Design Evaluation Based on Virtual Representation of Spaces

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When spaces are evaluated, clients and architects often discuss design proposals by looking at scale models. This overhead perspective forces viewers to imagine themselveslooking and seeing about within the model. Misperception may well result from such a point of view. With the advancement in virtual reality (VR) technology, and with its rising popularity in architecture, it is becoming plausible to consider using VR to evaluate design projects.

The projects presented here are of three types:

1. The first project compares people’s evaluation of several slightly modified virtual models of a space.
2. The second project compares how people evaluate a front view model of a space to how they evaluate a virtual representation of the same space.
3. The third project compares people’s evaluation of a real space to that of a virtual representation of this space.

The wide range of results presented provides one argument in support of using VR simulations to study spaces and how they are perceived. For example, results show that a virtual window serves to alleviate perceived crowding and that added furniture serves to make a virtual room feel slightly larger and less constraining. However, problems do emerge with using virtual reality simulations to gain information about people’s behavioral reactions to a space. Thus, one all circumstances under which VR representations are used create valid results. Differences appear to lie in the type of evaluation measured (e.g., dimensional versus behavioral). More research is needed to clarify this issue.


Introduction

The term virtual reality (VR) is used by many and in many ways. To some, VR is a specific collection of technologies (e.g., head mounted displays). To others, the term can be stretched to include movies as well as pure fantasy. In the context of this paper, virtual reality is defined as a way for humans to visualize, manipulate and interact with 3D computer generated worlds.

The purpose of this paper is to assess the potential for using virtual reality simulations to evaluate design proposals. Generally, studies using virtual reality have not concerned themselves with the validity of such simulation as an evaluation tool in architecture (Pinet 1996a).

A few such efforts in the discipline of architecture are taking place. For example, at the Human Interface Lab (University of Washington, Seattle), Davidson and Campbell (1996) use shared real time virtual spaces to review and evaluate a design proposal through collaborative discussions in VR. They point out potential pitfalls in human interfacing with such approaches and present suggestions about how to overcome these pitfalls.

The work of Henry (1999) and Henry and Furness (1993) more specifically focuses on evaluating how accurate perception of virtual spaces is in predicting perception of real spaces. Similarly, Snowdon et al. (1995) address the subjective component of perception in VR. Furthermore, research at TASA’s Marshall Space Flight Center (Vacca 1995) uses anthropometric information to assess the validity of VR by comparing task performance in a real space to that in a virtual representation of the space.

However, to this day, research in this area remains embryonic. We are at a time where VR is starting to reach a larger part of professionals in our field. ArchiCAD recently incorporated QuickTime VR (from Apple Computer) into their software (Sullivan 1996). Autodesk created the Cyberspace Development Kit, a package using C++ to create interactive VR applications. With the continued development in VR technology and with its rising popularity in architecture, VR will be used more commonly to evaluate spaces before they are built.

content

The projects presented here involve the design of a simple waiting room. Such a space was used to allow the researchers to focus on variations in spatial content without having to cope with complex shapes. It allowed results to be compared with those obtained from pre-existing models of waiting rooms built in the VISTA Lab. Finally, it allowed untrained undergraduate students to accomplish simple research projects in a short period of time.

The projects are of three types:

- The first project compares people’s evaluation of several slightly modified virtual models of a space.
- The second project compares how people evaluate a foam core model of a space to how they evaluate a virtual representation of the space.
- The third project compares people’s evaluation of a real space to that of a virtual representation of this space.

Project One: Data were collected from two groups of undergraduate students: 1. Kathy Hendrick, Anne Gesing, Stacey Keloe, and Amy Chin; 2. Dana Panzarello, Kara Alvey, Becky Patterson and Lynn Langston. Simulations (See Figures 1 and 4) in this case were designed by those untrained undergraduates in the context of a class project. Simulations were created with a simple software called Virtual Walk-Through Pro running on a Windows 95 platform. Walk-throughs were shown on Pentium 100 and Pentium 166 computers with 32 MB of memory.

Project Two: Data were collected by two undergraduate students, Michael Nelson and Jeremy Lear, in the context of a class project.
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Figure 5: Excerpt from the Spatial Evaluation Questionnaire

Tapping into the pre-existing skills of these students, the simulation was modeled using AutoCAD and was transferred into 3D Studio. Simulations were shown on a Gateway 486, with 8 MB of memory, running on a Windows 3.1 platform. The waiting room is simply defined by walls, a floor, and a door opening. Further research on this room also included plants. (See Figure 6)

Project Three: The project consists of a study pursued by the author. It is built with VR Creator 2.0, authored by Vream. 2.0 is a VRML (Virtual Reality Modeling Language) Web browser. (See Figure 8) As explained by Knapp and McCall (1996), the functionality and reputation of VRML is well recognized by Virtual Reality world builders. It provides a standard for uniformity from platform to platform on the World Wide Web. The simulation also includes the use of a VFXI head mounted display with trackers and a data glove by General Reality. The virtual simulation is built on a Cyrix P330 with 32 MB of memory, running on a Windows 95 platform.

Navigation: Davidson and Campbell (1996) explain that guests to a shared virtual space take about 30 minutes to adapt to navigation in the virtual space, which distracts them from their tasks. Thus, a different approach to navigation is used here: An assistant is on site at all times to facilitate the handling of the navigation by following the directions provided by the research subjects. Participants are allowed to move with six degrees of freedom within a particular VR world.

project one

This project was comprised of 1 control group and 2 experimental groups with 20 University students per group, for a total sample of 60 students serving as research subjects. Each group of subjects looked at virtual representations of a waiting room. The first experimental group looked at the same space as the control group (See Figure 5) except that the window was removed from the space. For the second experimental group, two chairs and a table were added to the space used for the control group. Note that the research subjects were not randomly assigned to research conditions (i.e., control, ftest experimental or 2nd experimental condition).

In all cases, research subjects (n=50 students) were brought one by one to sit in front of the computer to view one of the representations of the waiting room (i.e., with or without window, with or without added furniture). The navigation assistant sat to the side, showing the space to the subject. The subject was then asked to answer dimensional, behavioral and affective questions (See Figure 2) about the virtual wait-
ing room while looking at the simulated space. Then, she or he was asked to estimate crowding levels by observing dummies added to the VNR models. Subjects were asked to say when the number of dummies added made the room seem: (1) somewhat crowded; (2) moderately crowded; or (3) heavily crowded. The assistant would bring a dummy in the simulation and position the dummy in the space where the subject indicated it should be positioned. Dummies were brought in and positioned following the same procedure until the research subject felt there were enough dummies in the space for it to feel somewhat crowded. The process then continued until the subject felt the room was moderately crowded and then again until it felt heavily crowded.

**Windowless environment:** Figure 3 presents the average number of dummies per crowding category, allowing a comparison between results from the control group (room with window) and the experimental group (windowless room). These results show that the average number of dummies per crowding category for the windowless VNR room are systematically smaller than those for the VNR room with a window.

In line with this, when subjects are asked how large they would estimate the space to be, subjects evaluated the room with a window as slightly larger (average height: 13.2', width: 15.7', length: 10.3') than that without a window (average height: 16', width: 16.5', length: 8.4'). The windowless room is also evaluated as mildly small and mildly enclosed, whereas the other room is evaluated as mildly large and mildly open (these results are obtained by calculating the median of the evaluations by research subjects).

**Added furniture - spatial crowding:** This VNR model has two more chairs and one more table and is thus spatially more crowded than the control room. (See Figure 6). Figure 5 presents the average number of dummies per crowding category. These results show that the average number of dummies for the moderately and heavily crowded categories for the experimental group room (with added furniture) are slightly larger than that for the control room.

When subjects were asked how large they would estimate the space to be, they evaluated the room with added furniture as almost 5 feet wider (average height: 13.2', width: 15.7', length: 9.6') than the control room (average height: 13.2', width: 13.7', length: 10.3') but differences in the length and height were minor. Note that the furniture added is positioned along the width of the space.
Furthermore, the control room was evaluated as being mildly constraining and being mildly empty, whereas the other room is evaluated as neutral on these two qualifiers. Extensive comments could be made about how this information ties in with previous literature on crowding, furniture and windows. However, in line with the theme of this conference, we choose to focus on representation and on how it influences visual perception of spaces.

The wide range of results presented here provide one argument in support of using such simulations to study spaces and learn about perception. For example, the results suggest that a virtual window serves to alleviate perceived crowding and that added furniture serves to make the virtual room feel slightly larger, less empty and less constraining. Note that the window in Figures 1 and 4 is not transparent enough to suggest openness. You cannot clearly see outside through this window, but the symbolic representation of the window is enough to affect perceived crowding. If there was a view on the other side of the window, the results might be different. Thus, these results should not be carelessly generalized.

The studies presented here did generate clear trends of data about dimensional and affective evaluation of spaces. However, data about behavioral evaluations were not so clear. Questions seeking behavioral information are often referred to how one would act if somebody else was present in the room. Research subjects often reacted by asking the investigator about the gender of the other people present in the room because they felt this could influence their answers.

The avatars used are generic males but are quite neutral looking. (See Figures 4 and 6) This “neutrality” may well have been a source of confusion for our users, suggesting that any characteristics could be added to these non-descript avatars. Thus, behavioral results (here and elsewhere) will probably be unreliable unless avatars with clearer characteristics are used. Fortunately, extensive discussions have been
At the lowest level (i.e., "slightly crowded"), the average of occupants in the foam core model was 29 dummies. The average number of dummies for the "very crowded" level was 35. Realistically, it would be quite crowded to fit 35 people into a room of 3 by 30 feet (approximately 90 square feet), especially given that the research subjects tended to position people in the periphery of the room. By looking at the locations of 35 dummies in the room, we estimate that this typically leaves a bubble of about 1.5 foot radius around each dummy.

Indeed, 90 square feet gives about 12.9 square feet per dummy (i.e., 1.6 by 1.6 feet). Half of that (i.e., 6.8 feet) will give you the approximate radius of a bubble around each dummy. However, since most dummies are actually positioned along the wall, the space around them is actually smaller than that. If all 35 dummies were lined up against the wall at equal distance from one another, since the perimeter of the space is of 90 feet, there would be about 2.6 feet between them (or a 1.3 foot radius) from the core of one person to that of the next. Keeping in mind that the body of each dummy in the space occupies a space of about 1 by 2 feet, you are left with a distance varying from 0.6 to 1.6 feet (1.6 feet minus 0.6 or 1 or 2 feet) between dummies.

According to the classical work of Hall (1966) on interpersonal distances, 1.5 foot is the distance people choose to have with others with whom they are intimate. If there were to be as many people in a waiting room as the research subjects placed in the model, it would be quite uncomfortable.

In the computer simulation, the "very crowded" level had an average of 14 dummies. Following the same calculation process as used above, we find that the average space surrounding each of the 14 dummies results in a 6 foot radius bubble. The average number of dummies at the "slightly crowded" level was 8.8, while the space surrounding each person at this level of a 7 foot radius. This agrees more with the 4 to 12...
foot distance. Hall (1966) suggested it is typical between people in a social situation.

project three
In this project, research subjects were recruited to evaluate a real waiting room or a virtual representation of the same room. (See Figure 8) Each research subject were randomly assigned to a pre-selected set of research conditions. Some subjects look at the real waiting room, some at a virtual representation of it, some look at the room in stereoscopic view, some look at it in monoscopic view, etc. For example, a typical experiment goes as follows: The subject may be assigned to look at the real waiting room, in monoscopic. This subject is asked to wear an eye patch (on the eye of his/her choice) to induce monoscopic vision.

Preliminary results (n=180) indicate that when the space is viewed in monoscopy, average dimensional evaluations of the space [length: 11.9; width: 11.3; height: 11.1] are only slightly different when it is viewed in stereoscopy [length: 11.1; width: 10.6; height: 12.7].

It appears that a natural compensation occurs for the lack of stereoscopic vision. In a analysis of the literature on this subject, Thorpe and Hodges (1995) explain that stereoscopic viewing is particularly helpful when monocular depth cues are absent or ambiguous, when complex and/or ambiguous objects are presented, to provide fine depth or relative distance differences, or when complex 3D tasks need to be performed.

The waiting room presented in this study is simple and subjects are not required to perform any tasks. Thus stereoscopic viewing may not be as crucial to investigating the room as it would under the circumstances highlighted by Thorpe and Hodges (1995). Furthermore, the waiting room does contain clear monocular depth clues. Monocular depth cues refer to the classical artists' depth cues developed by architects during the Renaissance and highlighted by Helmholtz (1866). They include overlap, linear perspective, texture gradients, scale and shading. They provide information allowing the viewer to assess space distance. These clues, along with the context in which the room is studied, allow the viewer to provide a fair estimate of the room dimensions even in monoscopy.

discussion
Clients and architects often discuss design proposals by looking down at scale models. This overhead perspective forces the viewer to imagine him or herself looking and moving about within the model; misperceptions may well result from such a point of view.

With the advancement in virtual reality technology, with its increasing popularity in architecture, and with the emergence of virtual reality as a cross-platform standard, it is becoming more and more plausible to consider using VEs to evaluate spaces before they are built.

The wide range of results presented in this article provide one argument in support of using VR simulations to study spaces. However, problems did emerge with using virtual reality simulations to gain behavioral information because the research subjects wanted to characterize the avatars. Thus, not all circumstances under which VR representations are used will create valid results.

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One might say that the better the simulation, the more likely the results obtained are to be replicable in real life. Indeed, in the comparison of foam core and Vr models, it can be argued that the VR world was the more realistic model since it included colors, rendered lighting, and a realistic point of view. It also generated more realistic assessments of crowding, thereby seeming to replicate real life results better than the foam core model. However, improved realism in modeling does not always result in more realistic assessments of spaces. For example, though stereoscopic vision does add to the realism of VR representations, it did not influence dimensional evaluation of the space studied in Project Three.

Hence it is appropriate to ask “How good must simulations be in order to be valid?” In some studies, researchers find evaluation of real spaces to be very similar to that of computer simulated spaces (Berkner, 1987; Meyer et al., 1988), but for other studies, they do not (Craig and Feiner, 1987; Hetherington et al., 1993; Lange, 1993). Differences appear to be in the type of evaluations measured (e.g., dimensional versus behavioral); and the type of sensory channels of information involved (e.g., stereoscopy, viewpoint).

To this day, research about virtual reality remains scanty. We do not know which sensory information is most useful in creating VR worlds that are believable, and some sensory channels (e.g., touch, smell) are still largely unexplored in VR. More research is also needed to help reproduce human expressions and emotions as well as human movements through avatars. Finally, designers often have a good intuitive sense of orientation whereas beginning VR users often get confused about their position and orientation in VR worlds. Studies are needed to guide our understanding of wayfinding in VR spaces and to find out how to provide cues to help users orient themselves.

Substantial work also remains to be done to further advance VR software. Some VR software (e.g., Walk Through Pro) is easy to learn but it is also very limited in scope. Most VR software is difficult to use for non-programmers. For example, the VR world represented by Figure 8 was mainly built by the author using scripting language. If you are using to object libraries available to you, you will find object libraries in VR to be very limited in content. Finally, though VR provides a standard for uniformity from platform to platform, cross-platform applications are still in their infancy.

Another problem stems from the fact that it can take up to 30 minutes for a new user to learn to navigate through a virtual world. Even if finding your way in the space does not cause you any problem, learning to navigate through the space can, in and of itself, be a challenging task. The awkwardness this brings about may well interfere with the process a client goes through when he or she evaluates a design proposal seen in VR. Yet it is this capacity to freely navigate that allows VR representations to differ from simple walk-throughs. Unlike with walk-throughs, VR makes no previous assumptions about where you look or go, and it frees you to move around and interact with the model. In order for VR to be used to its full potential in architecture, navigational approaches need to become more intuitive.

Despite these limitations, VR already offers an array of opportunities for designers. It is already being used to evaluate design proposals (e.g., Urban proposal to replace San Francisco Bay Bridge presented in Computer Graphics Systems 1995). Unlike traditional modeling methods, VR can provide visual immersion, it allows the viewer to freely move in the space, and it allows interactivity with the spaces. Furthermore, VR has now become affordable. A virtual world can be built using the same computer hardware as that used for CAO. As shown in this paper, VR can serve to model design solutions (e.g., effect of adding a window to a space) and to estimate their potential impact on users.
In fact, VR applications in architecture are emerging in a variety of areas (Pine 1996b).

**Conclusion**

Beyond recognizing the potential for using VR world building in design, it is also important to recognize the role that designers may come to play in this arena. CAD designers can help VR development in many ways. They can use their expertise to help build VR objects libraries. They can help develop more realistic human avatars. These may be necessary for realistic evaluations of behavioral factors in modeled spaces. Finally, CAD designers can help apply architectural knowledge of wayfinding and spatial orientation to virtual world building.

In fact, Pate (1995b) believes that the CAD industry will be a major catalyst to the virtual reality industry. She predicts a need for VR world builders and suggests that CAD designers are well-equipped to become these world builders. Designers have an advantage when it comes to creating believable VR worlds since they are trained to know how to create visually correct spaces. We know where to locate lights and shadows, how to play with colors, and what size and scales are most appropriate to a given context.

This may well open a world of opportunities for our profession. The first experimental virtual villages and cities already exist, complete with people, private homes, museums, parks and shopping centers (e.g. Carl Lorriller’s Virtual Polis, reported by Pimentel and Teixeira, 1995). VR has started to emerge within architecture, but the expedition has just begun. It will take creativity and dedication for us to put it into use.

**References**


Computer Graphics Systems Development Corporation


