A Critique of Virtual Reality in the Architectural Design Process

Technical Report: R-94-3

Dace A. Campbell
Human Interface Technology Laboratory
FJ-15
University of Washington
Seattle, WA 91895

and

Department of Architecture
208 Gould Hall, JO-20
University of Washington
Seattle, WA 98195

Maxwell Wells
Human Interface Technology Laboratory
FJ-15
University of Washington
Seattle, WA 91895

ABSTRACT

An addition to a building was designed using virtual reality (VR). The project was part of a design studio for graduate students of architecture. During the design process a detailed journal of activities was kept. In addition, the design implemented with VR was compared to designs implemented with more traditional methods. Both immersive and non-immersive VR simulations were attempted. Part of the rationale for exploring the use of VR in this manner was to develop insight into how VR techniques can be incorporated into the architectural design process, and to provide guidance for the implementers of future VR systems. This paper describes the role of VR in schematic design, through design development to presentation and evaluation. In addition, there are some comments on the effects of VR on detailed design. VR proved to be advantageous in several phases of the design. However, several shortcomings in both hardware and software became apparent. These are described, and a number of recommendations are provided.

INTRODUCTION

The architectural design process can be broken into the following phases: schematic design, design development, presentation and evaluation, detail development and construction documents, bidding, and administration of the construction. In the schematic design phase the overall characteristics of the building are established. Significant issues are identified, and initial design decisions are made. During the design development phase the specific character and intent of the entire project are described. The presentation and evaluation phase is an iterative process during which proposals are presented for review by a client, review board, or design jury, and design decisions are finalized. Following the approval of the design, details are developed and construction documents are produced. These may be a combination of working drawings and written specifications which serve as a legal description of what is to be built. As the construction documents near completion, they are released for bidding, and a contractor is selected. The final phase of the design process is the one in which the architect administers the construction, interpreting changes and judging perfomance [7].

Throughout all of these phases, architects find themselves perfoming a variety of tasks, ranging from the most creative to the utterly mundane. Computers were introduced to the architectural profession with the hope that they would free architects of the mundane, manual tasks, as well as aid in the management of information. Use of Computer-Aided Design (CAD) has grown over the decades. It has aided in the automation of tasks and in the management of information, especially in the later phases of the design process.

However, CAD has had little impact on the earlier phases of design. Thus, there is a point in the design process when architects and designers must make a mental leap from sketches and study models to CAD representations in two or three dimensions.

Efforts are being made to encourage the development of CAD systems to enable their use by architects earlier in the design process [5,6]. An important prerequisite for the increased acceptance and use of CAD is an interface which will allow architects to create and interact with their digital designs more intuitively. Virtual reality (VR), perhaps the most advanced of three-dimensional interfaces, has much potential for enhancing the way architects and designers interact with their digital models [2,4].

VR has been proposed as a useful new tool for architects and designers [3,8]. It is recognized that most of these benefits (and subsequent use of VR by the design professions) will occur only after further advancements of the technology [1]. However, the specific advancements that are required can only be identified and implemented after extensive use of the technology. This iterative cycle of use, assessment, redesign, and use results in tools which are better suited to the job. The method of redesigning tools by observing how they are used is a common one among ergonomists and human factors professionals. The rationale is that accomplished users are best able to recommend and assess changes.

The goals of the project described below were to explore how architects can use today's virtual reality technology in the early stages of the design process, and to gain insight into its advantages and shortcomings. From this insight, it was envisioned that specific recommendations could be made for advancements of the technology. In addition to a general observation of the use of VR in the design process, our exploration focused on four issues. These were:

The effect of the type of interface (immersive or non-immersive) on the designer's ability to study the design.

The effect of the level of abstraction of a complex 3-D space on the perception of that space.

The utility of VR as a design medium during the earlier phases of the design process.

The utility and acceptability of fly-throughs as a tool for representing and presenting architectural designs.

METHODS

To explore these issues, we analyzed a design project implemented by a graduate student of architecture. The eight-week project was carried forward using available VR technology. The design project was an addition of a conference room and exhibition gallery to a building on the campus of the University of Washington and was part of a design studio for graduate students in architecture. Typical of most student projects, the designs from the class were developed from schematic design, through design development, to presentation and evaluation. It was not intended that the project cover into detailed development or the production of construction documents. The design represented with VR technology was compared to designs generated by other students, whose projects were designed by hand and with traditional 2-D and 3-D CAD.

PROCEDURES AND APPARATUS

In its earliest stages, the design was developed with sketches and small physical models. The information from these was input into a CAD modeling program. The database from the CAD program was then exported and converted for use in real-time fly-throughs with the VR technology. These simulations were recorded onto VHS tape for record keeping and for further study of the design. A detailed journal of the design and simulation processes was kept for later analysis.

The CAD software used was formZ (from auto.des.sys), a three-dimensional modeling software package hosted on a Macintosh computer. Data Interchange Format (DXF) files were exported from formZ and converted into two different formats on a weekly basis.

In one process, the DXF files were converted to Description of Geometry (DOG) files. These files were simulated in real-time with software in development at the Human Interface Technology Laboratory. The simulation software was run on a DEC Alpha 600 with a Kubota Denali 6/20 graphics board. The simulation was viewed on a high-resolution monitor (19", 1280x1024 resolution). Navigation through the virtual environment was accomplished with a Spatial Systems Spaceball, which allowed control of motion in six axes. These fly-throughs were not immersive.

In the other process, the DXF files were loaded into Autodesk 3dstudio (3DS), hosted on a DOS platform, and saved as 3DS files. These files were then converted to script (MAZ) and geometry (VIZ) files for use by dVISE software from Division. These converted files were then used in immersive simulations on a PROvision 200 system, also made by Division. This simulation was viewed on their Virtual Research Flight Helmet (360x240, 90-degree field of view). Head motion was tracked magnetically using the Polhemus 3Space Tracker. Movement of the head caused appropriate movements of the visual information on the Head-Mounted Display (HMD). Navigation through the virtual environment was accomplished by pointing the head in the intended direction of travel, and pressing a button on a hand-held wand.

THE DESIGN PROCESS

Schematic Design

A proof of concept demonstration was first attempted while the design was in early schematic development. During this earliest phase of an architectural design there are only rudimentary ideas to be represented. Therefore a "massing" model of the design, one in which only the basic forms of a design are represented without detail, was generated, translated, simulated and recorded. Once the DOG files were created and some initial changes were made to the model's orientation in the coordinate system, we added three lights to the simulation: a blue ambient light representing the sky, a yellow directional light representing the sun, and an orange point-light source tracked to the participant to aid in the perception of distance. A wireframe grid was also added to give a sense of horizon, to aid orientation in this initial environment. At this stage, the simulation was viewed with an untracked Optics-1 HMD, but the small field of view (23 degrees) and lack of head tracking did not allow adequate assessment of the design.

Design Development

The design was developed over the next several weeks, and each week a fly-through was conducted and recorded. It became apparent that the delay between the conception and visualization of design ideas did not provide direct or immediate feedback in the design process. However, the simulations did provide a way to examine the CAD model, to detect flaws in its construction. The simulations allowed the opportunity to evaluate design elements such as proportion, scale, and order; these things were not immediately apparent to designers using CAD models alone.

As the model was developed, the frame rate of the simulation dropped from fifteen Hertz at the beginning to about five Hertz. A significant challenge in the design process became the issue of level of detail. In order for the simulations to be of significance to the designer, the model had to be developed in such abstraction that the frame rate of the simulation was reduced appreciably. Decisions about how to abstract the design were made by the designer, based on aesthetic judgement and design sensibility.

About mid-way through the process, we enhanced the realism of the representation. The horizon grid was replaced by massing models representing the urban context of the design. The CAD database was organized into layers, and by exporting the CAD model by layers as multiple DXF files, we were able to assign unique colors and transparencies to an otherwise opaque and monochromatic model. These colors and levels of transparency were adjusted in real time using a dial box to adjust color (RGB) and transparency (alpha) values. Additive transparency was used to represent glass objects because other transparency algorithms (such as subtractive) proved to slow the frame rate to unaccepable levels. Texture mapping was also attempted, but the textures vibrated (swam) in the simulation, due to lack of resolution in the system (floating-point round-off error). Interactive section cuts, which would provide the capability to cut sections through the model with clipping planes in real time, were also considered. However, there were problems with getting the clipping planes to operate as desired.

Abstract elements of trees, furniture, and people (entourage) were added to the model to enhance the sense of scale. After experimenting with flat-shaded and wireframe representations, we found that by making the furniture transparent, the degree of which could be controlled in real time, it enabled us to evaluate the spatial implications of the design with and without the furniture. This was a useful design feature. Finally we added live video footage as texture maps, to represent the location and character of display and projection screens in the design. In this case, the swimming of these textures was imperceptible due to the motion of the video footage itself.

Detailed design

The use of VR early in the design process forced the detailed development of the interior space as much as the exterior. By having the opportunity to "go inside" the design and see it from within, the designer was forced to solve complex connections and details which would not have been apparent with other media. The design developed much more than those of other students not using VR as a design medium. With VR, the designer had to develop the entire three-dimensional model to a convincing level of detail, whereas other students concerned themselves with only specific views and details.

Once the model was colored and detailed such that there were more than 10,000 polygons to be rendered, the simulation slowed to unacceptable frame rates (3-4 Hz). In order to continue to develop the design in greater detail, a separate model was generated representing a portion of the design. This second model was then developed to a high level of detail not easily accomplished by traditional architectural modeling methods. When this was simulated, we found that the Spaceball and monitor (non-immersive VR) aided in the perception of details and connections, but it was quite difficult to maneuver in tight spaces. It was necessary to view the model more intuitively so that the details and connections could be more easily studied. At this point, we attempted immersive simulation with a tracked HMD and wand. This was a whole new paradigm for evaluating spatial qualities of the design. The frame rate was extremely low (1-2 Hz) and therefore quite disorienting, but we were able to inspect details and connections quite competently by having more intuitive control over the viewpoint.

In both the immersive and non-immersive VR, flying through the design, as opposed to walking through it, had some advantages as well as some disadvantages. Flying provided a means of adopting viewpoints that could not be easily achieved in the real environment. This was useful for inspecting interior details, or for evaluating the exterior of the building from a number of viewpoints. However, there was a certain loss in the sense of scale due to the absence of any effort required to move locations. This suggested a need for some type of treadmill to improve the navigational interface.

Presentation and Evaluation

This project included not only a study of architectural representation, but also of presentation. The VR system involved was not available for the presentation and evaluation of the design, so the real-time simulations were recorded weekly onto VHS tape for periodic review by design critics. The video was presented to the instructor of the design studio on a weekly basis, as well as to guest design critics (juries) throughout the duration of the project.

Initially, we found that the critics were unable to successfully critique the design with the VHS tape alone, because it was displaying a walk-through without pausing on certain aspects of the design which merited discussion. In later walk-throughs, we paused at specific views and details, anticipating that the critics would prefer to discuss those particular aspects. These presentations were also supplemented with drawings and still frames of the simulation, to allow the critics to refer to them as the video of the walk-through moved on. Unlike other student presentations, no physical presentation model was built. When the presentation consisted of a mix of video footage and still images, the critics were then able to succesfully critique the design.

DISCUSSION

VR is already a useful tool in the design process. There are, however, issues which need to be addressed as VR technology is integrated into the design fields:

Immersive vs. Non-Immersive VR

Both immersive and non-immersive VR were useful in the design process. Immersive VR, with a tracked HMD and wand, offered the designer a better perception of space and the opportunity to see the design from the inside. At the scale of a person within the building, the designer was able to examine details and connections more intuitively with an easy-to-control viewpoint. This became very useful later in the design process, as the designer was able to detect minor flaws in the model.

Non-immersive VR, with a monitor and spaceball, offered higher resolution and higher frame rates, both of which became necessary as the model increased in complexity. The non-immersion offered easier and quicker manipulation of the viewpoint. This was useful for moving around the exterior of the building for fly-throughs for presentations.

Level of Detail

Once a critical threshold of detail was represented in VR, the designer was able to perceive spatial characteristics of the design that may not have been apparent with other design media. Before the complexity of the model reached a certain level, the use of VR as a design tool seemed to be a viable, but not a unique, tool of representation.

The real-time simulations became more useful as a design tool as the level of detail of the model (color, transparency, and geometric complexity) increased. However, the level of detail needed to be kept in check to keep the frame rate at an acceptable level. The challenge presented by this conflict required both the generation of a second, more detailed model, and the skills of the designer to abstract the models. Although more powerful geometry engines are continually being developed, it is unlikely that we will ever be satisfied with the level of detail that can be simulated in real time. This may indicate a need for new ways to display complex geometry to the viewer, both in terms of rendering algorithms and in terms of the arrangement of the database.

New algorithms need to be developed such that complicated objects can be displayed with a certain level of abstraction. Currently, designers and modelers must make decisions about which aspects of a design are most critical to its character, and remove polygons which are not. This process is time consuming and subjective, relying on skills and intuitions of the designer or modeler. It would be more beneficial to design in digital media if there were algorithms to simplify geometry yet maintain its aesthetic character.

In addition to such abstraction in the display of complex geometry, the database could be arranged in a "hyper-geometry" format. Such a format could be developed so that higher levels of detail are represented only when a specific portion of a design is being studied. With the database arranged in such a manner, a designer in a room, for example, could pick a specific object or detail, and be presented with more information (geometric and alphanumeric) about that particular condition of the design. Such a "hyper-geometry" format would be consistent with the way architects are accustomed to representing their designs, with overall views as well as blow-ups and studies of typical and atypical details.

Immediacy of the Medium

Because the simulations were perfomed weekly, after exporting and translating files from the CAD database, there was no immediate feedback from the walk-throughs. Although VR was useful for evaluating the three-dimensional model, it was not useful during the conceptualization of the design. Instead, the design was developed using a combination of sketching and three-dimensional CAD modeling, followed by simulations in real-time.

If an inclusive modeling package was available to designers during conceptualization of design ideas, digital models could be generated in much the same way that physical models are constructed to enhance the perception of a design developed by drawing. If the VR medium could provide the immediate feedback of CAD or more traditional design media, it is entirely possible that VR could replace "modeling" as CAD is replacing (or has replaced) "drafting."

Two-dimensional media offer a limited means of representing three-dimensional space. Three-dimensional media enhance the perception of three-dimensional space. Designers need a digital design medium which allows them immediate, direct, and more intuitive control over their three-dimensional design, and VR can help. An inclusive, three-dimensional, world-building toolkit that matches the sophistication of today's CAD software would supplement, but not replace, other design media. Such software is sorely needed before VR can significantly enhance the design process.

Presentation Tool

The videos of the walk-throughs to present this project gave design critics the opportunity to visualize the design as it developed. They replaced the need for physical models and made clear what was not apparent in CAD drawings. The response from design juries was very positive, much more so than expected. Design critics often found the taped "walk-throughs" very convincing and conveyed that the design would make a very believable building. This says much about VR as a presentation tool; professionals and design critics, not just clients and laypersons, are able to visualize ones design intentions more clearly with VR than with traditional means of representation.

However, several design critics and jury members commented that they would have gotten more out of the experience had they been able to walk or fly through the design themselves rather that depend on views from a particular path flown for the presentation. A VR system was unavailble to them because of the high cost and complexity of moving it to the place of presentation. Even if the system was available to them, it would have been time consuming for each of them to walk through the design individually, and awkward to discuss the design with others not experiencing the simulation in three-dimensions. Clearly, this problem could be addressed by the introduction of an inexpensive, multiple-participant VR system.

RECOMMENDATIONS

Develop an HMD with higher resolution.

Develop methods for moving through virtual environments which do not contribute to a decrement in the sense of scale of space.

Develop algorithms which can abstract detailed geometry in a way which retains the aesthetic character of the represented object.

Develop a "hyper geometry" format for management and display of complex databases.

Develop sophisticated, immersive world-building toolkits for use by architects and designers in virtual environments.

Develop inexpensive VR systems that accomodate multiple participants and real-time communication.

ACKNOWLEDGEMENTS

We would like to thank Marc Cygnus for his help with programming and the real-time simulations. We would also like to thank instructors David Miller, Brian Johnson, and Jim Davidson of the College of Architecture and Urban Planning at the University of Washington for their advice and insight in this project.

REFERENCES

1 Airey, J., Rohlf, J., & Brooks, F. P. Towards Image Realism with Interactive Update Rates in Complex Virtual Building Environments. (25-28 March 1990). Computer Graphics: Proceedings of 1990 Symposium on Interactive 3D Graphics, 24(2), pp.41-50.

2 Astheimer, P., Felger, W., & Muller, S. Virtual Design: A Generic VR System for Industrial Applications. (November/December 1993). Computers & Graphics, 17(6), pp. 671-677.

3 Brooks, F. P. UNC Walkthrough. (August 1989). ACM SIGGRAPH `89 Course Notes: Implementing and Interacting with Real Time Microworlds, Course 29.

4 Brooks, F. P. (1993). Virtual Reality--Hype or Hope: What's Real? In Proceedings of the IEEE Symposium on Research Frontiers in Virtual Reality (p. 3). Los Alamitos, CA: IEEE Society Press

5 Furness, T. A. (1987). Designing in Virtual Space. In W. B. Rouse, and K. R. Boff (Eds.), System Design. Amsterdam: North-Holland.

6 Lansdown, J. (1994). Visualizing Design Ideas. In L. MacDonald and J. Vince (Eds.), Interacting with Virtual Environments (pp. 61-77). Chichester, England: Wiley.

7 McGinty, T. (1979). Design and the Design Process. In J. C. Snyder and A. J. Catanese (Eds.), Introduction to Architecture (pp. 152-190). New York: McGraw-Hill.

8 Schmitt, G. (1993). Virtual Reality in Architecture. In N. M. Thalmann and D. Thalmann (Eds.), Virtual Worlds and Multimedia (pp. 85-97). Chichester, England: Wiley.