Exploring the Possibilities of a Virtual Reality Aided Architectural Design System

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Creating a visual 3D model is a vital part of the architectural design process. In architectural scenes, immersion is important to perceive the connection between various aspects. The general interaction cannot meet the needs of immersion. The immersion and interaction of virtual reality (VR) allows architects to feel and design spaces better. However, VR is currently mainly used only for visualization and walkthrough of the architectural space. The design process is still done using modeling software. This paper proposes a method of architectural design in virtual reality, allowing designers to experience the model created in real-time and improve the design. The use of visual mesh positioning and ray limits can help users create accurate architectural models. The paper also applied the innovative design method to the participatory design process and showed that architectural design in virtual reality can improve design quality and better meet the needs of users.

Keywords: *Digital Architecture Design, Interaction, Virtual Reality, Design tool, Virtual modeling*

INTRODUCTION

Three-dimensional architectural model plays a positive role in improving the efficiency of architectural design. Architects are beginning to use more realistic visualization mechanisms in their design processes (Shiratuddin & Thabet, 2002). At present, the existing design tools cannot completely solve the immersive problem of virtual models. The general human-computer interaction interface is based on WIMP (Windows, Icons, Menus, Pointers). This way has been relatively mature after years of development. However, this approach does not allow people to experience architectural space. In addition, this human-computer interaction is not natural enough. The emergence of virtual reality technology has made it possible to expand the way of human-computer interaction. Virtual reality is a simulation in which computer graphics are used to create a realistic-looking world (Burdea & Coiffet, 2003). At present, with the progress and development of computer technology, virtual reality technology has been applied more and more in architecture. Virtual reality technology has three characteristics: immersion, interaction and imagination (Burdea & Coiffet, 2003). Different from the general interaction method, virtual reality can enable users to better experience the design space, which is conducive to improving the quality of design. This paper proposes a method to create house

type in virtual reality. By using game engine Unity and virtual reality device HTC Vive, a set of virtual reality design platform can be built. The platform allows designers to immerse themselves in the design of their buildings and interact in a more natural way. This platform is conducive to non-professionals to participate in the design process and reduces the cost of communication between non-professionals and designers.

RESEARCH OBJECTIVES

The existing CAAD software is very unfriendly to non-professionals. Virtual reality technology has broken the general form of architectural expression and lowered the threshold for non-professionals to participate in architectural design. In addition, the current architectural design process mainly uses mouse and keyboard as the interaction, and this human-computer interaction is not natural enough. Virtual reality technology makes it possible to innovate human-computer interaction in the process of architectural design. This study proposes a method to accurately create architectural models in virtual reality, which can expand human-computer interaction in the architectural design process. General virtual reality modeling software cannot achieve accurate modeling. This paper proposed using a visual grid to help users to locate. By limiting the collision point detection of gamepad ray to the grid intersection point, the virtual object can be created with accurate values. This will create a model that can be used in subsequent phases. The user can communicate with the designer and make suggestions on the design through this method in the early stage of design. Designers can also use this method to experience the design space and improve their design.

THEORETICAL BASIS

With the development of computer technology, there are not only two-dimensional and three-dimensional ways for the expression of architecture, but also immersive ways. Considering that most buildings are built for users, the users' experience with the building is particularly important. Users' participation and feedback on the design are valuable for designers. In addition, the human-computer interaction of virtual reality technology is an innovation compared with the general way. Using the gamepad and helmet, people can immerse themselves in virtual space, which is conducive to the evaluation of architectural design.

Application of virtual reality technology in architectural design process

When virtual reality technology first appeared, it was mainly used by architects to introduce design concepts. The characteristics of immersion make virtual reality technology have great advantages in expressing spatial experience. Virtual reality technology can break through the general form of expression, beyond reality. This is the main application mode of virtual reality in architectural design process. In the early stages of design, the use of virtual reality helps to understand spatial concepts. VR can be used for three-dimensional creation and interaction, modeling work (Schnabel, Wang & Seichter, 2008). In the mid-design phase, VR allows designers to experience the design space and adjust the design according to the effect. At the later stage of design, the combination of VR and BIM can lower the user's operating threshold, allowing users to experience the design space in real time. The system can also add the function of simulating physical dynamics (Yan, Culp & Graf, 2011).

Affordances of virtual reality and its impact on architectural design

Affordances refer to the fact that in order to interact with virtual objects, the user needs to perceive how the object is likely to change (Gibson, 1977). Affordances are properties related to the observer's body, sensorimotor ability, and intention, and related to the subject's perception and activity in the environment. By providing the observer with the possibility of different perspectives and increasing the content of the interaction, you can increase affordances (Grabarczyk & Pokropski, 2016). Virtual reality allows

users to view the environment and objects from various angles, increases the interaction content of users, and satisfies the corresponding relationship between users and virtual roles, so it has affordances. Based on this, the use of virtual reality to carry out participatory architectural design can meet the user's experience needs, so that users have a more sense of participation in the design process. Users can map themselves to virtual objects, observe the design results in all directions and modify the content in real time during the design process.

Advantages of using virtual reality in architectural design process

The general human-computer interaction limits the user's experience of space, resulting in deviations between results and imagination. Therefore, the application of virtual reality in the process of architectural design can better solve the problem of insufficient space experience. The introduction of virtual reality technology into the process of architectural design is helpful to improve the quality of design. The interaction of virtual reality shows that people can interact well with the virtual world. In order to be immersive, the technology should be inclusive, extensive, surrounding, vivid, compatible, and contain a story. Inclusive means that virtual reality prevents external stimulation of users. The technology of extensive, surrounding and vividness has the characteristics of wide vision, multi-sense and high simulation. Compatible and storyline refers to the fact that the virtual world stays in sync with the user as they move along, and that there is a certain plot theme (Slater & Wilbur, 1997). The virtual reality that meets these requirements is highly immersive, allowing designers and users to better experience architectural space. The immersion of virtual reality allows designers and users to better experience architectural spaces. Imagination allows the virtual scene to get rid of limitations. Specifically, the immersive three-dimensional environment influences multiple senses, allowing the users to better focus and absorb more information (Donalek et al., 2014). When a user wearing a helmet mounted display, the user will be completely surrounded by a virtual environment, and then experience the immersive space (Suh et al., 2005). Virtual reality provides a high level of immersion, and it provides an opportunity for architects and users to evaluate the space better (Lo & Gao, 2020). In addition, VR provides the possibility for the visual interaction of intelligent data, and users can interact with data more intuitively (Al Bondakji et al., 2019). In a word, architects can use virtual reality in the design process to experience the space well and get different feelings from multiple angles. Users are also able to participate in the design process better and interact with the data, and the final design of the space can meet the requirements.

Characteristics of the application of VR to participatory residential building design

The interaction of VR is more in line with people's natural habits, so the application of virtual reality in the process of participatory architectural design is conducive to the communication between architects and users. With the development of urbanization, high-rise residential buildings are gradually increasing. High-rise residential buildings in high-density cities have several characteristics. First, due to the urban population concentration, the scale of residential buildings is large. Second, users have a great demand for personalization. Third, construction industrialization leads to the reduction of the production cost of components. Based on the current problems, open building theory can meet the needs, and it requires users' participation. The design process of large-scale housing can be broken down into several simple tasks can achieve the goal of the user and the architect to design together (Lo, Schnabel & Moleta, 2016). Virtual reality is conducive to user participation and can achieve personalized customization of their own residential space. Architects can design residential buildings according to users' opinions and improve the quality. Users' participation in the design will make the final product adapt to diverse needs.

Diversity of virtual reality human-computer interaction in the process of architectural design

There is much room for innovation in the human-computer interaction of virtual reality. The existing human-computer interactions include virtual three-dimensional interaction, gesture and body interaction, mobile device interaction, voice interaction, tactile interaction, multi-channel interaction and so on. Many interactions are being investigated, and using gestures and tactile feedback to interact with virtual objects can improve the design experience (Camacho et al., 2019). Body recognition and interaction can also be connected with virtual reality, making it easier for users to interact with the virtual environment (Zhang, 2012). The integration of these interactions can promote the efficiency of using virtual reality in architecture. The use of virtual reality technology in architectural design will innovate the interactions and become more humanized.

A DESIGN TOOL USING VR TO EXPAND HUMAN-COMPUTER INTERACTION

VR-Aided Design

This paper introduces VR-Aided Design, which is a digital tool for user participation based on virtual reality. This digital tool uses a 3D display device and interactive input methods. The tool can import traditional design data and make precise modifications to the model. This program expands human-computer interaction in the process of architectural design, and reduces the threshold for non-professionals to participate in the design. This program realizes accurate modeling in the real sense by using the function of grid positioning. The development platform adopts the game engine Unity, and HTC Vive as the hardware support of virtual reality equipment. The Unity game engine has the ability of fast rendering and real-time interaction, which can be used for VR system content creation and interactive content programming. Unity and HTC Vive can work well together to create virtual reality applications.

Accurate creation of VR-Aided Design

The virtual design modeling platform proposed in this paper explores the accuracy of virtual reality modeling methods. Common virtual reality modeling software realizes the creation and simple interaction of virtual objects. Users can directly build simple objects in the virtual environment. However, current modeling software is still unable to accurately create architectural models. While the free creation approach allows users to be creative, a model that lacks the values cannot meet the needs of construction. In this paper, the platform uses grid location to solve this problem. We import a 0.5m grid picture into the virtual environment, and then match the size of the grid in Unity (Figure 1). Users can see an accurate grid plane after entering the virtual environment. We have optimized the gamepad's ray location function. When the user's gamepad points at the grid, the mark cube created is forced to be positioned at the intersection of the grid. All of the user's creation is controlled by the grid, so the exact value of the object can be obtained. For example, when the user is given a floor plan of the house type, the user can position the walls according to the grid plan. In addition, the grid can help the user determine the spatial scale, move and modify the furniture. The two-dimensional grid determines the size of the object, while the height information can be adjusted to the user's desired value in the software.

Figure 1
Grid plane and ray positioning of VR-Aided Design

Figure 2
Creates walls with a specified value on the grid

Implementation Logic and interaction of VR-Aided Design

Our platform is developed using the Unity game engine. It mainly solves several technical points. The grid plan is designed by external software, then imports them into Unity and matches the units with Unity. Since it is necessary to use rays to locate and create large-scale models in the future, we set the mesh accuracy to 0.5m to help users to identify in the virtual environment. Then we transferred the interface of HTC Vive device into Unity and obtained the functions of gamepad buttons and rays. After importing the grid plane, we designed the gamepad ray. The Handle ray design is a black straight line. When the user enters the virtual environment, the ray can be directly used to point to the grid points that need to be determined. This action allows the user to estimate the length of the object. We get the point of collision between the ray and the grid plane. When the user's rays collide with the grid plane, the script reads the coordinates of the position points in real time. When the user presses the trigger key, a cube with a width and height of 0.1m is created as a marker.(Figure 2) We have optimized the positioning accuracy to ensure that the marker points are created at the grid intersection. When the user points to another grid intersection with a ray and presses the trigger key, a second mark cube is generated based on the coordinate of the collision point. The midpoint of the line between the center points of the two marked cubes is the coordinate of the generated strip wall. Because the high wall will block the user's line of sight, we first use the rectangular cube to locate the plane, and design the layout of the house on a two-dimensional scale. When the whole wall position is determined, the user can undertake the arrangement of furniture. To make it easier for users to interior design, we preset furniture modules. Users can point a ray at the furniture they want. The ray carries out collision detection with the furniture components to obtain the coordinates and transfer them to the position of the handle. The user then uses the ray to position the grid, releasing the button at the specified location, and the coordinates of the furniture are transferred to the intersection point of the grid. In this way, the layout of the interior furniture can be designed and adjusted. After the furniture and the wall are positioned successfully, we set the MENU button on the handle. The height of the wall can be changed by using this key. Users can set the height of the wall by themselves. The default value is 3m. After the walls are formed, the enclosure of the space is determined. With the help of HTC Vive hardware devices, users can directly roam the space in the virtual scene. For spatial components that do not feel appropriate, the user can use the handle ray to change the position. The user can adjust the spatial layout in real time while roaming.

Testing and analysis of VR-Aided Design

This paper uses a case to test VR-Aided Design. In this paper, the design of an urban village youth apartment for undergraduate architectural education is selected as an experimental project. When college students just graduate, their career development is in the initial stage and their general income is low. Considering the economic problems, their living conditions will be relatively compact. Therefore, taking college students as experimental subjects for research is in line with the project user goal. This project site is located in Guimiao New Village, Nanshan District, Shenzhen City, Guangdong Province, China (Figure 3). The project is positioned as a youth residence in an urban village. The main users are young peo-

ple who have just entered the working stage. Low-income users have higher requirements for space utilization. The project was designed to meet the individual needs of the user and to achieve a complete residential function in a compact spatial layout.

Figure 3
Project site

This paper designs a participatory design experiment to test VR-Aided Design. The experimental process is to first let the architect design the overall building shape according to the external conditions, and then let the user participate in the design by using the platform (Figure 4). The project is located at the boundary of the village in the city, surrounded by roads, so the overall design adopts a semi-enclosed way to create a quiet interior space. On this basis, the volume was reduced to reduce the influence of sunlight in the west. After that, the public space and the terrace were added to improve the efficiency of the space (Figure 5). This time, 20 students were recruited to participate in the experiment. The students are mainly in automation, computer science, electronic information, etc., and the experiment arrangement ensures a multi-disciplinary background for non-professional users. Students directly used the VR-Aided Design platform to enter the virtual reality and designed the house type content under the conditions limited by the architect. The youth apartment project is mainly a single apartment of 48 square meters, and the modules are limited to the functional scale of 4m units. Students can choose three 4m*4m plane modules for combination and arrange the furniture (Figure 6). Then the architect adjusts and optimizes the house type design according to the user's data, and lets the students experience the design results. After experiencing the scene in VR, students filled in a questionnaire to evaluate how well the house type design meets the needs. The user also gave a subjective rating to the house type design. Using these data, we can intuitively evaluate the overall design quality and analyze the promoting effect of VR-Aided Design on participatory design.

Users' participation in design as a part of the experiment can help architects understand users' needs. Some users wanted more ventilation, so a ventilation corridor was designed in the house model. Some users wanted to see more views, so more windows were added on the side facing the inner garden. To meet the personalized needs improved the users' satisfaction. Users first used the platform to create a model and expressed their ideas directly. Due to the lack of professional knowledge by non-professional users, architects were required to adjust the design. The architect adjusts the layout of the house according to the user's design advice in VR-Aided Design, so as to design the final house type (Figure 7).

At the end of the experiment, we asked users to fill in a questionnaire to evaluate and score the design. Our questionnaire is divided into three questions. The first question was to ask the user how much VR-Aided Design helped them express their ideas. The second question was to ask how well the design results meet the users' needs. The third question was to ask users to give subjective ratings to the design. The results showed that 85% of users thought the platform helped them express their personalization ideas well or very well. By using the platform, they can communicate more directly with the architect. In addition, 80% of the users felt that the final design was good or very good in meeting their needs (Figure 8). Through this experiment, it has been proved that VR-Aided Design has a good role in promoting participatory design. Users had a high enthusiasm for this participatory design process and were more willing to provide design advice to architects.

Figure 4
Design of experimental flow

Figure 5
The architect determined the overall shape according to the constraints

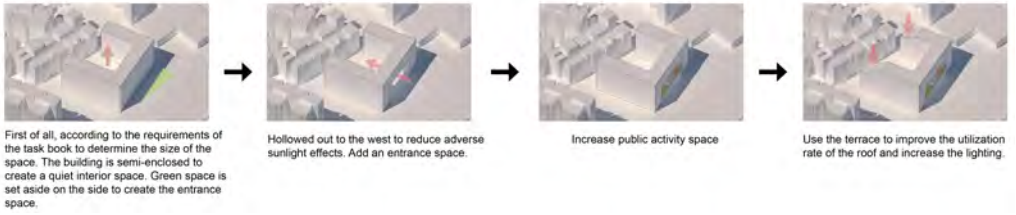

Figure 6
Students participated in building house types and arranging furniture

Figure 7
The house types designed by the architect with the help of the users

APPLICATION

Accurate building modeling tool in virtual reality

There have been many examples of virtual reality modeling, but a large amount of software has ignored the need for accurate modeling in architecture. Models created by existing products are not available for subsequent use due to the lack of precise values. To solve this problem, this paper proposed using a visual grid. The user can measure and directly build the model that conforms to the real data. This precise modeling makes architectural design in virtual reality possible. The architects will be able to control the spatial scale more accurately. Users can also directly use the tool to create and layout interior spaces that are consistent with the real world. Precise creation advantages help to truly integrate virtual reality into the architectural design process.

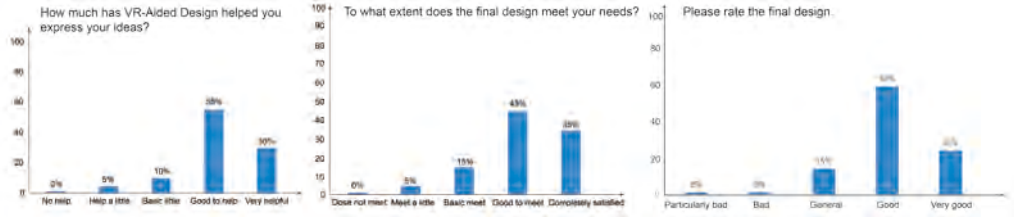

Figure 8
Users' evaluation analysis diagram

The tool for user participation in architectural design

As a virtual reality modeling platform, VR-Aided Design can help users to participate in the architectural design process, so that the final design can better meet the needs. The existing 3D modeling software can meet the needs of architects to create models. However, these software operations are relatively complex, and can not be well involved in the design of non-professionals. VR-Aided Design can be used as an auxiliary tool in the process of adjusting the design scheme. This tool can promote the public participating in the design of personalized high-rise residential. At present, China's urbanization process is accelerating, and the mass construction of high-rise housing in big cities leads to the boredom of apartment types. VR-Aided Design can be used to solve these problems.

The tool for designers to experience space

General architectural design tools cannot help architects to experience space. Architectural design assistance method based on VR can help architects to experience the space while modifying the design. This method is conducive for architects to adjust the overall layout according to the actual space effect. Virtual reality breaks through the general form of architectural expression and helps to better reflect the spatial effect. As a tool for design experience and modification, VR-Aided Design can be introduced into the architectural design process.

ADVANTAGES OF VR-AIDED DESIGN

Make it easier for users to participate in design

Based on the features of virtual reality, the platform can reduce the user's operation difficulty. After a long time of development, three - dimensional software has been equipped with powerful modeling functions. Existing 3D modeling software, such as Rhino, SketchUp, Maya, etc., can fulfill the requirements of architectural design very well. However, with the diversification of functions, the complexity of operation has also increased, and non-professionals need a higher learning cost to operate. VR-Aided Design is based on the interactive characteristics of virtual reality, which reduces the difficulty for non-professional users to participate in the design. Users can use a few simple keys to complete the design content, and express their needs directly. Compared with the common 3D modeling method, this kind of participatory design experience is more interesting, and users are more willing to try it.

Real-time virtual roaming

The virtual reality platform allows real-time viewing of the design results. The operation of 3D software is mainly presented in the form of perspective, which can clearly express the spatial relationship. However, users can only observe the model with a two-dimensional screen, and cannot perceive the space. Virtual reality allows users to experience the space more directly and see the results of the design in real time. The users will feel more present.

The design results are more consistent with reality

The model created on the platform has a scale closer to reality, and the results match the reality more closely. The existing 3D modeling software restricts the user's perception of the real scale, and the user can only judge whether the scale is appropriate by experience. The model created in virtual reality lets the user feel the real scale directly, so the design results will be more in line with the reality.

FUTURE IMPROVEMENT DIRECTION OF VR-AIDED DESIGN

VR-Aided Design uses virtual reality technology to innovate the interaction in the process of architectural design, but there is still much room for improvement in human-computer interaction. This paper proposes the following directions.

- The interaction should be more varied. At present, the interaction of VR-Aided Design mainly relies on the handle and helmet display of HTC Vive. While the immersive feel of virtual reality allows users to experience the designed space, the way controllers interact doesn't come naturally to people. The operation of the controller is not friendly to the first user. In addition, most controllers provide fewer interfaces, reducing the diversity of interactive feedback. Therefore, the addition of new interaction plays a positive role in improving the design efficiency of the platform and reducing the difficulty of operation. Existing human-computer interaction methods, including gesture and body recognition, can be connected to improve the usability of the platform and allow users to design more freely. In the future, when the platform is integrated with other interactions, the architectural design process based on this platform will become much easier.
- The accuracy of human-computer interaction needs to be further controlled. Currently, VR-Aided Design relies on the grid to position and create. Since the design required an overall control over the building, the platform required a variety of scale view transitions. The user should be able to create the model on multiple scales and translate it into real scales in real time. Subsequent platforms will add tools for scaling to design the buildings at different scales.
- The platform can add the function of parametric modeling. In the future, the current parameterized modeling platform can be connected to VR-Aided Design, so that people can interact with the parameterized virtual model more directly. Designers can create the desired objects in the virtual environment at will. The design process will become more efficient.
- The platform can add the process of digital construction. The precise design of the model can then be connected to the digital construction software in the subsequent process. The solid model can be obtained directly through 3D printing. Due to numerical and scale control, the usability of the model is guaranteed, and subsequent digital construction is also possible. VR-Aided Design has a certain innovation for the design process. The design can be automatically generated using parameters at the beginning, then the model can be evaluated and modified by architects and users in virtual reality, and finally built digitally. This process improves the efficiency of digital design. The finished product of the design can also meet the needs of users better.

CONCLUSION

This paper summarizes the characteristics and advantages of virtual reality in architectural design process, and points out the potential of virtual reality in participatory residential design. The application of virtual reality technology not only helps users and architects to better understand the space, but also provides opportunities for non-professionals to participate in the architectural design process. This paper proposes a virtual reality modeling platform VR-Aided Design.

In view of the problem that the general virtual reality modeling platform can not achieve accurate creation, a method of using visual grid plane to help users determine the value is proposed. In this paper, a project is used as a case to test the user participation design of VR-Aided Design. Through questionnaire analysis, VR-Aided Design can help to express ideas. Users can use VR-Aided Design to participate in the design process to better meet the needs. VR-Aided Design can be used as a tool to participate in architectural design. The platform can also be used as an auxiliary design tool for architects to experience space. In the future, VR-Aided Design can not only use more interactions, but also improve the accuracy and increase the function of parametric design.

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