Virtual Reality in Architectural Design

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1 author:

Chiu-Shui Chan
Iowa State University

VIRTUAL REALITY IN ARCHITECTURAL DESIGN

CHIU-SHUI CHAN
Department of Architecture, Iowa State University
482 College of Design, Ames, Iowa 50011-3093, USA

Abstract. Virtual reality represents a fundamentally revolutionary way of interacting with computers. It also is a powerful new medium of expression that is still evolving and changing. In this paper, systematic studies of VR and its applications in design are described. The major historical development of key components constituting an updated and contemporary VR system are illustrated. Based on the advantages, disadvantages, and limitations found in the current development, potential methods of generating a design tool are explained to explore future possibilities. It is hoped that by combining VR and the new information technology, VR can be used as a design instrument to increase creativity and as a research tool to meet the diversified information media challenges to be encountered in the 21st century.

1. Background Introduction

Two terms are applied to the world of information technology: cyberspace and virtual reality. The term "cyberspace" was first used by William Gibson (1984) in the book entitled *"Neuromancer"* to illustrate the imaginary world experienced by engaging within a globally networked data space. Therefore, cyberspace indicates the data space of the computer. All data are entered by the system users. And virtual reality means the world users experience while using the data system. It involves more emotional situations than what cyberspace can offer. In this paper, the definition of virtual reality refers to the data space in which some subset of human senses can be stimulated and reflected.

Virtual reality (VR) environments provide an immersive experience in which participants wear tracked glasses to view stereoscopic images, listen to 3-D sounds, and are free to explore and interact within a 3-D world. As an advanced human-computer interaction and interface tool (Durlach and Mavor, 1995; Mine, 1995a; 1995b), it not only provides diversified media for visually, aurally, and interactively experiencing architectural design (Ellis, 1991a; 1991b), but also allows designers to perceive, grasp, and move three-dimensional building elements in the VR space.

In a VR space, virtual displays surround users with three-dimensional stimuli. Users have a sense of inhabiting a new place instead of looking at a picture. With sensory immersion in the VR space, users become a part of the environment and can perceive and visualize the surroundings by walking around the space. For architectural designers, applying VR will enable them to understand the spatial qualities of their own designs intermediately, and will be able to comprehend their works by walking through the virtual space to visualize the color and texture of assigned materials, proportions of the spatial layout, and the aesthetic expression of structural elements. Therefore, VR will become a valuable visual tool for architectural learning and teaching, and is now in the rapidly developing research stage.

2. Evolution of Virtual Reality

In the following, the history of the evolution of major components needed for constituting a VR system is reviewed briefly.

2.1. HEADGEAR

The most significant aspect of VR is that it gives users the impression of actually being in a synthetic world rather than simply perceiving images and events. The earliest development to produce such an effect were stereoscopes, holographic stereograms, and 3-D film shown on a wide-screen motion picture system attempting to immerse viewers. An early experiment which closely approached the contemporary VR systems is the Stereoscopic Television Apparatus for Individual Use (STAIU) developed in 1957 by Morton Heilig. He designed headgear for the STAIU which included wide-angle optics and individual lightweight display screens for each eye of the viewer. Extending this idea further, he designed the Sensorama Simulator in 1961 to incorporate "color, visual movement, 3-D sound, breezes, odor and tactile sensations." Both STAIU and Sensorama were based on a pre-determined model of user perception instead of allowing users to determine substantial aspects of his or her own experiences.

2.2. HEAD-MOUNTED DISPLAY (HMD)

Ivan Sutherland's work represented the first step towards creating a VR beyond the flat screen of the monitor interface. It was the first computer-based head-mounted display (HMD) developed at MIT in 1966. This helmet-like device earned the nickname "Sword of Damocles" due to the mass of hardware that was suspended from the ceiling and hung over the user's head, and featured two video displays. Sensors connected to the HMD recorded the user's head position and movement.

2.3. HELMET

In 1982, Thomas Furness developed the "Super Cockpit," a flight simulation system which was designed to assist training pilots to fly high-speed aircraft. Test pilots wore the oversized helmet and sat in cockpit mockup. This specially constructed helmet allowed the pilot to see a computer-synthesized environment on the inside of a shield. The pilot's glove was lined with position sensors so that by pointing to virtual buttons various functions could be controlled.

The flight simulators later initiated the VR technology in real time animation, display hardware, and sensor electronics by the American National Aeronautics and Space Agency (NASA) to develop the field of telepresence--the use of VR to place humans in inaccessible and hostile environments. In particular, NASA has developed remote sensing and manipulation systems for inaccessible site exploration. Another helmet developed by NASA enables astronauts working inside a space station to visualize a robot operating outside. This remote sensor controlling system was further developed to allow the helmet to be used together with a data glove for passing signals of hand and finger movements to the robot.

2.4. GLOVES AND JOYSTRING

In music, Thomas Zimmerman and L. Young Harvill created a DataGlove (a virtual hand) to strum virtual guitar strings on a virtual instrument. One important aspect of glove technology offers users the ability to feel the weight, texture, and pull of various materials and objects. A significant example was developed by Frederick Brooks, Jr. at the University of North Carolina in 1968 to handle radioactive materials through a remote manipulator device to simulate the force-feedback. In the 1980s, a joystring was developed by Richard Feldman to generate appropriate force through the manipulation of a T-Shaped joystring control. The computer reads the user's movements through shaft encoders and generates appropriate force.

The research into VR technologies conducted by the military, space agencies, and industry has spread into other areas such as toys and video war games. Those developments concentrate more on challenging a user's manual dexterity, hand-eye co-ordination, quick reactions, and the ability to predict likely developments. In medicine, surgeons can rehearse complex operations in VR prior to surgery, and drug designers focus on the molecular structure of diseases through new VR simulations.

2.5. CAVE AND C2

The CAVE, conceived by Tom DeFanti and Carolina Cruz-Neira (1992), is the most advanced and sophisticated display. With a 10'x10'x9' three-sided theater, participants can get inside the cube and be surrounded by images. The high resolution of the projected images and the large scale of the immersive space provide an excellent environment for scientific visualizations. The second generation of CAVE named C2 installed at Iowa State University has attracted much research.

3. Development of VR in Design

Until now, architects have had to communicate their design ideas through scale models and perspective drawings. If clients wanted changes, drawings and models needed to be redone. A tool that allows the clients to visit the design and to walk around in it before it is built, would benefit architects and clients tremendously.

Frederick Brooks at UNC had modeled the new computer science building, Sitterson Hall, with working drawings as a guide. Using a powerful graphic computer, the viewpoint can be positioned anywhere in the model for rendering. By controlling speed and direction, consecutive interior and exterior images can be generated. With the use of a treadmill and handlebars, users can physically walk down hallways. Other programs for architectural walkthrough were also developed at UNC to generate a visual tool for evaluating design concepts (Brooks, 1986).

The first commercial VR product for marketing design concepts is the virtual kitchen designed in April, 1991 by Japan's Matsushita Electric Works. Customers can experience what a custom-built kitchen will look like (Bylinsky, 1991). These computer simulations provide designers and clients valuable knowledge that can be used to improve the environment and design. John Walker, one of the founders of Autodesk, started the "Autodesk Cyberspace Initiative" in 1988. Applying the VR peripherals of glove and goggles (head-mounted display), they started VR in PC platforms. The first product is the core of a new object-oriented 3-D simulation language entitled "Cyberspace Development Toolkit." This toolkit provides programmers with an easy way to create complex virtual environments.

Detailed introductions to the VR history and current development can be found in Pimentel and Teixeirz (1995). Other information about VR in design are in Bertol (1997).

4. Characteristics of VR

VR systems are rapidly developing along with the quickly advancing computer hardware and software technology. Currently, the most advanced platform to run VR efficiently and powerfully is the Silicon Graphic Machine. Five features describing the characteristics of VR systems are: (1) three-dimensional viewing, (2) dynamic display, (3) users are active navigators, (4) the image displayed in the VR is from the point of view of the user's head, and (5) multimedia interaction (Stuart 1996). VR is a human-computer interface in which the computer creates a sensory-immersing environment that interactively responds to and is controlled by the behavior of the user. Thus, two extraordinary features exist in the VR scene: immersion and interactivity.

4.1. IMMERSION

The success of creating a VR environment isn't whether the created virtual world is as real as the physical world, but whether the created world is real enough for viewers to suspend their disbelief and to create the experience of being there for a period of time. This relates to the notion of immersion which means to block out distractions and focus selectively on just the information with which you want to work. In order to achieve this immersive effect, the image of the world on the display is viewed from the perspective of the user (that point which is being manipulated by the control). Thus, the explorer of a virtual environment will view that world from a perspective akin to that of a camera placed on the explorer's head, rather than on a fixed camera position and viewpoint.

The effect of immersion is similar to that of an audience and a theater production. Only when the audience is immersed in the theater will their attention focus on the actors' performances. If a theater has an immersive atmosphere, then through setting, drama, and music, audiences are invited in the performers' story. When it works, the theater has the power to engage the audience and hold the audience's attention. This immersive experience can convince, teach, and inspire.

4.2. INTERACTIVITY

Interactivity is a crucial aspect of VR which has two dimensions: navigation within the world and the dynamics of the environment. Navigation is the user's ability to move around independently. It also relates to the capacity of the number of degrees of freedom provided by the VR software. The dynamic of the environment is the flexible positioning of a user's point of view. It could be used, for example, to move through the design of a new building as if in a wheelchair to test whether it really will be wheelchair accessible.

5. Methods of Modeling a VR environment

There are many ways of generating a VR space, although the generic procedures of constructing buildings in the SGI platform have the following sequences. It is necessary to first collect floor plans, elevations, and other documentation of the building. A solid building model can be constructed by the MultiGen program or any 3-D package and saved into DXF file format transferable to the SGI machines for visual display.

The key program of VR is the MultiGen software available in SGI machines. To import a DXF file of the building model into the MultiGen application, the file needs to be converted to an FLT file via VisModel or Converter. The converted FLT file will be accepted by MultiGen for adding details, modifying the curvilinear shapes, assigning color and materials, setting up lighting, and textural mapping of the model for realistic rendering purposes. After the model is fully developed, users can use Performer package and the function of Perfly for navigating through the space. These are the basic procedures of constructing VR architectural models.

6. Representation of VR

In VR, viewers can navigate through the space and quickly get a computer-generated 3-D image perceived as a perspective view. In generating a realistic scene, buildings can be modeled by any of the 3-D solid modeling software. However, to accurately represent the reality in the VR space to obtain the effect of immersion, realistic representation is the key issue.

To honestly reflect the color and texture of building materials, a rendering package can be used to create a very close image and texture, mapping it onto the surface of the modeled objects. Users also can take photographs of real objects, scan them through the scanner, and map the scanned image to the modeled object. These methods apply to the construction of grass, clouds, and sky for the VR environment. On the other hand, there are difficulties in representing the landscape, especially, trees, flowing water, fire, rain, smoke, and mountains. Although the techniques of texture mapping can be utilized to generate a still simulation image, it will lose the sense of reality in the animation mode. One solution is the fractal programming technique. By generating a large number of fine and particle elements three-dimensionally, a landscape simulation will be more realistic although adding the risk of using a large amount of computer memory.

The other issue about representation is the level of detail and accuracy which are the criteria for evaluating the success of architectural models. The higher the level of detail and accuracy that can be expressed in a model, the more realistic it will appear. Of course, more time, effort, and memory size are also needed to complete the building model.

7. Design Tool in VR

Most of the VR environments require the completion of a building model before it is imported and displayed in the VR space. In other words, design can't be executed transparently and directly in the VR space, and its product can't be visualized intermediately. As such, the technology sets up limits to the flexibility and plasticity of its application in the design processes, which is a drawback. For example, a full-scale model can show every building part. Designers are able to discover that a beam is not in the right position, and the entire section of a building needs to be redesigned and the model rebuilt. After the remodeling is done, a new model is needed. In the current VR setting, one can not go backwards and compare the new with the old version just by reloading a database. Therefore, an on-line computer system and methods of saving design data are needed.

Meanwhile, a designer has difficulty designing in VR without having any tools available. If there are building materials and modeling operators available in virtual space, designers can simply select and execute rather than constructing the building model outside the VR space. This is the notion of building a CAD system to help with design (Sutherland 1965, Foley et al. 1990). An ideal CAD in VR should have selection icons as inventories stored in VR for 3-D modeling. Similar efforts can be found in 3DM (Butterwork et al. 1992) and ISSAC (Mine, 1995a).

To enhance design in VR to make it more productive and user friendly, it is necessary to install a CAD in the VR space. This is one of the ongoing projects of Architectural Design Virtual ENvironmenT (ADVENT) at ISU. The goal of ADVENT is to set up a design environment in which design activities are executed, metaphorically speaking, by manipulating and constructing three-dimensional building blocks. The 3-D building blocks are any 3-D building materials stored in the VR space. Users can apply any 3-D elements or customize their own building elements (e.g. structural parts, special columns, beams, bricks, etc.). In this system, design thinking occurs while operating the 3-D elements to construct the concepts of the designer.

8. Research Tool in VR

A VR system can be utilized as a tool for observing a designer's thinking process to understand how information technology and virtual reality affect design thinking.

8.1. TOOL FOR STUDYING DESIGN PROCESSES

The designer's mind has been compared to a "black box" because it is impossible to see what happens during the creative process (Chan, 1997). To understand the design thinking processes, an intermediate environment is needed allowing users to see the design sequences and to save them as data for later redisplay. A VR system can provide a suitable intermediate environment. The concept is to apply the Internet technology to coordinate multiple VRs and users into a net system. The increasing availability and use of the Internet have opened up opportunities for designers to collaborate with each other in ways not previously possible. The impact of geography, with its tyranny of distance, has been changed dramatically. Through the net system, designers can now work on the same design at different geographic locations either synchronously or asynchronously.

One component of the net system is network connections for sending interactive data across the net to share and exchange design experiences. In such an environment, designers can visualize any design changes simultaneously and offer feedback. Issues of transmission time delay and local versus remote processing (Biocca, 1992; Mine, 1995b) need to be resolved for efficiently transporting files to users on various platforms. Another component of the net system is certain data recording mechanisms capable of saving the processed information for later manipulation. For instance, the sequences of arranging columns, staircases, and openings will show personal design methods for structural arrangements and principles of circulation. If the sequences of designing are stored and displayed again, critiques can be given based on visualizing the process. The saved data also provide resources to simulate the design process and to visualize the cognitive aspect of creativity.

8.2. TOOL FOR STUDYING DESIGN CREATIVITY

In architectural design education, most students are staggered by the lack of a clear understanding of better design processes and have no definition of creativity. Many students, therefore, do not have a good approach to design and the quality of their design work is not satisfactory. To rectify this situation, a better understanding of the nature of design processes and the factors that foster design creativity may provide opportunities to improve these deficiencies. If designers have a better understanding of the phenomenon of design processes, they will know the paths that lead to a more efficient way to design. If the definition of creativity is well set up, designers will be able to find ways to improve their ability to design a better living environment.

In order to explore the "myth" of creativity, to describe what happens during the design processes, and to provide a means to increase creativity a VR recording system can be applied. The design data generated and saved by the VR system will yield potentials for: (1) the designers to visually understand their design processes three dimensionally, which will provide hints to broaden the creative sources to achieve a higher level of creativity; (2) instructors to have a wider angle of observing students' processes of design generation for better critiques and pedagogies; and (3) researchers to have significant data to study the designer's processes of creation. Efforts to develop such an interactive environment, in which architectural design can be seen intermediately, will create a new world for the design profession that will break with convention and improve design quality.

9. Future of VR in Design

Traditionally, architectural design begins with an idea. The two-dimensional concept is then sketched on paper and a three-dimensional model is constructed to evaluate the designed product. This convention is very much culture-bound and it limits stimulation and inspiration for idea generation. The phenomenon of providing diversity during a design yields the potential for improving design quality. In the design profession, diversity will broaden personal vision, enrich the memory of mental images, and stimulate multidirectional thinking.

Although architects have used a pencil-and-paper medium to translate ideas into physical products for generations, computer technology has revolutionized architectural representation during the past decade. A design product can be displayed on a computer from various angles with amazing visual effects. Changes are easy to make and results can be shown instantly. The interactive nature of the computer technology is an excellent teaching tool. Virtual reality promises even more. Users of virtual reality actually experience the environment created by the computer. Applying virtual reality in an architectural design studio, students can understand the spatial qualities of their own designs immediately, visualize the color and texture of materials, comprehend the major components of the HVAC system, experience the proportion of the space, and appreciate the aesthetic of the structural elements. VR will make possible the expression and construction of ideas never before dreamed possible. Design studios taught in this fashion will be very effective.

Providing such VR environments at different locations and linking them together, designers can see and share information. If the system can collect data which is sent to different sites in different countries, designers would learn various design principles, methods, and processes inherited in various design cultures. Potential clients can visualize results and provide feedback instantly. Efforts to develop an interactive environment, in which design can be seen intermediately, will create a new world for the design profession to break with convention and improve quality. VR will not only change the way we communicate, it might also change the way we think.

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