from different majors learn from each other and work together to produce more realistic products in the end. The VR-based environment can be used to help the students to understand the impact from different design scenarios. By using this teaching and learning tool, we expected that students learn more through these active and hands-on activities; emphasize more in problem formulation and solution. In addition, previous research [1] also showed that the application of VR techniques can facilitate the communication across different stakeholders involved in a design project and thereby efficiently support participatory design or decision-making. As a result, by using VR techniques to support learning and teaching in the built environment cluster, it can help students verify some design theories in practice and, in return, improve their capability of applying, analyzing, synthesizing, evaluating or even creating new design principles. A case study of

using VR in learning and teaching at XJTLU UPD can be found from Chen and Chen [2].

In addition, a game was developed to guide the students to explore a virtual construction site by answering technical questions and carrying on tasks resolving safety hazards on site. Students from the Civil Engineering were invited to play the game and give feedbacks using a questionnaire. Positive comments were given by the students showing that they were very interested in playing such a technical game. All of them wanted to play more rounds in order to improve their performance and to find answers to the questions they failed to answer correctly earlier. Most of the students were willing to spend more time in finding answers after playing that game. The results of the project had been published and presented in two international conferences [3][4][5].

2 AIMS AND OBJECTIVES

The fundamental aim of the proposed project is to strengthen the learning-by-doing approach. A VR-based design and construction environment will be developed as a teaching and learning tool. The objectives are: (1) to build a VR design environment for students to experience corresponding impact from different scenarios, which will help the students understand and investigate different design theories and schemes; (2) to build a VR construction environment for students to investigate how the building is built and how the design will affect the user experience in reality; and (3) to provide a CDIO activity for design and construction through a complete building project featuring active and experiential learning.

3 METHODOLOGY

As shown in Figure 1, the VR environment is designed to comprise two main groups of structures, which are Communities and Infrastructures. Communities will be used for planning and design purposes to include a large scale of area. Different buildings will be designed to form communities. Meanwhile, Infrastructures consists of bridges and roads, which will be a necessary part to be considered in the built environment. Level of Details (LoDs) will be decided to meet those different requirements.

Design projects in different scale can be assigned to students to fulfill different needs in terms of urban planning (large scale, which can include communities and infrastructure), architectural design (Intermediate scale, which can include several buildings), or structural design (small scale, which can be one building or one bridge). Once the design projects have been done, a construction activity can be triggered to show a virtual construction site of the buildings or the bridges, and roads. Construction progress will be simulated by attaching time information for individual components of the structure.

Navigation and interactions will be developed to enable the students to explore and change the VR environment freely and get instant feedbacks, such as Environmental Impact and User Experiences. With the integration of some simulation tools, impacts from different design scenarios, such as traffic flow, daylighting, views, etc. can be presented in the VR environment. Since the students will be immersively stay in the virtual environment, which means that they can experience the impact in a much more realistic way, compared with traditional ways. Those experiences will help the students improve their design and gain better user experiences.
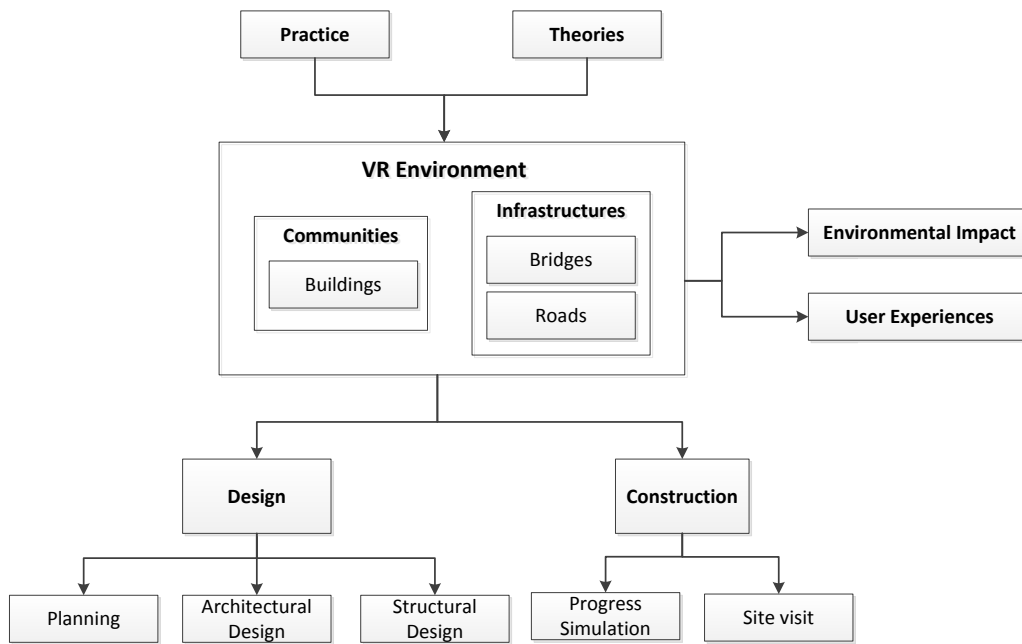
Figure 1: Framework of a VR design and construct environment

3.1 Requirements Identification

First of all, requirements for the development were identified in terms of design, construction of a building project based on teaching experiences. Students who involved in the development from the Built Environment cluster and the Computer Science department (CS) were asked to work together to design the VR environment settings according to the requirements as if they are working on a design project in a module. The VR settings were developed by the CS students by using the VIVE VR toolkits and programming language. The difference between the VR-based design and the traditional design is that, in a virtual environment, the user experience is more realistic and, in return, more feedback can be given instantly.

3.2 Create Existing Buildings

To give the students spatial awareness in the virtual environment, existing environment should be created. Building models are created via SketchUp with detailed layers on different components constructing the building. Figures 2(a) and 2(b) are examples for buildings in a university campus. To convert SketchUp models into virtual reality environment, we have to export the model into a readable file format by Unity Editor. There are two file formats that commonly supported by Unity and SketchUp software, which are '.obj' and '.fbx'. The former one stores *Mesh* and *Textures* into two separate documents, thus might cause some material missing problem. Therefore, it is suggested to use the .fbx format, under which the model and its relevant materials are combined into one file. Besides, a 3D model covering a large area is created by using taking pictures using a drone and reconstructed by using image processing. However, due to limited resolution, this model is only used for a top view and not for detailed design work.
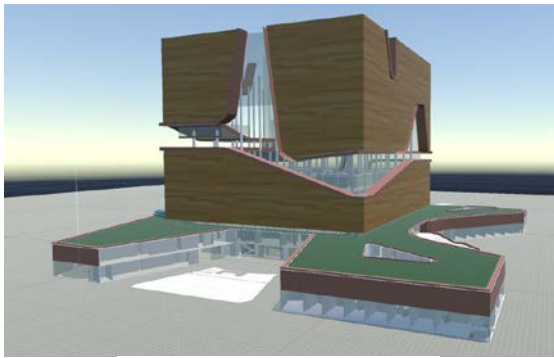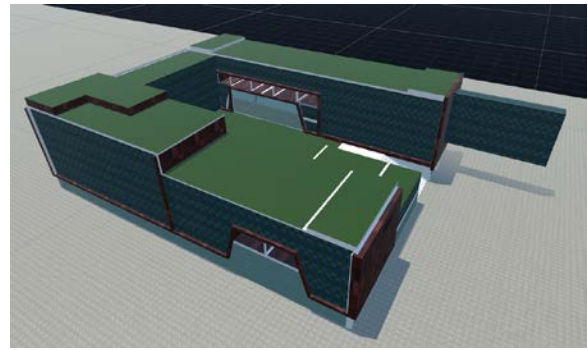
(a) Central Building   (b) Engineering Building

Figure 2: Sample Buildings in a University Campus

3.3 Navigation via Teleport

Teleport is chosen as the main navigation technique to prevent motion sickness and nausea that usually take place during translations in virtual reality environment. By pressing the trackpad of the left controller, a curved raycast will be shot out. The point where the ray hits the ground will be considered as the desired destination. Then by releasing the trackpad user will be moved to the position selected instantly, as shown in Figure 3. The maximum distance allowed for transportation can be defined freely within the Unity Editor.

(a) Ready for Teleport   (b) After Teleport

Figure 3: Navigation using Teleport

3.4 Designed Functionalities

A set of functionalities have been designed to facilitate the users to apply the similar functionalities for design.

3.4.1 Selection Panel

Figure 4 shows the UI that designed for selecting a single mode on the right controller. The trackpad is divided into four quadrants, each specifying a mode for interacting with the

architecture. The white quadrant is for indicating current selection on the specific function mode. The selection is made by: 1) moving the finger into the quadrant area which the desired function belongs to; 2) pressing the trackpad. Then the white indicator will automatically rotate to be aligned with the quadrant of the selected mode, indicating the success of selection.

Figure 4: Selection Panel on the Controller

3.4.2 Distance Measurement

After selecting this function, a straight ray will be cast from the head of the controller. The vertical height of the point that the ray hit will be displayed above the controller. In reality, height is a very abstract conception, which is sometimes hard to estimate only by observing. While in VR environment, it would be possible to train students' ability to feel and explore the sense of "height" by visualizing it with data.
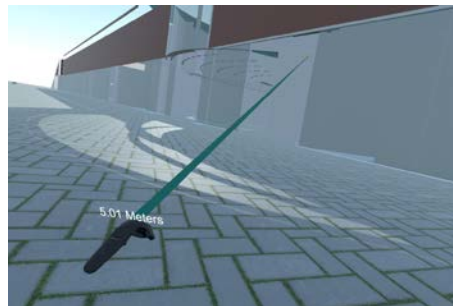

Figure 5: Measuring Distance

3.4.3 Make Notes/Comments by using Virtual Keyboard

Again Raycast is used as the selection technique. User can leave a comment by pointing the ray to the desired position. Then after pulling the trigger, a blue tag will appear together with the virtual keyboard for input. The input text will appear on the tag. User can click on the "Enter" on the keyboard to confirm the input. Then the tag with the input text is fixed at the selected point. The tags will rotate according to current head orientation of the user, so the view of the tags would never be occluded.
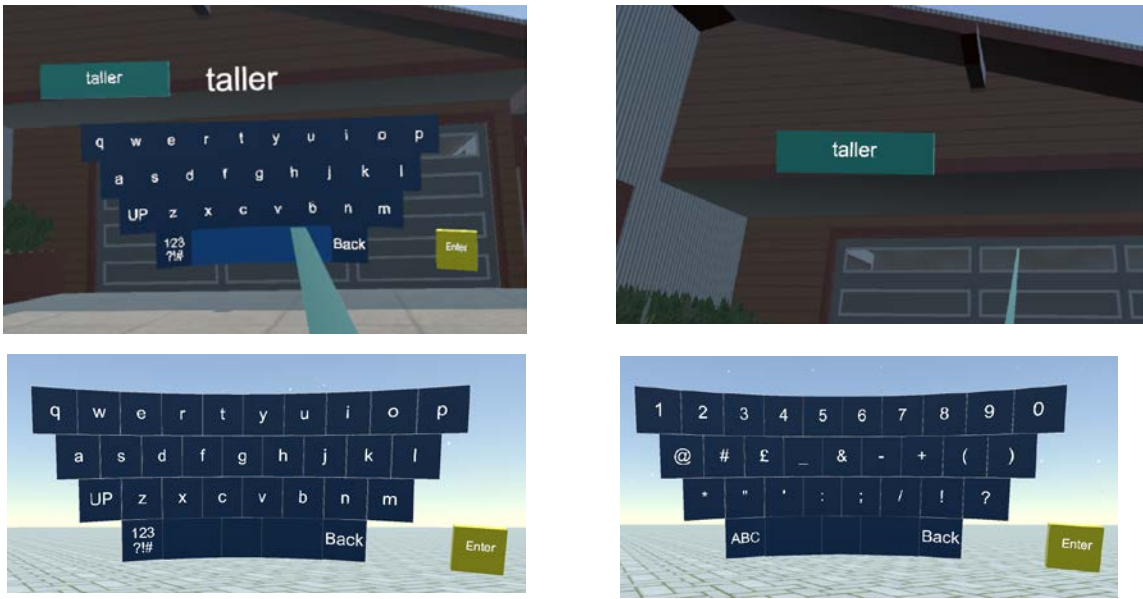
Figure 6: Input Comments by using a Virtual Keyboard

3.4.4 Create New Objects

The function of design buildings is developed starting from drawing rectangles on the ground. As shown in Figure 7, firstly, switch to "Draw" mode by pressing the trackpad. Secondly, point the ray to the ground, with the point being hit as the initial vertex for constructing the rectangle. Thirdly, press the trigger and move the controller to change the hit point. A rectangle will be formed with the initial point and current hit point serving as the diagonal vertices. Finally, release the trigger to finish constructing the rectangle.
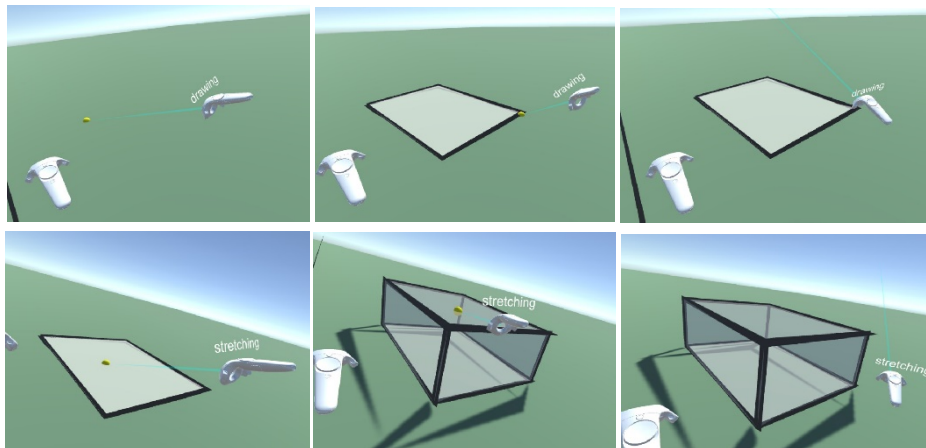

Figure 7: Steps of Creating New Objects (A Box)

Next step is to stretch the solid by pressing the trackpad to switch to "Stretch" mode. Then point the ray to triangle surface just created, followed by pressing the trigger and moving the controller up/down to lift/drop the surface. Then a solid will be automatically formed by the

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surface on the ground, and another surface you are manipulating. Finally, release the trigger to finish constructing the solid.

3.4.5 Other Functionalities

Besides the basic functionalities introduced above, other functionalities are also developed to enable the students design in this VR environment. Such as changing material of the façade, simulate the sunlight, calculating the FAR, etc.

3.5 Testing

A prototype system is developed and several students are invited to experience the VR Design Environment. Figure 8 shows a student is using the prototype and his design result of a group of buildings.
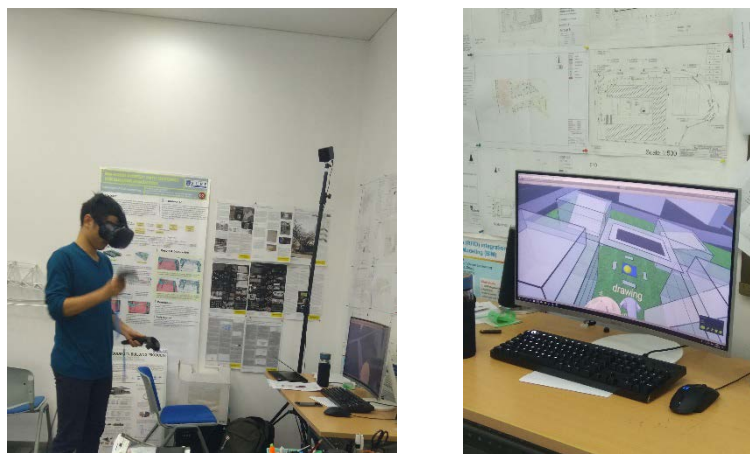

Figure 8: Testing the VR Design Environment

4   GAME DEVELOPMENT

To enhance the engagement of Civil Engineering students and encourage active learning, a virtual construction site investigation game is developed as well. 3D construction site environment is built based on BIM models and relevant objects common on construction sites are created to enhance the realistic. Navigation and Interactions are developed to enable the students to explore the virtual sites freely and get instant feedbacks. Different modules, such as Questions and Tasks, are developed to exam how well the students master the domain-related knowledge, as shown in Figure 9. The architecture, mechanism and the implementation are described in detail in [5].

This pedagogical methodology aims to improve the quality of learning by transforming traditional instructional delivery techniques into technology-based active learning. Students' engagement in the learning process is improved by establishing a contextual connection between ordinary textbook materials and technologies that students use in their daily routines.
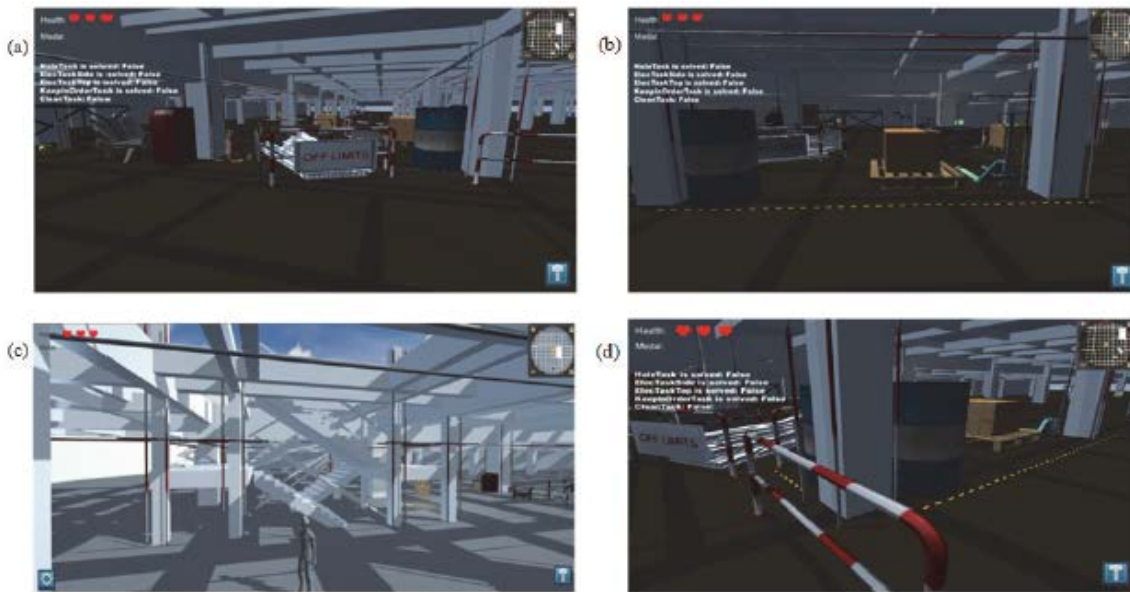
Figure 9: Designed Game for Construction Site Scenes [5]

5 DISCUSSION

Comments from the students were collected based on their experience of using the VR-based techniques. Since the team includes the students from different domains, such as urban planning, architectural, and civil engineering students, communications between those students are different in a VR-based environment instead of using sketches, 2D drawings, etc. These differences were identified and analyzed to check the effectiveness of the VR-based learning and teaching tools. By analyzing the feedbacks collected through a questionnaires, we got some preliminary results, which shows that Civil Engineering students are be more supportive in collaborative design by getting more understanding from urban and architectural design.

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