DESIGNING FOR HUMAN-VR INTERACTION

How VR interaction can be designed to bring better design participation

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Abstract. The research in human-computer interaction (HCI) has been ongoing for years until present-day to observe how humans interact with computers and digital technologies. Then comes the development of virtual reality (VR), one where it allows users to be immersed in the virtual environment for various kinds of experiences. This paper takes a close reference to the research method in HCI and brings the examination to the context of VR to understand the user behavior towards human-VR interaction (HVRI). A workshop is done based on the new HVRI method, and students are given the task to explore what are the elements of architecture that can be interacted and how they can be performed in the immersive environment. This paper will describe the HVRI designed and analyze how the new interaction method helps to bring about closer relationships between the human and the virtual model beyond just visualization.

Keywords. VR; Interaction; Design Participation; HVRI; Design Studio.

1. INTRODUCTION

The arrival of the artificial intelligence has brought new possibilities for human-computer interaction design. Before *AutoCAD* appeared in 1942, architects needed to use a pencil and rubber to draw design plans in drawing paper. The whole process costs a lot of human resources and material resources. In 1950, the gradual rise of Computer-Aided Design (CAD) made the architectural design transition from paper and pen drawing design stage to computer drawing design stage. Since then, architects have gradually got rid of the shackles of paper, pen, and board on scheme design, and presented their design ideas to the world through computer graphics(Lo and Gao 2020). Although the two-dimensional drawing method can accurately express the architect's design idea, in the era of the rapid development of information technology, this method has been unable to

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meet the needs of the architect for the presentation of the scheme. The emergence of three-dimensional (3D) modeling technology provides architects with a better visual effect of space. However, since 3D design software is usually based on the interaction of plane, pen, computer screen and multiple interfaces of the model, users can not fully understand the spatial scale of the model only through the computer screen or software interface. In addition, converting a two-dimensional solution design into a three-dimensional space design is a relatively complicated operation process. The designer needs to perform corresponding operations according to the requirements of the software system, which affects the expression of the designer's creative thinking (Dorta, Kinayoglu and Hoffmann 2016). However, the architect needs to evaluate the architectural scheme in the space in order to get a more accurate evaluation. Therefore, virtual reality technology has gradually entered the vision of architects.

In the Virtual Simulation Laboratory of Strathclyde University in Scotland, Maver et al. realized the immersion of the scene by projecting images on the curved screen to achieve the simulation of the remote environment, dangerous environment, and nonexistent environment (Maver, Harrison and Grant 2001). Although this kind of equipment can bring real experience effect to the experimenter, it is not ideal because of its huge size, complicated operation, and human-computer interaction. Schnabel et al. used a Hybrid Virtual Environment 3D (HYVE-3D) system to restore and present the environment of narrow alleys in Kashgar (Schnabel et al. 2016). This practice not only provides a new situation for the spread of historical heritage buildings but also achieves a breakthrough in the process of immersive collaborative 3D sketch drawing. Lo and Schnabel discussed how students can make full use of software and virtual display devices in the process of architectural design to achieve a breakthrough in architecture teaching methods (Lo and Schnabel 2018). Virtual reality devices can provide users with a visual operation platform through real-time interaction. Users experience the spatial scale through virtual reality devices, increasing the feasibility of human-VR interaction (HVRI).In this paper, the application of HVRI in the field of architectural design will be studied. By analyzing the design process of each group of students in the workshop, we explore how this new interaction method can help make the relationship between people and virtual models closer within the immersive environment. The results of the study will provide a new scheme design process for the field of architectural design.

2. FROM HCI TO HVRI

In the 1980s, the concept of model human processor was proposed, which gradually opened the prelude to human-computer interaction methods. Although interaction is only a simple process of information transmission, there are many ways of information transmission (Dix, Finlay and Abowd 1998). The application of human-computer interaction in the field of architectural design starts from the use of CAD by architects, but it is gradually optimized and updated with the continuous development of virtual reality technology. Dorta et al. used hybrid virtual environment 3D technology to operate 3D cursors and used digital board to sketch on hand-held tablet computers, so that the experiencer can experience the concept scheme directly in the immersive display (Dorta, Kinayoglu and Hoffmann 2016). By studying the application of virtual reality technology in architectural education, Sorguç et al. put forward the concept of virtual learning environments (VLE), and proved that this kind of education can help improve students' cognition of spatial relationship and creativity (Sorguç et al. 2017).

In recent years, due to the extensive use of scientific research, virtual reality technology has developed rapidly in software and hardware. According to the different moving range, the HMDs can be divided into mobile head-mounted displays and stationary head-mounted displays. In general, the mobile HMD is realized by adding a smartphone which can process the display information into the spectacle bracket. The technology of stationary HMD is similar to the smartphone, which combines the external environment information recorded by sensors with optical tracking technology. HTC Vive and Oculus Rift two typical stationary HMDs. HTC Vive has a similar display effect with Oculus Rift, but HTC Vive can provide an interactive experience with different room sizes. Wearing a head-mounted display can completely isolate the user from the real world (Lindeman et al. 2004).

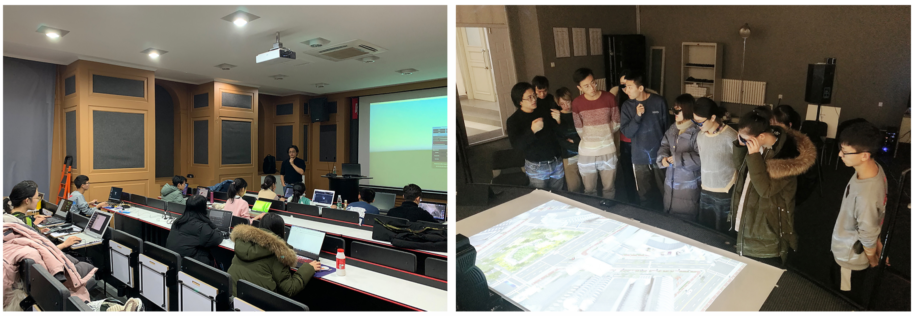
The traditional HCI process is the user's interactive application with the virtual equipment in the real environment, and the real world has strong interference to the interactive process. Restricted by the external environment conditions, the tester can only complete the relevant activities in the virtual environment through the controllers, tracking positioner and other control equipment. HVRI is the process of immersive simulation interaction, which places the tester in the virtual environment, without the interference of the real environment and space restrictions, and can provide users with more real scene experience. HVRI method can not only use the controllers handle and other devices, but also complete the scene interaction process through the gesture tracking or posture capture(Lo and Gao 2020).

This workshop provides the desktop holographic projection equipment for students. In the dark test environment, 3D images can be regarded as the interaction activities in the virtual environment. By examining various types of VR equipment and how its system could assist the design process, this research will study the various aspect of the interaction method; from the presentation of the building information to the comfort level of using the equipment to the degree of design collaboration among users. This paper will then introduce a new interaction method between the human and the virtual reality that can push beyond the current design capabilities within the immersive environment.

3. THE WORKSHOP

A design workshop is held to explore how VR interactions can be designed for better virtual engagement (Figure 1a). Based on computational design methods and virtual reality technology, this workshop was organized to help students understand the application of VR interaction design in the field of design. It is one of the 'computational design 2019' series activities held by the computational design committee of the Chinese Architectural Society. There are nineteen student participants with one workshop instructor who is also the principal researcher for this paper and a technical workshop assistant to aid with any technical problems. These nineteen students are from the first-year undergraduate to the second-year graduate students majoring in architecture, urban planning, landscape, or visual communication design. The students are evenly divided into three groups, each with a different year and study major to balance the group in terms of experiences and their knowledge and all students can complete basic design modeling.

During the workshop, each group of students was asked to explore how architects can VR to design the scheme. They are also introduced to an AEC software call *Fuzor*. *Fuzor* is a virtual reality interactive platform that can realize real-time and bidirectional synchronization with *Revit*, *AutoCAD* and other modeling software. Through its own 3D game engine, *Fuzor* can realize the real-time rendering of the model and the real-time VR scene experience, and can support multiple people to work together in the cloud server. Ample time was given to the students to discuss among their members in the groups to design the simulated scenarios. They were free to create or choose existing simulated scenarios. A digital model is generated using their familiar 3D modeling software, which they will then import into *Fuzor* to insert their desired HVRI. During the process, they aim to achieve the goal of human-computer interaction in the virtual environment and explore the problem in presenting their design through interaction practice. They also observed if such architecture details can be easily understood by laypersons through their designed interaction. In the whole design process, a series of VR equipment are provided for students to explore the availability of HRVI, such as HTC Vive, Table-top VR projection, and other controller devices such as gamepad and *leapmotion* (Figure 1b).



(a) (b)

Figure 1. (a)Task arrangement and software training; (b)Demonstration of different human-computer interaction practice.

4. EXPLORATORY RESULTS

4.1. GROUP 1: GAMIFIED ENVIRONMENT

The first group of students took the game “Monument Valley” as the design prototype to build a gamified interactive scene (Figure 2). Firstly, they designed a background based on their interests: in a quiet night, a little boy has to overcome many difficulties to climb to the top of the lighthouse and obtain the key to the future. Secondly, they used *SketchUp* to create a basic model of the whole scene. In the process of modeling, they not only considered the unique properties of geometric shapes such as cubes and cones, but also adopted parametric modeling to improve the accuracy and complexity of the scene model. Finally, they carried out the creation of simulation scene special effects, audio, and video import and interactivity test in the *Fuzor* platform.

In order to make the whole game scene more vivid, they added a rotation mechanism in the scene. When the tester approached, the mechanism would be triggered, the geometry obstructing the path would rotate, and then the stairs would appear in front of him. In the stage of scene improvement, team members have tested in virtual reality scenes many times to explore the experience of different trigger mechanisms in response to distance and rotation speed of the obstruction. In addition, they also tried to add scene animation effects and model elements to enhance the fun of the tour process. They selected scene elements by actions and gestures of the testers when they first entered the immersive scene and combined with participants' subjective feedback. In the end, they decided to introduce water and cave elements into the scene.

In the actual operation process, how to make the scene vivid and interesting and let the participants successfully complete the whole process is the main difficulty they face. Therefore, they tried to give the scene a vivid story background and introduce the corresponding background music and special effect sound in different scenes. In the course of HVRI testing, they found that although the testers can successfully complete all the hurdles, due to the interference of the surrounding environment and the narrow size of the moving path, the testers cannot quickly and accurately determine the moving path. Therefore, during the post-debugging process, they optimized the spatial proportion of the scene and added prompt information to assist the passers-by to complete the game. In the process of the experiment, some members were responsible for observing the behavior activities of the experimenter. They took the expression and language feedback of the experimenter in different scenes as the criteria to evaluate the quality of the scene design. If the scene design was successful, when the scene passed through dangerous stimulation, the experimenter would scream or the body would produce defensive action, and vice versa. They took the feedback of the behavior and expression of the tester as the focus of interaction design research, explored the action and expression feedback of the tester in the game scene, and hoped to use it as the basis of HVRI in architectural design, and provided the evaluation basis of subjective feedback for the designer. It can be seen that HVRI method can be implemented in an immersive interactive scene, combining the physical activities of participants in the virtual scene and subjective feedback results to improve the construction of the architectural space scene.

Figure 2. Design process and outcome by Group One.

4.2. GROUP 2: SMART ENVIRONMENT

The second group of students had an in-depth discussion on the construction of the indoor scene of the building, and tried to introduce their idea of the interior design, and try to realized it in this workshop (Figure 3). Firstly, they choose to design a smart environment in the small villa building, and construct the typical scene. In *SketchUp* platform, the existing building model was refined, and tables, chairs, sofas and other indoor furniture were introduced. They also considered the outdoor landscape, adding outdoor fountains, flower beds, lawns and other architectural sketches. Then, they imported the completed building model into the *Fuzor* software simulation platform, and design the scene animation. The music effect corresponding to the instrument was added in the piano room, and a series of triggering actions were set. When the reader came to the piano room, clicked on the instrument, the indoor light and music could be turned on at the same time. Finally, the scene was optimized in the virtual reality device. In order to let visitors fully understand the overall situation of the building, they also designed the outdoor environment of the whole building according to the changes of the four seasons of the year. When observing the night effect of the building, they found that the experience effect of the building was very different from the real environment, so they added the trigger switch of the indoor light.

This group of students explored the application of virtual reality technology in the interior space design of buildings by using the HVRI method. Due to the participation of students majoring in visual communication design, the scheme of this group was more inclined to scene design and display. Therefore, how to let the experimenter quickly understand the design of the whole interior scene and attract their attention was the main difficulty they face. They chose to add scene sound effects and trigger sound effects in special scenes to gradually bring users into the scene through the sound environment.

In the process of HVRI method pre-test, they found that a single outdoor environment could not accurately express the lighting changes of indoor space. Therefore, during the later debugging process, they added the outdoor environment of rain and snow, day and dark days, and the experimenter could automatically switch to different weather as required. This group of students used the form of questionnaire feedback to evaluate the interior space design. After completing the whole scene experience, the tester would fill in the questionnaire according to his real experience results. The questionnaire includes four aspects: spatial layout, spatial color, interior furnishing layout and outdoor landscape layout. They hope to explore the subjective feedback of the tester in the virtual reality scene to the indoor and outdoor space according to the simple architectural space layout, and provide theoretical support for the site experience of the complex architectural space in the future.

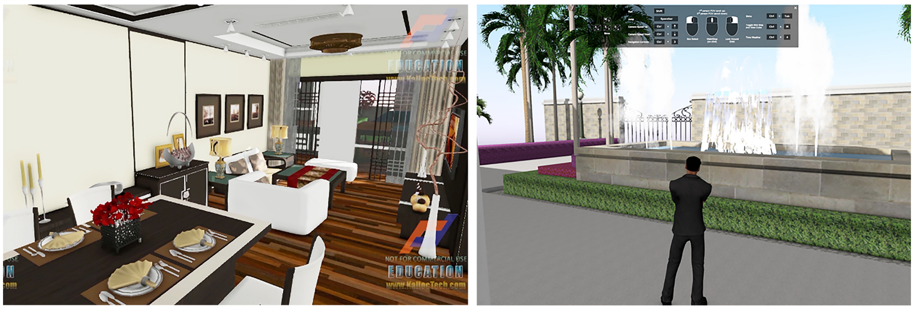


Figure 3. Design process and outcome by Group Two.

4.3. GROUP 3: OPEN-CHOICE ENVIRONMENT

The third group of students used virtual reality technology to explore the interior layout of the existing building space and how they can allow user participation to design the space to state their needs (Figure 4). Firstly, they used rhino parametric modeling method to build the spatial model of the office area. In the process of modeling, they try to restore the characteristics of building space as accurately as possible. They then imported the model into *Fuzor* and added scene special effects in the room. When approaching the glass door, through the interface prompt, the experiencer can click the trigger button to enter the room. When the experiencer approaches the model display rack, the display model will generate corresponding action special effects and play related introduction content. At the same time, an introductory video of the office area will be scrolled on the display in the conference area. Finally, they designed a scene that allows the experiencer to arrange the building space to focus on the purpose of human-computer interaction.

With the help of the *Fuzor* platform, the tester can arrange the interior furniture according to his ideal office space, making the tester not only the visitor of the environment but also the designer of the space. Through the pop-up window, the tester can gradually complete the construction of all space scenes in accordance with the order of the tour. How to create a model base containing a large number of furniture models in the system without affecting the fluency of software operation was their main technical problem. In addition, in the process of importing *Sketchup* models into *Fuzor*, they also need to continuously adjust and modify the proportion of furniture through HVRI method.

In the process, the testers not only designed their favorite scene space, but also had a deep understanding of the proportions of furniture. This group of students use questionnaires and interviews to determine the satisfaction of the testers with the building space. They considered that the layout of interior space is a flexible way of architectural space design, so it was difficult for the tester to express his real feelings with several options in the questionnaire. Therefore, their questionnaire was only the evaluation of furniture types and space forms. The team members will interview the testers to discuss the technical difficulties in the process of space design and the testers' ideas when placing furniture. They hope to use the simple office building space design as the basis to explore the needs of different groups for office space use, and provide a theoretical basis for future office space design.

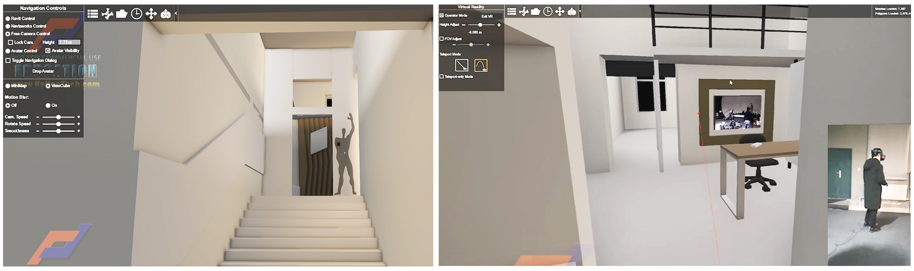


Figure 4. Design process and outcome by Group Three.

5. ANALYSIS AND DISCUSSION

Based on the analysis result, this paper will contemplate future trajectories for the novel strategies to improve HVRI, that one day may lead to genuinely immersive design interaction. By observing the students' application of virtual reality technology and tools to the project design, we believe that the design mode of human-computer interaction design feedback is gradually promoted. The full application of virtual reality software and equipment shows the feasibility of application and promotion of HVRI in the field of architectural design. In the scheme preparation stage, design stage and later practice verification stage, virtual reality tools provide decision-making support for designers in the form of architectural space. But to use virtual reality equipment better, architects need to study software operation and equipment operation.

In the scene design process, all groups of students used the HVRI method to optimize the design of scene, but the focus of each group was different. The first group of students put the focus of the test on the creation of scene immersion effect, hoping that each game scene will give people a unique or vivid and interesting effect. They try to use sound effects and story scenarios to bring the testers into the game. Therefore, they built the basic space in the computer, and the team members tested the built space with HTC Vive equipment and explored the possibility of more changes. After debugging, they use the desktop holographic projection equipment to let more users in the workshop participate in the test process, so as to optimize the whole game plan. They adopt the design idea from HCI to HVRI. The second group of students focused on the display effect of the scene, they want to let the tester fully understand the layout of the building space and the surrounding environment. Therefore, in the process of testing, they introduced seasonal and temporal changes to provide more possibilities for the tester to observe. Since the design purpose of this group is to intuitively show the space scene to the testers, they need more real experience data than the other two groups, so they directly import the built space model into the desktop holographic projection device for debugging. The third group of students is to focus on the open design form, through continuous testing to optimize the proportion of furniture and space size, to bring better experience for the tester. Therefore, this group of students needs to conduct preliminary research and evaluation on the size and placement of furniture and the actual office scene in the early stage of design. After obtaining accurate survey data, they imported the completed spatial model into a desktop holographic projection device for debugging. The design idea of this group of students is to combine the survey results with the HVRI method to design the scene. From this point of view, HVRI is an immersive interactive experience technology that can work closely with other research methods. Through the close cooperation of various research methods, the designer can realize the optimization of scheme design.

Each group of students pay close attention to the experience of testers, actively collect the opinions of testers and feedback the effect of field experience, so as to achieve the effect of HVRI. Since the first group of students is to test and evaluate the game space, they mainly focus on the interest of the tester in the game process and whether there are common operation difficulties in the experience process. They record the time required for each tester to break through the barrier, and deleted the route and content of the scene according to the time when the tester had visual fatigue during the experience. They judge the success of the scene construction based on the tester's language and action behavior feedback during the experience, and use this as the criterion for the tester's behavior judgment in the future HVRI. The second group of students is about the design of the exhibition space, so they pay more attention to the interest of the tester in each space and whether they are willing to complete the whole space tour. Therefore, they not only record the time spent by each tester in the whole experience process, but also record the time spent by the tester in a certain space, and interview the tester after completing the test to ask the space they are most interested in. According to the interview results and the actual experience time of the participants, they show more details of the rooms with higher interest points. They use a questionnaire survey to conduct a post-user evaluation of the constructed architectural scene, and the results provide theoretical support for the future experience of the complex architectural space.The third group is to explore the open space, so they spend more time on the feasibility of the furniture layout in the space and the fluency of the tester's operation process. Different from the other two groups, in the process of experience, the team members try to discuss the possibility of indoor furniture placement with them, so that the team members can be clearer about the needs of the tester, and pass the operation and technical guidance to the tester when appropriate. Therefore, they integrate the time required by the tester to complete the whole process, and set prompts under the key options node to improve the fluency of the interaction experience. They use questionnaires and interviews to comprehensively understand the satisfaction of the testers with the architectural space, and provide a theoretical basis for the future design of office space. In conclusion, HVRI method not only provides more possibilities for interaction design, but also provides more options for users to evaluate and feedback.

6. CONCLUSION

This paper believes that HVRI, a new human-computer interaction method, can help to make the relationship between human and virtual model closer and provide decision support for all stages of architectural design. It provides an innovative and efficient design method for architects. So that the designer can experience the real building scene and display the image of the two-dimensional interface in the three-dimensional immersive space. It can complete the construction and design of the relevant content of the scheme in the virtual scene, and truly realize the collaborative interaction between the experiencer and the virtual reality device. This method makes the form of architectural design more diversified, and the design results closer to the needs of users.

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