

EVALUATING RELATIVE IMPACT OF VR COMPONENTS SCREEN SIZE, STEREOSCOPY AND FIELD OF VIEW ON SPATIAL COMPREHENSION AND PRESENCE IN ARCHITECTURE

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ABSTRACT

In the last couple of years, computing technology has brought new approaches to higher education, particularly in architecture. They include simulations, multimedia presentations, and more recently, Virtual Reality. Virtual Reality (also referred to as Virtual Environment) is a computer generated three-dimensional environment which responds in real time to the activities of its users. Studies have been performed to examine Virtual Reality's potential in education. Although the results point to the usefulness of Virtual Reality, recognition of what is essential and how it can be further adapted to educational purposes is still in need of research.

The purpose of this study is to examine Virtual Reality components and assess their potential and importance in an undergraduate architectural design studio setting. The goal is to evaluate the relative contribution of Virtual Reality components: display and content variables, (screen size, stereoscopy and field of view; level of detail and level of realism, respectively) on spatial comprehension and sense of presence using a variablecentered approach in an educational environment. Examining the effects of these independent variables on spatial comprehension and sense of presence will demonstrate the potential strength of Virtual Reality as an instructional medium.

This thesis is structured as follows; first, the architectural design process and Virtual Reality are defined and their connection is established. Second, Virtual Reality display and content variables are explained and prior research is reviewed. Following this, the dependent variables, spatial comprehension and presence are discussed and hypotheses are generated. A 2^{5-1} fractional factorial experiment with 84 subjects was conducted. Data analyses, results are presented followed by discussion, conclusions and recommendations for future research. This research as part of a larger study is focused on display variables while Nikolic (2007) concentrates on content variables and examined their effect on spatial comprehension and presence. For more in detail information on this joint research endeavor, refer to Kalisperis et al. (2006).

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CHAPTER 1

ARCHITECTURE AND VIRTUAL REALITY

1.1 Architectural Design Process

The architectural design process is considered to be an ill-structured problem, where problem defining is more important than problem solving (Simon, 1973). It can be broken down into several stages: (1) program development, (2) schematic design, (3) preliminary design, (4) design development, (5) contract drawings, (6) shop drawings, and (7) construction (Laseau, 1980). The above mentioned design activities can be categorized as (Coyne & Subrahmanian, 1993): (1) generative – generation of partial solutions, (2) evaluative – evaluation of proposed solutions, and (3) patching – patching incompatibilities in solutions. The architectural design process can be also broken into two stages: the conceptualization and execution stages. Conceptualization consists of problem recognition, problem definition, and problem solving. Execution describes the materialization into a physical form, considered to be highly computable. Computer software mostly support this execution stage (Yessios, 1987).

The architectural design process is an iterative process and the architectural design goes through many phases from its inception to its finish. The "virtual objects" conceived in the "mind's eye" of the designer are communicated through representations (Porter, 1995). Representation is a powerful aid in enhancing the reasoning and creative process and critical to the architectural design process. It takes many forms such as drawing, text, verbal language, or mental images, and always involves abstraction. Abstraction is used primarily because of the complexity of design problems and cognitive limitations on the part of the designer. As such, the medium used by architects should be able to communicate both abstract ideas and a designer's intentions to an audience. To overcome the limitations of one medium, architects and designers began to experiment with different forms of representations.

Starting from conceptual ideas usually in forms of symbolic and abstract representations, designers progress to more detailed and illustrative stages where they have to make decisions about the sizes of architectural spaces, their relative correlation and affiliation with one another, and their qualities and properties. At different stages of the design process, architects choose diverse techniques to represent the designer's intentions and evaluate the created spaces (i.e. sketches, line drawings, perspectives, hand-made and computer models and animation) (Henry, 1992). These representations are generally one-sided and a number of them are typically needed to form a complete picture employing intellectual abstraction. None of these representations can afford the sense of "being there" or walking through them.

Traditionally, one of the commonly used techniques for representation of the design is the hand-made scale model. Though being very close to ideal, the scale models have a serious drawback. They are scaled down and as such, it is hard to imagine one self in them, walking and experiencing the spaces. Even if we were capable of doing so, the experience would differ immensely from the real scale models or previously built project prototypes (Henry, 1992). Over time, hand-made scale models were replaced partly by computer models which have the advantage of unending design modifications. However, this approach to representation transformed three dimensional scaled models into a two dimensional medium with the illusion of depth, and did not resolve the problem of scale. For this reason, computer monitor representations fail to represent the designed architectural spaces better than the traditionally used techniques (Henry, 1992). To improve this medium of representation, computer display would have to offer a more suitable sense of scale, a more compelling sense of depth, and a better equivalent to exploring spaces in real environments.

One potential answer to an improved representation process could be through using virtual reality or computer generated three dimensional environments. These immersive environments have become increasingly popular in many areas in the last decades. What sets apart virtual reality from other traditional mediums are the potential for experiential learning, movement through space and time, and interaction with the design. In addition, it provides for a more qualitative representation of spaces by utilizing three dimensional spatial information, as well as creating the illusion of depth. At the present, virtual reality is considered to be complementary to existing forms of representation, and is not intended to replace them completely. As a medium of representation, it is especially useful in the evaluation stage allowing the design to be seen from the viewer's perspective.

1.2 Virtual Reality

The advance in computer technology brought new approaches to learning such as multimedia presentations, simulations, and more recently virtual environments. Virtual environments, also known as virtual reality, are computer generated stereoscopic three dimensional environments which respond in real time to the activity of their users. Virtual reality capabilities developed greatly during the 1980s and 1990s with its promotion in the mass media (Otto, 2002). In a nutshell, virtual reality represents a computer technology that offers a convincing and intense illusion of involvement of the viewer in an artificial world that exists only in the computer. Features such as head-mounted display and data glove are used to immerse users in computer simulated worlds. That is why the system is often referred to as sensory immersion technology (Otto, 2002).

According to Whyte (2002), virtual reality as a medium is defined by interactivity, three dimensionality, and real-time response to actions. VR technologies create a synthetic world that is immersive, navigable and interactive. Such an interactive environment increases participation and understanding, and improves the quality of decision making (Orland et al., 2001). Five characteristics are essential to a virtual reality system (Orland et al., 2001) and they are: (1) illustrative – information offered in a clear manner; (2) immersive – deeply involves and absorbs the user; (3) interactive – user and computer act reciprocally through the interface; (4) intuitive – virtual information is easily perceived; and (5) intensive – user emotional/experiential responses to persuasive

information. Immersion and interaction are typically used to evaluate a virtual reality system. Furthermore, the level of immersion creates a distinction between: (1) immersive systems – which cover the users' field of view through the use of large screen or head-mounted displays, (2) non-immersive systems – do not cover in full the users' field of view (i.e. small display) or, (3) augmented systems – overlay the virtual display over visual field as the users view the real world.



Figure 1.1: CaveTM



Figure 1.2: ImmersadeskTM

Sources: <u>http://content.answers.com/main/content/img/CDE/_CVTRAIN.GIF</u> <u>http://www.polymtl.ca/rv/rv/Images/immersadesk.jpg</u>

Nowadays, widely available virtual reality systems include flight simulators, CAVETM, or ImmersadeskTM environments. While the flight simulator was developed for industry and military purposes, CAVETM and ImmersadeskTM were created in the academic setting. CAVETM is a projection-based virtual reality system in the form of a cube containing display screens surrounding the users. The immersion is achieved by projecting three dimensional computer graphics viewed with stereo glasses, tracking the movement of the user, and adjusting the perspective accordingly displayed in real-time. ImmersadeskTM is also a projection-based virtual reality system consisting of a screen tilted at a 45° degree angle and covering the viewers' field of view. A user is equipped

with stereo glasses, location tracking sensor allowing an accurate perspective to be generated, and an interactive device enabling immersion. Projection-based systems have an important advantage in enabling interaction and information sharing in a virtual world, and they have been applied in many fields, such as medicine, science and engineering. Although there has been substantial research and development in this area, the potential of virtual reality systems are far from fully explored.

1.3 Virtual Reality and Architecture

Virtual reality emerged quite some time ago as new technology, but only recently has been used for representing architectural space. Architecture as a field appears to be an ideal setting for taking advantage of what virtual reality has to offer, considering the stages of the architectural design process and its issues of representation, perception, cognition, and interpretation (Kalisperis et al., 1998). Increasingly, it is becoming the best solution to represent and be absorbed in an architectural design by enveloping participants in scaled three dimensional worlds and driving them into exploring their environment (Henry, 1992). Due to its attributes, the virtual environment affords the closest experience to the real one and aids its users in perceiving the modeled space as if it were real or already built. Therefore, representing designed space in a virtual environment should be as accurate as possible, helping participants to create valid judgments about modeled spaces during discovery and evaluation (Henry, 1992). This can create favorable communication between an educator and a student, or between a client and a designer. Thus, it would be beneficial to establish how a virtual environment can represent an architectural design, and identify what potential drawbacks might be.

Visualization and visual thinking are main aspects of the architectural design process. The process of visualization generates physiological and emotional responses similar to real-life experiences, hence making the image stronger and more meaningful (Samuels & Samuels, 1975). Markham (1998) identified three main factors contributing to visualization in a virtual environment: (1) immersion – experience concepts intangible

in real world, (2) interaction – move from passive observer to active thinker, (3) engagement – experienced is part of the real world belief.



Figure 1.3: Immersive Environments Laboratory Source: <u>http://www.gettingtoone.org/content/view/60/122/</u>

The ability to visualize space is of utmost importance, especially for students beginning architecture programs. Visualizing space is one of the more difficult skills to acquire (Kalisperis, 1994). One of the reasons is that design students begin their education with very limited personal experience in observing and understanding spaces and forms. The other reason would be that the media used to represent and manipulate space are limited as well (i.e. manual graphics) (Kalisperis, 1994). Therefore in their program of study they are encouraged to explore other approaches to design and its representation, such as digital design. In the Architecture Department, in the College of Arts and Architecture, at the Penn State University, students are given the opportunity to investigate the possibilities of the ITS/SALA Immersive Environments Laboratory (IEL). The IEL has developed as part of architectural design course, and is one of the first to promote virtual reality as part of architectural education and exploration. It provides a large three-screen, panoramic, stereoscopic virtual environment display giving the students an opportunity to visualize their designs on an actual/human scale. Usability studies have confirmed the advantages of key virtual reality system components -

interactivity, screen size, wide field of view and stereoscopic viewing - for architectural visualization in the context of exploring and evaluating architectural designs at all stages (Otto, 2002; Kalisperis et al., 2002).

While experienced architects are good at visualizing architectural spaces, students, builders, and clients may not be. Given that buildings are costly as well as time consuming and expensive to erect, visualization instruments such as virtual environments are justified if they can improve design quality, clients' satisfaction and reduce expensive design revisions (Mandeville et al., 1995). Visiting design spaces mentally and visually is essential for experiencing and comprehending architectural spaces, which is important to the overall design process (Mandeville et al., 1995). Virtual environments can play a main role in facilitating visualization, design and spatial comprehension.

Given that visualization and visual thinking are crucial for design, it would be beneficial to establish the impact of virtual reality systems on design and spatial comprehension. In addition, it is important to determine how accuracy of a virtual environment plays a part in representing architectural design. Since the architectural design process and design comprehension are very complex, a focus on spatial comprehension is necessary to build on spatial skills and design education.

A review of prior research demonstrates that there are some evident gaps. Research on the effects of virtual reality system components on spatial comprehension in an architectural setting has not been extensively explored. Subsequently, the recent onhand studies have a box-centered approach to virtual reality, which means they treat virtual reality technology as one entity. Therefore, empirical assessment of the relative impact of virtual reality system variables on spatial comprehension is hard to extract from the general findings. A variable-centered approach (Nass and Mason, 1990) where the technology is taken apart into its components or variables may be of more benefit. In this way, key variables can be identified and their relative contribution separately assessed. Box-centered approach used previously in the usability studies (Kalisperis et al., 2002; Otto, 2002), was an indispensable introduction to this approach that identified prominent variables of virtual reality system that should be further explored individually. Both approaches have their advantages and disadvantages, but for the task at hand a variable-centered approach seems more beneficial. In this way it can yield more in-depth results on specific variables examined.

The purpose of our study is to apply variable-centered approach and bridge these gaps in examining virtual reality technology. This research can help future users of the virtual environment in using the immersive environments being aware of their advantages and shortcomings. For the designers of the immersive environments these results can guide them in the future improvements of the virtual environment systems.

CHAPTER 2

REVIEW OF PRIOR RESEARCH

2.1 Display and Content Variables

Three virtual reality system attributes - stereoscopy, screen size, and field of view – have proven to be essential in creating a virtual environment appropriate for architectural design representation (Kalisperis et al., 2002). Our study intends to evaluate the relative impact of the selected virtual reality system variables on spatial comprehension and sense of presence. In addition, this thesis as part of a larger study focuses on display variables, also referred to as technological or hardware variables, as opposed to content or software variables that are also incorporated in this research endeavor. For concentration on content variables and their effect on spatial comprehension and presence, please refer to Nikolic (2007), and for more in detail information on this joint research endeavor refer to Kalisperis et al. (2006).

2.2 Independent Display Variables: Stereoscopy, Screen Size and Field of View

2.2.1 Stereoscopy

Visual perception is a complex process having multiple levels and is important in vision and cognition. The human eye, a delicate instrument is the optical interface between the environment and the human visual system (Hubona et al., 1997). In everyday tasks we perform, we have to interpret successfully a multitude of these perceptual cues. They provide information about our surroundings like size, shape, color, motion, and depth.

Perception in the real world uses the abundance of visual cues available. The virtual environment is not in possession of all these visual cues by the very nature of the system. As a result, the ones that are present presume a stronger role. However, the most important visual cues to create a three-dimensional virtual environment are the ones for depth or distance. The key is that these cues should be presented accurately in the virtual environment, especially the stereoscopic cues which affect the relative depth judgment (England et al., 1992).

Previous studies on depth visual cues are numerous and based on these studies we can distribute them in: (1) primary cues (i.e. stereopsis or binocular vision - accommodation, convergence and disparity, and motion parallax); and (2) secondary cues (i.e. linear perspective, occlusion, size, texture, shading and shadow, light, color, etc) (Kelsey, 1993). In the absence of primary depth cues, viewing relies on secondary depth cues. The strongest primary depth cue is stereopsis or binocular vision.



Accommodation and convergence are associated with the eye muscles, and interact with each other in depth perception.

Source: http://ccrs.nrcan.gc.ca/resource/tutor/stereo/chap2/chapter2 5 e.php



Figure 2.3: Binocular disparity

Binocular disparity is the difference between the images of the same object projected onto each retina. The degree of disparity between the two images depends on the convergence angle. Source: <u>http://ccrs.nrcan.gc.ca/resource/tutor/stereo/chap2/chapter2_5_e.php</u>



Figure 2.4: Linear perspective



Figure 2.5: Lighting and shading

Sources: http://www.artyfactory.com/perspective_drawing/perspective_1.htm http://www.cs.duke.edu/courses/fall02/cps124/projects/room/cornell_shadow1.jpg

Advances in computer technology and three-dimensional representations have raised interest in stereoscopic viewing in the last couple of decades. Stereoscopy is closely connected to binocular or retinal disparity and explained by it. Human eyes are approximately two and a half inches apart and the image viewed with both eyes has two distinct reflections on each retina. The brain then puts these two reflections together and processes information on size, shape, color, and location of objects in an image (Hubona et al., 1997). Retinal disparity refers to the two different object images that appear on the retina of the eyes. With retinal disparity we perceive depth while looking at the objects in the space, and they come into view as being closer or further. Without retinal disparity we would perceive all objects as being on one plane or monoscopic (England et al., 1992).

Research on stereoscopy in general is divided over its relative importance as a visual cue in depth perception. Based on prior research, stereopsis is considered to be a powerful, possibly even dominant cue for the relative location, size, shape, and orientation of objects in a three-dimensional space (Hubona, 1999). Stereoscopy has been acknowledged as valuable in many instances such as task performance. Studies were done in the 1990s on the human performance with the aid of stereoscopy in viewing, manipulation and recognition of object images, and relative depth perception (Hubona et al., 1997). Stereoscopic viewing did not consistently support performance, though many studies report that stereopsis augmented certain monoscopic cues and with that helped users' performance in the given tasks.

The main challenge of an architectural representation is to depict design in three dimensions on a surface or display that is intrinsically two dimensional. Another important aspect is to show spatial relationships in the space using certain visual cues (Hubona, 1999). Various depth cues can be used for the illusion, but they have to be rendered in a way as to assist spatial comprehension. Valuable perceptual cues regarding the properties of perceived objects in the virtual environment can come from photorealism and by means of using stereopsis and adding a sense of depth to the perceived images. Two dimensional representations of three dimensional objects are fundamentally ambiguous and there are always inconsistencies. Depth cues rendered on a computer display are usually indistinct (Hubona et al., 1997), but stereoscopy has the effect of clearing up the representation of the third dimension. Nonetheless, its impact and possible benefits and detriments in the architectural setting should be explicated further.

2.2.2 Screen Size

One of the fundamental issues in digital media presentation or graphical user interface design is the limitation of display space. While screen size has more or less remained the same over the years, the size and scope of the information that needs to be communicated has increased dramatically, leading to challenges in navigation, interpretation, and recognition (Carpendale & Montagnese, 2001). The main shortcoming of using computer displays for architectural analysis is that when compared to the traditional media presentation such as drawings, the limited screen real estate offers a relatively restricted display which may make the reflection process and the integration of information difficult (Norman, 1993). Large screens have potential to overcome this limitation.

Several important studies show the benefits of large displays regarding task performance. Swaminathan & Sato (1997) argued that "when a display exceeds a certain size, it becomes qualitatively different." They studied a 6 x 3 foot display and concluded that large displays support three kinds of context: social, work and navigational. The large display, viewed from 8 feet away, had advantages and disadvantages for office work. The advantages were that the users did not need to turn their heads in order to view the content, and it offered a large working surface. The disadvantages were eye strain and no privacy for single-user office work.

Large displays, head-mounted displays, and desktop monitor displays were also compared regarding the level of spatial comprehension gained while navigating a virtual environment (Patrick et al., 2000). Researchers concluded that the large screen and headmounted display had a greater impact on creating a mental map as opposed to the desktop monitor. They also recommended a large display over head-mounted display for providing an immersive experience, since it was both easy-to-use and inexpensive.

Large displays with wide field of view used in three dimensional immersive navigation tasks has also been studied (Tan et al., 2001). The researchers came to the

conclusion that the users achieved better results in given tasks, and benefited considerably using this set up as compared to using a small display. Possible interpretation could be that large displays cause improved recognition memory and peripheral awareness (Czerwinski et al., 2003). Numerous studies demonstrate the advantages of large displays in three dimensional immersive virtual environments (Tan et al., 2003). Spatial orientation tasks are more effectively executed when the users work on large displays compared to desktop monitors (Tan et al., 2003). As a continuation of this research, Tan et al. (2004) explored how large displays affect spatial comprehension and performance while interacting with the virtual environment. They observed that the participants performed better in the navigation tasks on larger displays. Although another variable, interactivity, aided in task performance, this effect was found to be statistically independent from the size of the display.

The Immersive Environments Laboratory (IEL) study on large displays would continue this research and determine their effectiveness in eliciting spatial comprehension and sense of presence in an architectural setting. The IEL is a large three-screen projection, virtual environment display that was developed to overcome the limitations of the single-user displays, such as a desktop monitor, or head-mounted display. Given that the three screens partially surround the user and the images can be projected in stereoscopic mode, the result is the "illusion of immersion" in the virtual environment (Cruz-Neira et al., 1993). The size of the projection display also supports multi-users, where a number of users can share the same space and experience while maintaining visual contact and communication (Czernuszenko et al., 1997). In an architectural setting, the main advantage of the virtual environment display when integrated with the three dimensional model is to allow the designer and their audience to walkthrough and freely view the design from a first-person perspective. Virtual environment displays also allow a designer to visualize the spaces in an intuitive way, being immersed within an artificial world, and to explore their design in an exciting approach that was not attainable before (Shiratuddin et al., 2004).



Figure 2.6: Immersive Environments Laboratory Source: <u>http://www.gettingtoone.org/content/view/60/122/</u>

In the last few years, there has been an increase in interest to research large displays, but there are no empirical studies that demonstrate advantages of large displays in an architectural design setting. The goal of our study is to build on the previous research done on large displays but focus it on their potential impact on architectural design comprehension. This study is a screening study and designed to reveal more on the virtual reality components, and large displays, while employing the lessons learned in the previous work.

2.2.3 Field of View

The effective field of view (FOV) in humans covers roughly 200° degrees horizontally by 170° degrees vertically. Each eye has its own field of view of 150° degrees horizontally. The binocular field of view or the overlap region is approximately 120° degrees with 30° - 35° degrees of monocular vision on each side (Lin et al., 2002). Peripheral vision is used to draw attention of the eye to the visual events in the environment, and then focus on recognizing and identifying objects (Arthur, 2000) whilst

aiding self-orientation and positioning in space during movement. Blocking peripheral vision affects in a negative way one's ability to navigate through space, spatial comprehension. In addition, it degrades performance on visual search, and disrupts perceptions of size and space (Arthur, 2000).





 Figure 2.7: Horizontal field of view
 Figure 2.8: Vertical field of view

 Source: http://www.inition.co.uk/inition/images/guide hmd fovt.jpg

Essential in perceiving the real environment, the field of view is even more important in perceiving the virtual environment. Real field of view differentiates from the virtual one. The real field of view is the angle formed by the image's two ends on the screen projected into the user's eye. The virtual field of view is the angle of the viewing used, such as for an architectural virtual walkthrough. A display's field of view (hardware) can also be distinguished from the camera's field of view (software) (Polys et al., 2005). A display's field of view is a visual angle formed by the two ends of the image on the screen when projected into the user's eye. For comparison, a three-screen display provides roughly three times more visual angle than a single-screen seen from the same distance. By default, a large visual angle would elicit surplus eye and head movements for the image to be absorbed visually by the user. A software's field of view refers to a visual angle of a camera in the scene projected on the screen. The visual angle of the model is typically manipulated like the lens of a camera. Previous research done on the field of view generally focused on only one definition of field of view excluding the others. The display's field of view is one of the primary perceptual variables explored, in this study. There are several relevant studies of display's field of view and distance perception.

Connection between field of view and distance perception was explored in the study by Knapp and Loomis (2004). The authors report that limited field of view did not produce significant underestimation of distance. They rule out the level of realism, and charge the combined effect of display resolution, field of view, level of detail, immersion and presence, can all influence the mistakes made in distance estimation. More research is needed to determine the real cause of large under-perceptions of distances.

Distance perception in a virtual environment studied using head-mounted displays with various horizontal fields of view showed no significant effects of different fields of view on distance estimation accuracy (Arthur, 2000). Conversely, previous research reported in this study was conflicting and implied a tendency of limited field of view to shrink the virtual environment and make objects emerge as nearer to the user (Arthur, 2000).

The effect of limited field of view on the distance perception was explored by Watt, Bradshaw & Rushton (2000) as well, and the researchers found that restricted field of view generated minor distance underestimations. On the other hand, Kline and Witmer (1996) found that narrow field of view limited the ability to differentiate distances by comparing the indicated perceived distances in a virtual environment between various targets. They explain this with the decline or exclusion of perspective cues with the limited field of view.

Research on field of view by Neale (1995) has found that a restricted field of view has a greater impact in a virtual environment than in the real world. In other words, it takes less restriction in the field of view to produce performance losses in a virtual environment than would occur under larger restrictions in the real world. On the same note, restricted field of view causes perceptual, cognitive, and performance problems for individuals. The effects of field of view are task dependent. Not only do they depend on the type of task, but they also depend on the complexity of resource demands imposed by the task.

The main objective of an architectural walkthrough in a virtual environment is to acquire spatial comprehension and an accurate spatial layout and orientation within the space. Connection between spatial comprehension and field of view has been established in previous studies. It is expected that users will achieve better spatial comprehension if they had a sense of "being there" in the virtual environment (Lombard & Ditton, 1997). Therefore the relationship was further explored between spatial comprehension, immersion and presence under different fields of view (Lin et al., 2002). The users were more immersed in a virtual environment with a wide field of view (Lin et al., 2002; Hendrix & Barfield, 1996), had better sense of presence, and consequently, higher spatial comprehension (Lin et al., 2002; Alfano & Michel, 1990). Virtual environment effectiveness is often measured by the sense of presence induced and reported by the users. Most research done has concluded that wide field of view elicits a higher sense of presence. Remaining still, is the need to verify or refute these findings in an architectural setting of the Immersive Environments Laboratory.

2.3 Independent Content Variables: Level of Detail and Level of Realism

From the early to the final stages of an architectural design, the visualization requirements change considerably. A designer starts with more abstract representations and moves into more realistic and detailed ones. In this study we are interested in how display variables - screen size, field of view, and stereoscopy, impact spatial comprehension and how they interact with the content variables: namely, level of detail, and level of realism. We want to determine if the impact of the display variables on spatial comprehension varies differently for varying levels of content variables. For this

study we make a distinction between level of detail and level of realism (referred to as photorealism), even though prior research used the two terms interchangeably.¹

2.4 Dependent Variables: Spatial Comprehension and Presence

2.4.1 Spatial Comprehension

Spatial comprehension is a concept that can be encountered in many disciplines, but most of the research on spatial comprehension and cognition is done in cognitive psychology. The concept can be explained by the two words of which its name is comprised: "spatial" which stands for something to do with space, and "comprehension" which is related to a conscious mental activity such as thinking, understanding, and learning. Broken down like this, it comes down to the process of thinking, understanding, and learning space.

Spatial comprehension in the architectural setting is associated with way finding, the creation of mental maps, the ability to navigate through spaces and orient oneself (Henry, 1992), and the understanding of the proportions and relationships between various spaces (Pinet, 1997). Also, it is associated with the ability to conceptualize three-dimensional objects and being able to remember a physical space.

Spatial comprehension became very important with new media technology that included interactive virtual three-dimensional images. In order for us to recreate those images and the entire virtual environment we have to engage in the process of spatial comprehension. Therefore, it is important to find out how architectural students utilize their spatial skills to interact with the virtual environment.

¹ For the operationalization of content variables, refer to Chapter 3: Method of Inquiry or Nikolic (2007) for more in depth analysis of content variables and their interaction effects on spatial comprehension and presence as part of the joint research endeavor (Kalisperis et al., 2006).

The ability to visualize space is a prerequisite for solving spatial tasks as part of the architectural design process. This ability can be further developed by accurately perceiving scale and spatial character, and being able to represent and transform objects mentally. In addition, it is developed through the comprehension of relationships between objects in the interpretation of images (Osberg, 1994). Thus it is imperative that the spatial skills of architecture students improve over time, since architects should experience the world as observers not just participants: aware of form, proportion, scale, light, color, and texture. They should understand not only the visual, but many different aspects of the natural and constructed environment (Kalisperis, 1994). Virtual environments can have an important impact on enhancing spatial and visualization skills, depth perception, sense of perspective (Trindade et al., 2002) and can even augment creative thinking (Rice, 2003). Visualization of space includes the representation of its shape, size, volume, proportion and scale, but it also involves more perceptual cues such as color, texture, light and shade. A virtual environment provides comparable representations of scale and depth to the perceptions of the real world which are important features of spatial comprehension. Display variables - screen size and field of view – offer more spatial information in a real world scale. Stereoscopy and content variables – level of detail and level of realism – act as depth cues and further augment the spatial visualization.

2.4.2 Presence

The concept of "presence" can be found in many disciplines, although most of the research is in the field of virtual reality and immersive environments. In this context, sense of presence is tied to experiencing the computer-generated virtual environment and is the key to defining virtual reality in terms of human experience, rather than technological hardware as "a real or simulated environment in which a perceiver experiences telepresence" (Steuer, 1995).

Presence is a multi-dimensional concept and is reliant on a large number of interconnected factors that form a complex relationship (Kalawsky et al., 1999). It is also defined as "the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer and Singer, 1998). Slater & Wilbur (1997) define presence as "a state of consciousness, the (psychological) sense of being in the virtual environment." The sense of presence is strongly tied to immersion, and the authors argue that the more inclusive, extensive, surrounding, and vivid the virtual environment is, the higher the sense of presence it elicits.

2.4.2.1 Presence Components

There are two key factors to experience presence: involvement and immersion (Witmer and Singer, 1998). Involvement in the virtual environment experience leads to immersion, and immersion to a heightened sense of presence. Involvement is defined as "a psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events" (Witmer and Singer, 1998). Immersion on the other hand is considered to be an individual experience, not an objective description of the virtual reality technology. As a subjective experience, immersion is defined as "a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" (Witmer and Singer, 1998). Factors that affect immersion are: isolation from the real environment, self-inclusion, interaction with and control of the virtual environment, and perception of self-movement (Witmer and Singer, 1998).

While the sense of presence is defined as a subjective experience, and quantifiable by the user experiencing it, "immersion" is an objective category, defined as "the extent to which the computer displays are capable of delivering an (...) illusion of reality to the senses of a human participant" (Slater & Wilbur, 1997), and by that are objectively quantifiable (Schubert et al., 2001). Measuring presence therefore should cover the factors influencing involvement and immersion. These factors can be the same or they can differ, but the levels of involvement, immersion and presence are inter-dependent (Witmer and Singer, 1998).

Presence is influenced also by the characteristics of a medium or visual display such as image size, image quality and viewing distance (Lombard and Ditton, 1997; Witmer and Singer, 1998, IJsselsteijn et al., 2000). Image size and viewing distance are assumed to elicit heightened sense of presence given that the user is closer to the image and the viewed scene. Image quality depends on its resolution, color, sharpness, brightness, and contrast, and brings a sense of reality. This added sense of reality or photorealism, reflected in light, shadows, and texture, is argued to bring greater sense of presence (Witmer and Singer, 1998). Contrary to this, increased visual realism and vividness can lead to the opposite outcome – reduced sense of presence – due to potential sensory overload (Steuer, 1992; Osberg, 1994).

2.4.2.2 Presence and Learning

Many factors that are tied in with the sense of presence are known to improve learning and performance. Assuming that learning improves when the user is an integral part of the stimulus flow, and that meaningfulness and active control over a user's experiences aids learning, then immersive environments likely are better training tools than standard computer-based training environments (Witmer and Singer, 1998). Virtual environments that are involving and immersive can profoundly impact students' visual thinking process and imagination (Osberg, 1997) and result in more engaging, motivated and deeper learning (Witmer and Singer, 1998). For architecture students, a virtual environments impact would help the development of higher spatial skills and allow them to investigate designs in a new and exciting 3D world. Virtual environments would allow students to create or simulate reality, and allow them to explore new forms and new connections to technology by being fully immersed in them (Norman, 2001). Finally, learning from these experiences would help expand visualization and spatial skills and allow students to implement them into future designs.

2.5 Further Research

Studies done thus far, provide a strong starting point and confirm spatial perception and comprehension as being very complex and with many variables. All of the five abovementioned VR features - screen size, stereoscopy, field of view, and level of detail and level of realism - can be considered fundamental in creating an effective VR experience. These variables have an important impact on spatial comprehension and sense of presence, according to usability studies done identifying them and confirming their significance (Kalisperis et al., 2002; Otto, 2002). They are considered to have profound influence on visual thinking process, imagination and developing of essential spatial skills (Osberg, 1997; Norman, 2001). However, the intensity of their impact is still to be determined and evaluated and further research is needed.

Until the advent of projection-based VR displays, using small computer screens with restricted displays for architectural presentations and critiques made the reflection process more difficult. Screen size does make a difference since the availability of information is limited to small segments and their integration for exploration and comparisons is hindered (Norman, 1993, p.27). Large displays have the potential to overcome this limitation. Examining the effects of small screens versus large screens on spatial perception yielded the conclusion that one system has a clear advantage over the other. However, this comparison was not fully explored in an architectural setting such as a design studio. Furthermore, large displays with wide fields of view support peripheral vision and might provide more insights into spatial comprehension and discover its unexplored aspects. On another note, 3D perception of space may play critical role in the design field like architecture and stereoscopic viewing is yet to show its contribution to better understanding of spatial relations.

Previous studies showed either consistent underestimation of dimensions in the virtual environment (Henry, 1992) or their correspondence to real dimensions and depth perception to be very close (Plumert, 2004). Way finding, orientation and creation of mental maps of the space are other important features of spatial comprehension and virtual environments and are also very interesting for further investigation.

Recognition of what is essential for spatial comprehension is still absent, and there is no confirmed relationship between spatial comprehension and sense of presence. The review of prior research shows much more room for investigation of these aspects and the nature of immersive systems.

CHAPTER 3

METHOD OF INQUIRY

3.1 Research Question

Virtual reality in architecture has proven to be valuable and beneficial in the visualization of architectural design. Components of virtual reality identified to be essential for spatial perception and comprehension were selected as variables for this research and grouped into display variables – stereoscopy, screen size, and field of view - and content variables – the level of detail and level of realism. This study aims to determine and evaluate relative impact of display and content variables on spatial comprehension and sense of presence. The variable-based approach will provide us with more insight into how these variables can possibly interact and how effects may vary between our different manipulations. Two or more independent variables may have a combined interaction effect on the measured outcome.

The assumption is that there must be an advantage to stereo viewing, additional screen real estate, and wide field of view. A variety of studies have looked at different combinations of these variables and their combined effects on spatial perception (Hubona et al., 1997; Hubona, 1999; Patrick et al., 2000; Tan et al., 2003; Czerwinski et al., 2003; Tan et al., 2004; Arthur, 2000; Knapp and Loomis, 2004; Lin et al., 2002; Alfano & Michel, 1990). Those studies done on stereoscopic viewing identify benefits in perceiving, recognizing and understanding object shapes, but a few of them do not give credit to stereopsis unless its benefits are task specific (Hubona et al., 1997). On the other hand, stereopsis does provide important depth cues about object shape, and as such, it is included in the display variables in this research. In the wide field of view peripheral vision adds additional perceptual cues which are critical in the acquisition of spatial knowledge of a layout in a virtual environment. We hypothesize that large displays with wide fields of view have a positive impact on both distance estimation in spatial
comprehension, and sense of presence in the given environment. Presence plays an important role in a virtual environment. The assumption is that presence has an effect on the learning process; therefore in addition to determining the impact of independent variables on presence it is also beneficial to assess the impact of presence on spatial comprehension. To summarize, the research question is: What is the relative impact of screen size, stereoscopy and field of view on spatial comprehension and sense of presence?

3.2 Research Method

3.2.1 Variable-centered Approach

Given that virtual reality is a complex technology and has multiple variables, it is complicated to determine the relative impact of each selected variable on concepts like spatial comprehension or sense of presence. Prior studies had a box-centered approach to virtual reality, so it was very hard to determine the impact of each of these variables separately on the dependent measures. A potential solution to this is to have a variablecentered approach proposed by Nass and Mason (1990). As opposed to box-centered, the variable-centered approach takes apart the technology into its components or variables. In that way key display or content variables are identified and their relative contribution assessed. Although both approaches view virtual reality technology as a whole, the variable-centered approach understands its components as variables and examines them individually through their mutual interactions. Box-centered approach was on the other hand important to identify precisely which characteristics of virtual reality system are relevant, and served as an essential introduction to taking apart the technology into its components. Studies with variable-centered approach have fewer problems with external validity and offer an opportunity to make broad theoretical statements or conclusions, but the breadth is across variables rather than across technologies (Nass and Mason, 1990). In other words, the results can have implications for all technologies that have a particular value, and other values, for the identified variable.

The best method or research design to use for variable-centered approach would be an experiment with key display and content variables included. This type of experiment assesses the relationship between one or more independent variables and one or more dependent measures (Smith, 1988). This research model is called also factorial design and can be written in a form of 2 x 2, 2 x 4, or 2 x 2 x 3. A 2 x 2 design has two independent variables with two levels each. A 2 x 2 x 3 design had three independent variables, with two, two and three levels respectively (Smith, 1988). Furthermore, 2 x 2 x 2 design can be shortened into two to the third degree, or 2^3 . With this type of experiment, main effects of the independent variables as well as interaction effects of two or more variables on the dependent measures can be determined. The advantage of this approach is that it is implemented in a controlled setting, and the confounding or intervening variables are monitored. Internal validity is assured by this and main and interaction effects are attributable solely to the independent variables in play.

3.2.2 Fractional Factorial Experiment

Variables	Stereoscopy	Screen Size	Field of View	Level of Detail	Level of Realism
Levels	Stereo/	Large Display/	Wide FOV/	High Detail/	High Realism/
	Non-stereo	Small Screen	Narrow FOV	Low Detail	Low Realism

Table 3.1 Five variables each having two levels

A fractional factorial experiment design was chosen over the full factorial design for a variable-centered approach to study a VR system due to its more efficient costbenefit ratio. For comparison, a full factorial experiment for our study would be a 2^5 factorial design, i.e. 5 factors, each with two levels, which would entail 32 treatment combinations and a large subject pool (i.e. 320 subjects) with an architecture background. This approach would explore every possible combination of the levels of factors and it would yield information on main effects and all interactions. A fractional factorial design 2^{5-1} was chosen over a fully crossed factorial design as it would cut the experimental conditions down to a more manageable 16. This is half fractional factorial 2^{5-1} , and for example quarter fractional factorial 2^{5-2} would have 8 experimental units. In this case the number of experimental units, number of subjects and time required for gathering data was kept within practical limits.

3.2.3 Experiment Design

The objective of the study was to recognize any main effects and lower order interaction effects that can influence spatial comprehension and sense of presence. To generate the design, the highest order interaction, i.e. the five-factor interaction "stereoscopy * screen size * field of view * level of detail * level of realism" was used. This gave us the design of resolution V and in this case none of the main effects or twoway interactions is confounded with any other main effect or two-way interaction. Resolution gives us the degree to which main effects are confounded with two, three, etc -level interactions. Higher resolution provides better experimental design and improved explanation of lower order interactions. The downside is that the fractional factorial design is unable to yield information considering higher order interactions since only half of the experimental units are used, in this case 16 instead of 32. This approach gives us the option of running the other half of design afterwards and completing the full factorial at a later date, in case stirring findings need more statistical power to be supported.

3.3 Operationalization of Independent Variables

3.3.1 Display Variables

The operationalization of independent variables were broken down as follows; Display and content variables both had two levels as direct opposites (refer to *Table 3.1*). For this study display variables - stereoscopy, screen size, and field of view – and their variations were explored in correlation with content variables – level of detail and level of realism – in order to determine their relative impact on spatial comprehension and sense of presence and their interactions with content factors.



Figure 3.1: Plan of the Immersive Environments Laboratory Source: http://viz.aset.psu.edu/ga5in/ImmersiveEnvironmentsLab.html

The Immersive Environments Laboratory (IEL) was used to conduct the experiment. It contains an affordable immersive projection display with three 8' x 6' rearprojection screens which allows 3D models to be presented in stereo at full scale (see *Figure 3.1*). The lab was built with the usage of virtual reality (VR) techniques in mind in the fields of architecture and engineering.

Depending on experimental condition, stereoscopy was controlled by presenting the stimulus in either stereo or non-stereo (mono) mode using polarizing (IEL screens) or shutter (stereo monitors) glasses for the 3D effect. Stereoscopic PlayerTM software was used to play both stereo and non-stereo conditions. Screen size was operationalized by using either large (3x) 8' x 6' rear-projection screen(s) or (3x) 19" desktop monitor(s),

marked as large or small screen. The wide field of view was achieved by rendering the 3D model of the two-storey residence in 3D Studio MaxTM using a 3:1 display ratio for three screens (IEL screens or desktop monitors), and the narrow field of view using a 4:3 display ratio for the one screen (refer to **Appendix C**: Stimulus Material).



Figure 3.2: Non-stereo and stereo effect <u>http://www-static.cc.gatech.edu/classes/AY2002/cs4451_spring/groups/group8/images/Figure6.gif</u>



 Figure 3.3: Shutter glasses
 Figure 3.4: Polarizing glasses

 http://resumbrae.com/talks/vassar/images/shutter-glasses.jpg
 http://www.screen-tech.de/ST-Shop/ThemeParkStyle.jpg

To clarify, the wide field of view, or a three screen condition, was used to approximate the field of view variable. The narrow field of view was addressed as a one screen condition. For the simplicity of explanations and comparisons with previous research, we will refer to this variable as field of view, though in this research it was operationalized as number of screens deployed for the experiment.

3.3.2 Content Variables

A virtual environment may attempt to have a high representational and functional similarity just as a real world environment. Representational similarity is determined by how successfully the virtual representation matches the real world and functional similarity comes from how successfully the virtual world behaves or reacts with respect to a corresponding real world experience (Otto, 2002). For this study representational similarity is achieved with photorealistic representations of the virtual environment complete with color, texture, light, shade, and shadows. They all can act as cues in perceiving spatial depth according to Michel (1996), especially texture and shadow. Greater pictorial realism is considered to increase the sense of presence as well (Witmer and Singer, 1998). Functional similarity was disregarded in this study since there were no navigation or behavior measurements.

High and low levels of realism were decided via a pre-test to determine what the reasonable amount of cues is necessary for the given tasks. Varying levels of realism were created by gradually adding color, texture, light, shade and shadows to the 3D model (Kalisperis et al., 2006). High realism environments contained reflections, refractions, and environmental maps, in addition to previously mentioned attributes. Low realism had plain colors instead of textures, and shadows, reflections, refractions, and environmental maps were removed.

In architectural practice, as a project progresses towards the final stages of design, visualizations fill up with more functional elements and details, which add to realism and also act as depth cues. The function of these cues is important, since errors in regard to relative size can be deceiving (Michel, 1996). These elements in our study were classified into four categories (Kalisperis et al., 2006):

- basic furniture elements: to help understand and evaluate the function of the space (i.e. dining table, bed, etc.)
- standardized fixtures: to help determine the size and scale of spaces due to their fixed sizes and location with respect to human height (i.e. doorknobs, light switches, etc.)
- furniture elements: to further contribute to one's understanding of objects and space relations (i.e. shelves, cabinets, etc.)
- decorative elements: not highly standardized in their appearance (i.e. plants, etc.)

High and low levels of detail were decided on during the pre-test, in regards to the level of realism. The high condition contained all four categories, and in the low condition, fixtures and decorative elements were discarded. Please refer to Nikolic (2007) for a detailed explanation of the operationalization of these independent variables.

3.4 Stimulus Material

The stimulus used for the experiment was a six-minute long walkthrough of a two-storey residence. The residence consisted of living room, dining room, kitchen, study room, laundry and restroom on the first floor, and master bedroom, guest bedroom and bathroom on the second floor. A residence was chosen because of simple floor plan and effortlessly identifiable spaces that are easy to remember. The model developed was rather straightforward and a predetermined walkthrough path was assigned to it. This was done to minimize the time to adapt to the new environment and the sense of overwhelmness that virtual environments may bring to new users. By using a residence that most people, and especially architecture students, can easily relate to overwhelming feelings are minimized. More complex designs were avoided to lessen ambiguity and facilitate recollection of visited spaces.

A predetermined walkthrough was used for this experiment, despite the fact that navigability is one of the key features of virtual environments. This was done to exclude individual differences of the subjects during navigation and to improve the precision of the study. It also ensured the comparability and consistency of the users' experiences considering the viewpoints, speed, and path of moving through the space.



Figure 3.5a: High Detail High Realism



Figure 3.5c: Low Detail High Realism



Figure 3.5b: High Detail Low Realism



Figure 3.5d: Low Detail Low Realism

Figure 3.5: Combination of varying levels of detail and realism for the living room used in the stimuli

Sixteen versions of the stimulus material were created based on the 16 experimental units for the half fractional factorial 2^{5-1} . Based on the experimental condition, screen size was controlled by presenting the stimulus on either large (3x) 8'x6' rear-projection screen(s) or on (3x) 19" desktop monitor(s). For the wide field of view, a 3:1 display ratio was used to present the stimulus on three screens. Conversely, for the

narrow field of view, a 4:3 display ratio was used for the single screen. Stimulus could be presented in either stereo or non-stereo mode. Content variables, level of detail and level of realism could be either high or low. All this was based on the operationalization of the independent variables explained previously.

The model was created using 3D modeling software Form.ZTM and the various stimulus material animations were rendered in 3D Studio MaxTM. Stimulus was presented using Stereoscopic PlayerTM by Berezin Stereo Photography Products playing both stereo and non-stereo conditions. Nonetheless, due to software limitations, the resolution of half of the animations with wide field of view (three screens) had to be reduced by 25% compared to the resolution of animations with narrow field of view (one screen). This was done in order to ensure consistency of speed and length of stimuli in all conditions for consistency. This potential limitation is acknowledged duly in the Limitations section in **Chapter 5**: Discussion.

For the illustration of the stimuli in combination of different levels of detail and realism, see *Figure 3.1*. In this example, these images could be seen on either a large or small display, with narrow field of view (one screen or 4:3 display ratio), and in non-stereo mode. For the illustrations of the stimuli in all combinations of different levels of detail and realism, including all the key stops in presenting the stimuli, please refer to **Appendix C**: Stimulus material.

3.5 Participants

Participants for this study (n=84) were drawn from second through fifth year of the undergraduate program in the Department of Architecture at Penn State University. The variability among subjects was controlled by choosing students of architecture as a homogeneous group which is familiar with the tasks given in this study. The average age was 21.5 (*S.D.*=1.75). The number of male and female participants was equal.

3.6 Procedure

Participants were greeted on arrival and briefed about the procedure. Given that participation in the experiment was entirely voluntary, participants were asked to carefully read the consent form and sign it if they were willing to participate. Following this they completed the first page of the questionnaire with demographic information, i.e. age, gender, height, academic major and academic standing (please refer to **Appendix B**: Questionnaire). They were then informed about the nature of the experiment, its length, type of questions and number of sections encountered in the questionnaire. Also, they were asked to notify the researcher after each section was complete to proceed with the experiment.

Participants were checked for normal or corrected to normal vision before the experiment started. Participants in the stereo condition were tested for stereo blindness by viewing a short clip in stereo mode using polarized stereo glasses to confirm that they could perceive the depth of the clip (i.e. 3D effect).

Subjects were randomly assigned to one of 16 experimental conditions. Each condition had a unique combination of different levels of the independent variables. Depending on the experimental condition, the appropriate stimulus (walkthrough of a two-storey residence) was presented to the subject and the subject was asked to respond to the presence part of the questionnaire, in Section 1, containing 13 questions.

The same stimulus was presented again and paused six times at the following predetermined key stops: exterior, living room, dining room, kitchen, study room on the first floor, hallway on the second floor (please refer to the key stops in **Appendix C**: Stimulus Material). At each stop the participants were asked to answer the questions in the sections corresponding to the view (Section 2 – Section 7) mainly with distance estimation tasks. After watching the stimulus for the second time, the participants were asked to tackle questions regarding spatial organization (Section 8). This part included the sketching of a cognitive map. The subjects had to draw the outlines of the spaces the way they were organized on the given outline of the first floor, label them and map the path of their movement through the first floor. They were asked also questions on the organization of spaces, i.e. the location of various rooms with respect to other rooms above or below it, in order to determine if they were able to grasp the vertical relations of spaces.

The last part of the questionnaire (Section 9) dealt with prior experience with the virtual reality facility and computer use. After the completion of the questionnaire, at the end of experiment, the subjects were debriefed, asked for confidentiality considering the experiment, and thanked for their participation.

3.7 Measurements

3.7.1 Spatial Comprehension

Spatial comprehension can be defined as ones' understanding of a given space. Previous studies done on spatial comprehension or related terms (Henry, 1992; Pinet, 1997; Osberg, 1994) have operationalized it as:

- one's understanding of the proportions of a given space,
- the relationship between various spaces, or
- wayfinding, or one's ability to orient in a given space.

The assumption is that an immersive virtual environment will have a more direct impact on spatial comprehension, and that in turn, can influence architectural design comprehension and reasoning as higher-level processes. Since this is an exploratory study, our goal was to capture the impact of the independent variables on the various subcomponents of spatial comprehension. Spatial comprehension was operationalized in this study as ones' understanding

of:

- the dimensions and proportion of the various spaces,
- their scale or in other terms their relationship to the human body,
- their location and relationship of spaces with one another in terms of their relative sizes and position, and
- way finding.



Figure 3.6: Depth, Width and Height Estimation

After visiting each space on the first floor of the two-storey residence in the stimulus material, the participants were asked to estimate its dimensions (width, depth and height – see *Figure 3.6*), asked to measure some elements in the scene, and, asked to estimate distances between different objects. Some of the distance estimation tasks were open-ended, and overall width, depth and height scores were calculated. Few distance estimation tasks were closed-ended with 5 response choices to keep the subjects' estimation within reasonable boundaries and to avoid large under-estimation or over-estimation given this tendency in prior research (Henry, 1992; Patrick et al., 2000; Knapp & Loomis, 2004; Plumert et al., 2004). Additional spatial tasks were given to subjects to compensate for estimating dimensions in imperial units - feet and inches - that can appear as less intuitive. The subjects' perception of space in respect to their own body was

materialized in the tasks: estimating the number of steps required to walk from one point to another, guessing how many people a space can accommodate, etc.

Building a cognitive map and ability to retrace ones' movement through the visited space is an important component of spatial comprehension and was measured with the following; Participants were asked to sketch the layout of the spaces visited and listed in the first floor of the two-storey residence given the exterior wall outline. They were asked to label the different rooms and to map their movement path. The sketched cognitive maps were coded for accuracy of space locations, their proportions, and the correctness of the movement path.

3.7.2 Presence

Presence was measured using a 13-item, 8-point Likert type scale. The items were adapted and modified from the Banos et al.'s (2000) Reality Judgment and Presence Questionnaire, Igroup Presence Questionnaire (IPQ) by Schubert et al. (2001), and Witmer and Singer's (1998) Presence Questionnaire (PQ). Initially questions were carefully selected from the abovementioned questionnaires, then slightly altered according to the stimulus material, and pre-tested. The results showed what questions were more relevant, and what questions should be discarded. A presence scale was pre-tested, the questions were fine tuned again, and unreliable questions were dropped from further analyses.

The presence questionnaire items were trying to capture the different dimensions of presence. Ones' sense of immersion was measured using questions such as: *To what extent did you feel you were physically in the house?*, *How realistic did the house appear to you*?, and *To what extent did you feel you could reach into the house and grasp an object*?. The questions: *To what extent was it easy for you to get used to the house*?, and *To what extent did the experience require a mental effort from you*?, were used to measure the extent of the required mental effort for immersion. The congruence of the

walkthrough experience with reality was measured with the following questions: *How much did your experience in the house seem consistent with your real world experience?*, and *How compelling was your sense of moving around inside the house?*.

3.8 Control Measures

Controlling for extraneous variables is a method used to maintain the accuracy of the findings. In this way, the impact of the independent variables was evaluated more precisely. Some of these extraneous variables were kept at the constant level, i.e. distance from the screen, height of the chair where the participants were seated, etc. The other ones were measured for statistical control, i.e. demographic factors, previous experience with the immersive lab facility, knowledge of computer graphics, and extent of use, etc. This was done to prevent bias of their potential influence on the experimental outcome and to improve the accuracy as well as the internal validity of the experiment.

3.9 Manipulation Check

A manipulation check questions were included in the questionnaire where the subjects rated how well furnished and how photorealistic various spaces were. This was done to confirm that the operationalization of high and low levels of detail and realism based on the results of the pre-test was successful. An independent sample t-test with unequal variances was performed for the level of detail, t (81) = -5.53, p<.01. It turned out to be significant and corroborated that subjects perceived the stimulus as more detailed in the high detail condition (M=5.43) compared to the low detail condition (M=4.09). A similar test was performed for the level of realism, t (80) = -6.19; p<.01, and validated that the participants perceived the stimulus as more photorealistic in the high realism condition (M=5.43) compared to the low realism one (M=4.00).

CHAPTER 4

DATA ANALYSES AND RESULTS

4.1 Data Analyses

Analysis of Variance (ANOVA) was performed to answer the research question in this study: What is the relative impact of screen size, stereoscopy and field of view on spatial comprehension and sense of presence? Analysis of Covariance (ANCOVA) was conducted instead of ANOVA in cases where there was a possibility that one of the control measures could make a difference and affect the results. The results for covariates are not reported here, unless we thought they were important, since they were not the focus of this study. The results are reported significant if they have a p-value less than 0.1 instead of the standard 0.05 since this is a screening experiment and our goal was to identify the trends. In the case that interaction effects among independent variables were found statistically significant, main effects of those variables are not discussed since they are of less importance in comparison with interactions.

Data analyses were performed with the following dependent variables - level of immersion, ease of immersion – defining presence, overall depth score, overall width score, overall height score, spatial organization score, proportioning score and way finding score – defining spatial comprehension.

4.2 Index Construction

4.2.1 Presence

A principal components factor analysis¹ was used to analyze the dimensionality of the thirteen items used to measure presence. The number of underlying factors was determined with the criteria of eigenvalues² greater than or equal to one. Based on these criteria, three factors specified above were identified accounting for 63.23% of the variance. Rotation of the items was done using the Varimax procedure³, and seven items loaded noticeably onto the three factors with their highest loading exceeding 0.6 and the other two loadings less than 0.4. The remaining six items cross loaded across the factors and were discarded from further analysis. The rotated solution yielded three factors:

- Level of immersion,
- Ease of immersion, and
- Experiential congruence with the real world.

The last factor "experiential congruence with the real world" consisted of only one item clearly loading and was dropped from further analysis, since single item scale cannot be checked for reliability.

The items for level of immersion that were measured were: the extent to which the subject felt "they were in the house", the extent to which they felt they could "grasp an object in the house", and how "real" those objects felt. The items for ease of immersion that were measured were: the "ease of getting used to the house", the "ease of getting a good feel of the spaces", and the "extent of mental effort required for the

Source: http://ingrid.ldeo.columbia.edu/dochelp/StatTutorial/SVD/

¹ Principal component analysis is a technique for simplifying a dataset, by reducing multidimensional datasets to lower dimensions for analysis (Smith, 1988).

 $^{^{2}}$ Eigenvalue is defined as the sum of the squared loadings associated with each factor. Factor is statistically meaningful if it has an eigenvalue of 1.00 or greater (Smith, 1988).

³ Varimax rotation is a method for rotating axes of a plot such that the eigenvectors remain orthogonal as they are rotated. These rotations are used in principal component analysis so that the axes are rotated to a position in which the sum of the variances of the loadings is the maximum possible.

experience". Consequently, these two indices: level of immersion and ease of immersion were created by averaging the three specified items above, respectively, and the only ones used for analysis. Even though the original presence index created by additively combining the 13 items would have a good reliability (Cronbach's $alpha^4=0.82$), we decided to take this approach to provide more meaningful and useful results for facilitating design of virtual reality systems.

4.2.2 Spatial Comprehension

Spatial comprehension was measured by estimating distances, spatial organization proportioning, and way finding scores. For estimating distances, overall depth, width and height scores were computed. Since the distances that were to be estimated varied considerably, each response was divided with the correct response, and in that way standardized. All standardized responses were averaged to produce an overall score. This was done separately for overall width, depth and height and used for further analysis. An accurate estimation was marked with a value of 1.0, over-estimation had a value above 1.0 and consequently under-estimation a value of less than 1.0.

Scores for the positioning, proportioning of the spaces, and way finding were done in the following way. Correctly positioning of spaces received the score on the scale 0 (min) to 8 (max) of the eight spaces sketched on the first floor. Proportioning of spaces (five out of eight possible chosen on the first floor) had the index from 0 to 10, depending on the three levels of tolerance each space would fall in, spaces would receive between 0 (min) and 2 (max) points. Way finding had a scale of 0 (min) to 6 (max) corresponding to the six different parts of the moving path on the first floor of the residence. Two independent coders scored the responses based on the agreed coding criteria and they had an inter-coding reliability of 86%.

⁴ Cronbach's alpha is a tool to assess the reliability of scales. It measures how well a set of items measures a single one-dimensional latent construct. It is a coefficient of reliability (or consistency) and .70 or higher is considered acceptable. Source: <u>http://www.socialresearchmethods.net/tutorial/Young/eiweb2.htm</u>

4.3 Results

4.3.1 Level of Immersion

For level of immersion, controlling for the extent of computer use, ANCOVA found a significant interactive effect between the:

- level of detail and field of view, F(1,65) = 5.41, p<.05,
- display size and stereoscopy, F(1,65) = 4.11, p=0.1, and also
- level of detail and stereoscopy, F(1,65) = 6.05, p<.05.





Figure 4.1: Interactive Effects of Level of Detail and Field of View on Level of Immersion

For high level of detail, the level of immersion is greater for wide field of view (M=5.21) with respect to narrow field of view (M=4.40). For low level of detail, wide field of view has lower level of immersion (M=4.90) compared to narrow field of view

(M=5.37) (see *Figure 4.1*). Data suggest that immersion is facilitated by wide fields of view and high detail, as well as narrow fields of view and low detail.



Interactive Effects of Stereoscopy and Screen Size on Level of Immersion



For large display size, the level of immersion is much greater for stereo condition (M=5.56) when compared to non-stereo condition (M=4.47). For small screen size, there is not much difference in the level of immersion between stereo (M=5.44) and non-stereo (M=5.29) (see *Figure 4.2*). Data suggest that sense of immersion is greater for large display with stereo effect, and for small screen stereo effect does not make any difference.



Interactive Effects of Stereoscopy and Level of Detail on Level of Immersion

Figure 4.3: Interactive Effects of Stereoscopy and Level of Detail on Level of Immersion

For high level of detail, the level of immersion is greater for non-stereo condition (M=4.91) compared to stereo condition (M=3.90). For low level of detail, there is little difference in level of immersion between stereo (M=5.44) and non-stereo (M=5.29) condition (see *Figure 4.3*). Data suggest the users feel more immersed in stereo with low detail, but the immersion is almost equally high for non-stereo combined with high or low detail.

4.3.2 Ease of Immersion

For ease of immersion, controlling for the extent of computer use, there was a significant interaction effect between the:

- screen size and field of view, F(1,63)=3.27, p<0.1 and also</p>
- field of view and realism, F(1,63)=3.37, p<0.1.



Interactive Effects of Field of View and Screen Size on Ease of Immersion

Figure 4.4: Interactive Effects of Field of View and Screen Size on Ease of Immersion

For large display size, there was almost no difference in the ease of immersion between wide field of view (M=6.05) and narrow field of view (M=5.80). On the other hand, for small screen size, the ease of immersion was greater for the wide field of view (M=6.61) compared to the narrow field of view (M=5.55) (see *Figure 4.4*). Data suggest that ease of immersion is higher with wide field of view especially paired with small screen.



Interactive Effects of Level of Realism and Field of View on Ease of Immersion

Figure 4.5: Interactive Effects of Level of Realism and Field of View on Ease of Immersion

For wide field of view, the ease of immersion was almost the same for high (M=6.74) and low realism (M=6.61) conditions, while for the narrow field of view, the ease of immersion was much greater for the high realism (M=6.50) compared to the low realism condition (M=5.55) (see *Figure 4.5*). Data suggest that high realism aided narrow field of view in achieving greater ease of immersion, though wide field of view had equally high impact on ease of immersion.

4.3.3 Overall Depth, Width and Height Estimation Scores

Overall depth, width, and height scores were computed for all open-ended distance estimation tasks. The estimated distances were standardized before combining by dividing each response by the correct distance. Consequently a value of 1.0 would represent an accurate estimation of distance, value above 1.0 would mark over-

estimation, and less then 1.0 would indicate under-estimation. All standardized responses for the depth, width, and height questions were averaged separately and created an overall depth, width, or height score, for open-ended estimation tasks. The results from this procedure were used for final analyses.

4.3.3.1 Overall Depth Score

Analysis for overall depth score, controlling for subjects' academic standing (2nd to 5th year of study), disclosed significant interactions between:

- screen size and level of detail, F(1,64)=4.49, p<0.05 and</p>
- field of view and level of realism, F(1,64)=7.80, p<0.01.



Interactive Effects of Level of Detail and Screen Size on Depth Perception

Figure 4.6: Interactive Effects of Level of Detail and Screen Size on Depth Perception

For the high level of detail, there is almost no difference in depth perception between large display size (M=1.22) and small screen size (M=1.20). While for the low level of detail, depth perception was more accurate in large display condition (M=1.16) compared to small screen condition (M=1.25) (see *Figure 4.6*). Data suggest that overestimation of depth perception by 20% on average was slightly better on the large screen with low detail, and much worse on small screen with low detail.



Interactive Effects of Level of Realism and Field of View on Depth Perception

Figure 4.7: Interactive Effects of Level of Realism and Field of View on Depth Perception

For wide field of view, depth was greatly overestimated in the high level of realism (M=1.37) compared to the low level of realism condition (M=1.20). For narrow field of view, there is hardly any difference in depth perception between those in the high level of realism (M=1.24) and low level of realism (M=1.25) (see *Figure 4.7*). Data suggest that depth perception is more precise with wide field of view and low realism. However, we should be aware of the great overestimation with wide field of view and

high realism. Narrow field of view paired with high or low realism results in overestimation by approximately 24-25% in either case.

4.3.3.2 Overall Width Score

For overall width score, controlling for the subjects' academic standing, there was a significant interaction effect for:

• field of view and level of realism, F(1,63)=9.28, p< 0.05.



Interactive Effects of Level of Realism and Field of View on Width Estimation

Figure 4.8: Interactive Effects of Level of Realism and Field of View on Width Estimation

For high level of realism, wide field of view results in greater overestimation of width (M=1.28) compared to narrow field of view (M=1.16). Conversely, for low level of realism, wide field of view results in lesser overestimation of overall width (M=1.16) compared to narrow field of view (M=1.24) (see *Figure 4.8*). Data suggest that wide field

of view with low realism, and narrow field of view with high realism yield more precise width estimation. On the other hand, we should be aware of greater overestimation of width in the case of wide field of view with high realism, and narrow field of view with low realism.

4.3.3.3 Overall Height Score

For overall height score, controlling for the subjects' academic standing, there were significant interactions between:

- screen size and stereoscopy, F(1,60)=5.49, p<.05 as well as</p>
- level of detail and stereoscopy, F(1,60)=3.73, p<0.1.



Interactive Effects of Stereoscopy and Screen Size on Height Estimation

Figure 4.9: Interactive Effects of Stereoscopy and Screen Size on Height Estimation

For the large display size, and stereo condition, perception of overall height was more precise (M=1.13) compared to the non-stereo one (M=1.23). For small screen size, the overall height estimation was more or less straight to the point for both stereo (M=1.11) and non-stereo condition (M=1.10) (see *Figure 4.9*). Data suggest that stereo effect does not make a great difference in estimating height on a small screen. But in a case of large screen, stereo effect enhances height estimation, while non-stereo effect comparably hinders it.



Interactive Effects of Level of Detail and Stereoscopy on Height Estimation

Figure 4.10: Interactive Effects of Level of Detail and Stereoscopy on Height Estimation

For the stereo condition, high level of detail resulted in overestimation of overall height (M=1.20) compared to low detail (M=1.11). For non-stereo, there was no difference between high and low detail (M=1.10) in estimating overall height (see *Figure 4.10*). Data suggest that we should be aware of stereo effect combined with high detail which can result in higher overestimation of height, while other combinations of stereo or non-stereo and detail should not be alarming considering height overestimation.

4.3.4 Spatial Organization Score

Spatial organization task of sketching the map of the first floor of the residence proved to be more or less accurate and successfully done throughout the various conditions. For spatial organization score, controlling for the subjects' experience with computer graphics and academic standing, there were significant interactions between:

- screen size and stereoscopy, F(1,60)=4.04, p<0.05 and also</p>
- level of detail and stereoscopy, F(1,60)=3.43, p<0.1.



Interactive Effects of Stereoscopy and Screen Size on Spatial Organization

Figure 4.11: Interactive Effects of Stereoscopy and Screen Size on Spatial Organization

For the large display size, the spatial organization score was much higher for the stereo condition (M=8.44) compared to non-stereo condition (M=6.46). For small screen size, there was little difference in comprehending spatial organization between stereo (M=8.22) and non-stereo condition (M=7.95) (see *Figure 4.11*). Data suggest that stereo

effect plays a positive role in enhancing spatial comprehension especially with large screen, while on small screen the difference between combinations with or without stereo effect is negligible.



Interactive Effects of Level of Detail and Stereoscopy on Spatial Organization

Figure 4.12: Interactive Effects of Level of Detail and Stereoscopy on Spatial Organization

For high level of detail, the score was much lower for the stereo (M=6.30) compared to non-stereo condition (M=8.62). For low level of detail, there was no major difference between stereo (M=7.95) and non-stereo conditions (M=8.22) in spatial organization score (see *Figure 4.12*). Data suggest that spatial comprehension is equally high for stereo or non-stereo coupled with low detail, while non-stereo with high detail yields even higher scores, but stereo with high detail hinders critically spatial comprehension score.

4.3.5 Proportioning and Wayfinding Score

There are no significant findings for the proportioning and wayfinding score in the data analysis possibly due to slight difference between the experimental conditions in their influence on the two scores.

CHAPTER 5

DISCUSSION

Data analysis yielded results that strongly emphasize the inclination of students to overestimate dimensions in VR throughout all the conditions. When standardized, all estimations of depth, width, and height had values over 1.0, which would normally indicate a correct estimation. This outcome is in direct opposition to previous studies in virtual environments in which subjects consistently underestimated distances (Henry, 1992; Arthur, 2000; Watt, Bradshaw & Rushton, 2000; Knapp and Loomis 2004). A few possible interpretations of these conflicting findings could explain these results. Given that a small sized building type was chosen for the stimulus -i.e. a residence - and the confined nature of the interior spaces, most of the estimates were made on relatively short distances. Previous research has confirmed that people have a tendency of increasingly underestimating distances when they are beyond 40-60 feet range. However, estimates are quite accurate up to these distances (Plumert et al., 2004). On another note, some studies (Henry, 1992; Patrick et al., 2000; Loomis and Knapp, 2003) used head-mounted displays with restricted vertical and horizontal field of view, which led to the wellestablished finding that people underestimate distance in virtual environments involving HMDs. That would furthermore explain quite the opposite in our experiment, due to the unlimited field of view of the displays used.

Since this section of the 2-part study focuses on the display variables and their interactions with content variables, the results reported here will be focused on display variables. For additional insights in this matter please refer to Kalisperis et al. (2006) and Nikolic (2007), for the other half of this study which focuses on content variables.

5.1 Level of Immersion

The items for level of immersion measured: the extent to which the subject felt "they were in the house", the extent to which they felt they could "grasp an object in the house", and how "real" those objects felt. The results confirmed our assumption that the large display with wide field of view and stereoscopy would play a key role in increasing the level of immersion. This finding coincides with the previous studies done on display variables (Cruz-Neira et al., 1993; Patrick et al., 2000; Tan et al., 2001; Tan et al., 2003). There are other noteworthy results considering the interactive effects between the field of view and the detail, as well as stereoscopy and level of detail.

Level of Immersion	Low Detail	High Detail
Narrow FOV	M=5.37	M=4.40
Wide FOV	M=4.90	M=5.21

Table 5.1: Interactive Effects of Level of Detail and Field of View on Level ofImmersion

Wide field of view aids the level of immersion and consequently, the sense of presence when coupled with the high level of detail. It does not have as strong of an impact when combined with the low level of detail. This is what we would expect based on the review of prior research (Lin et al., 2002; Hendrix & Barfield, 1996; Alfano & Michel, 1990) and common sense that wide field of view is of importance in the presence experience.

Contrary to this, the narrow field of view with low level of detail elicited an even higher level of immersion than the wide field of view with either low or high level of detail. That is not the case when the narrow field of view is combined with high detail. This would lead us to the conclusion that wide field of view increases the level of immersion in any case, but if it is narrow, the level of detail might seriously affect it.

Level of Immersion	Non-stereo	Stereo
Small Screen	M=5.29	M=5.44
Large Screen	M=4.47	M=5.56

Table 5.2: Interactive Effects of Stereoscopy and Screen Size on Level ofImmersion

Stereoscopy adds to the level of immersion and sense of presence in combination with large display size the most. This is what we would expect and hope for in building a VR system. When coupled with small screen size, the presence or absence of stereoscopy does not make a difference in the level of immersion and sense of presence. On the other hand, stereoscopy elicits high level of immersion in either condition, so it is up to VR system engineers to decide which is more practical; small or large screens.

Level of Immersion	Non-stereo	Stereo	
Low Detail	M=5.29	M=5.44	
High Detail	M=4.91	M=3.90	

 Table 5.3: Interactive Effects of Stereoscopy and Level of Detail on Level of

 Immersion

Combined with the high level of detail, stereoscopy does not aid the level of immersion as much as monoscopy, which is counterintuitive. In relation to low level of detail, stereo or non-stereo does not make a difference in the level of immersion, but it is still greater when compared to high level of detail, especially with stereo influence. Since these relationships are contrary to what we would anticipate, they are still to be explained. One of the possible interpretations would be that adding up depth cues leads to the opposite effect, less immersion, due to the amplified perception of depth and sensory overload (Epstein, 1995; Osberg, 1994).

The effect that display variables - field of view, stereoscopy and screen size – had on level of immersion in previous analyses listed here is noteworthy. They support our assumptions. However, a follow-up of this research would be needed to increase statistical power.

5.2 Ease of Immersion

Items for ease of immersion measured: the "ease of getting used to the house", the "ease of getting a good feel of the spaces", and the "extent of mental effort required for the experience". The results confirmed our assumption that the display variables play an important role in increasing ease of immersion. This would be in agreement with previous studies done on this matter (Lombard & Ditton, 1997; IJsselsteijn, 2000; Patrick et al., 2000; Tan et al., 2001; Tan et al., 2003; Shiratuddin et al., 2004; Lin et al., 2002; Hendrix & Barfield, 1996; Alfano & Michel, 1990). There are other noteworthy results considering the interactive effects between the field of view and the level of realism.

Ease of Immersion	Narrow FOV	Wide FOV	
Small Screen	M=5.55	M=6.61	
Large Screen	M=5.80	M=6.05	

 Table 5.4: Interactive Effects of Field of View and Screen Size on Ease of

 Immersion

Specifically, large screen size coupled with field of view shows no difference in the ease of immersion between wide and narrow field of view. Contrary to that, small screen size working with wide field of view has a much larger impact on the ease of immersion and accordingly sense of presence then when coupled with narrow field of view. Therefore, wide field of view should be considered when building a desktop VR system. In addition, large displays have a beneficial influence on ease of immersion in either field of view condition, as expected.

Ease of Immersion	Low Realism High Realis	
Narrow FOV	M=5.55	M=6.50
Wide FOV	M=6.61	M=6.75

Table 5.5: Interactive Effects of Level of Realism and Field of View on Ease ofImmersion

Wide field of view combined with high level of realism has almost the same effect on the ease of immersion as when accompanied by low levels of realism. In the case of narrow field of view, high level of realism aids much more to the ease of immersion and as a result, sense of presence. Ease of immersion is also higher for the wide field of view in general, which is to be expected.

Considering immersion in general – its level and ease – it is important to mention that the decision was made in this study to exclude navigability and interactivity of the virtual environment, even though those may be significant contributors to sense of presence (Whyte, 2002; Otto, 2002; Orland et al., 2001; Markham, 1998). As mentioned in the study limitations, this led to uniformness and simplification of this experiment and comparable experience of the virtual environment offered to the users. These features may positively affect the feeling of immersion and consequently, a user's sense of presence. Despite these initial restraints, immersion – its level and ease - is demonstrated to be affected by the display variables in an important way.

5.3 Overall Depth Score

Depth Perception	Low Detail	High Detail
Small Screen	M=1.25	M=1.20
Large Screen	M=1.16	M=1.22

 Table 5.6: Interactive Effects of Level of Detail and Screen Size on Depth

 Perception

Large display size accompanied with high level of detail (M=1.22) does not show any improvement in depth perception as compared to small display size with high level of detail (M=1.20). Conversely, large display applied with low level of detail shows more accurate depth perception (M=1.16) when judged against small screen with low level of detail (M=1.25). In both cases, the overestimation of the overall depth is on average, close to 20%.

The perceived overestimation of depth can be explained in two ways. One of the interpretations may be that the distances estimated were less than 40-60 feet, which is considered to be the boundary between being accurate and increasingly underestimating distances in the virtual world (Plumert et al., 2004). Another explanation may be that the number of details in the scene influenced the perception of space as being larger, in order to accommodate all the furniture and items. This may have led to overestimation of distances in a space that appeared to be larger. Then again, the small screen condition joined with low detail resulted in even larger overestimation. Compared to the large display where distances can be analogous to real world and human-sized, small displays may be missing the scale reference, along with depth cues contained in the level of detail. This may account for the 25% increase in space and size perceptions.
Depth Perception	Low Realism	High Realism		
Narrow FOV	M=1.25	M=1.24		
Wide FOV	M=1.20	M=1.37		

Table 5.7: Interactive Effects of Level of Realism and Field of View on DepthPerception

The wide field of view with the high level of realism has a negative impact on overestimating depth (M=1.37). However, the wide field of view with low realism is more accurate (M=1.20). Narrow field of view does not differentiate between high and low levels of realism on its impact on depth perception and equals to approximately 25% of overestimation (M=1.24 and M=1.25 respectively). In both cases, the overestimation of overall depth is something we should be aware of, especially with wide field of view and high level of realism.

These findings are congruent with previous studies on depth perception and prior studies confirming that adding depth cues can lead to overestimation of the space dimensions, making it come out as larger (Epstein, 1995). Added depth cues are even multiplied in the wide field of view, which would explain almost double overestimation. This might point to the downside of using wide fields of view with photorealistic renderings for the purpose of sizing the space - unless we want to achieve the effect of the space appearing larger.

5.4 Overall Width Score

Wide field of view with high level of realism results in greater overestimation of width (M=1.28) compared to narrow field of view (M=1.16). Coupled with low level of realism, wide field of view results in less overestimation of overall width (M=1.16) compared to narrow field of view (M=1.24) which does just the opposite. Wide and

narrow fields of view coupled with high and low levels of realism, respectively; represent a chance of greatly overestimating width by 24-28%. On the other hand, wide field of view with low realism and narrow field of view with high realism leads to equal overestimation of depth by 16%.

Width Estimation	Low Realism	High Realism		
Narrow FOV	M=1.24	M=1.16		
Wide FOV	M=1.16	M=1.28		

Table 5.8: Interactive Effects of Level of Realism and Field of View on WidthEstimation

Similar conclusions can be drawn as for the depth perception involving field of view and realism. Additional depth cues in high realism, multiplied with wide field of view, can lead to viewing a virtual space as larger. Similar to depth perception, narrow field of view displayed with low level of realism, could have the effect of overestimation due to lack of depth cues and spatial information. This should be taken into consideration if we are trying to present the space correctly on the display, with the above mentioned characteristics.

5.5 Overall Height Score

Height Estimation	Non-stereo	Stereo	
Small Screen	M=1.10	M=1.11	
Large Screen	M=1.23	M=1.13	

Table 5.9: Interactive Effects of Stereoscopy and Screen Size on HeightEstimation

Large screen size with the stereo effect helped overall height perception to be more precise (M=1.13), compared to the non-stereo condition (M=1.23). Small screen size with or without the stereo effect had close to accurate height estimations in both cases, with 10-11% over the right dimension (M=1.11 and M=1.10 respectively). According to our assumptions, large screen size and stereoscopy aided height perception to be more accurate, even though height estimation on the small screen size was just as good in both conditions, stereo or non-stereo. It should be mentioned here that all the spaces had the same standard height except the living room which was twice as high. This would explain the most precise spatial estimations among depth, width and height.

Height Estimation	Low Detail	High Detail		
Non-stereo	M=1.10	M=1.10		
Stereo	M=1.11	M=1.20		

 Table 5.10: Interactive Effects of Level of Detail and Stereoscopy on Height

 Estimation

High level of detail viewed in stereo resulted in overestimation of overall height (M=1.20) compared to low detail in stereo (M=1.11). High or low level of detail viewed in non-stereo both yielded 10% over estimation of overall height (M=1.10). Stereo effect in this case paired with high level of detail resulted in higher overestimation of height by almost 10%.

It is noteworthy to comment on the overestimation of height by 20% with high level of detail viewed in stereo, since all the other estimations are rather precise. This finding can be explained by the previously mentioned adding of cues; in this case, amplification of number of details in stereo mode, which made the virtual space appear larger. One way to prevent this joint effect in the future is to add other scales of reference, such as human figures. Another way would be to make sure that stereo parameters are correct and comparable between conditions, and not augmenting objects in the scene.

5.6 Spatial Organization Score

Spatial Organization	Non-stereo	Stereo	
Small Screen	M=7.95	M=8.22	
Large Screen	M=6.46	M=8.44	

 Table 5.11: Interactive Effects of Stereoscopy and Screen Size on Spatial

 Organization

Large screen size in tandem with stereoscopy had greater impact on spatial organization scores then without stereo effect (M=8.44 compared to M=6.46). On the other hand, small screen, with or without stereo effect, had similar effects on spatial organization scores (M=8.22 and M=7.95 respectively). This is consistent with our assumption that large screen size and stereoscopy enhance spatial perception. On the other hand, large display without stereo effect showed much less influence over spatial perception than small screen size, with or without the stereo effect. This leads us to the conclusion that stereoscopy plays a certain role in enhancing perceptions of space.

Spatial Organization	Low Detail	High Detail		
Non-stereo	M=8.22	M=8.62		
Stereo	M=7.95	M=6.30		

 Table 5.12: Interactive Effects of Level of Detail and Stereoscopy on Spatial

 Organization

High level of detail with stereoscopy had a negative impact on the spatial organization score then without the stereo effect (M=6.30 compared to M=8.62), which is counterintuitive and needs to be explained further. Low level of detail with or without stereo effect showed no major score difference in spatial organization (M=7.95 compared to M=8.22), but it was high on both grounds.

The conclusion is that students managed to develop more accurate cognitive maps of the space in the non-stereo condition. Stereo combined with high detail had a hampering effect, possibly due to providing excess of spatial information and lowering cognitive abilities in forming the mental map. This would coincide with previous conclusions of this study drawn from estimating distances tasks.

At this point it should be taken into consideration that the model of the residence had an open plan for easier movement through the space, allowing for more spatial information to be absorbed on the walkthrough. However, it might be that its lack of boundaries affected the positioning and proportioning tasks as part of spatial organization altogether. Visiting the residence without the walls provided more insight into its plan and spaces that it contains at the same time. This could have led to too much information offered to the participant in the sense of abundance of cues and stimulations, and the attention shifted, not focused on the current space. Conversely, if the walls remained, the field of view would be drastically obstructed and variable, and the movement through spaces would have to be altered.

The proportioning and wayfinding tasks did not show significant differences between conditions, so they will not be discussed further. The reason for non-significant findings might be that the method of sketching the cognitive map is not the most accurate measurement for capturing one's perception of space. Sometimes there is no direct and positive correlation between the correct mental map and its transition on a sketch (Henry, 1992). The open floor plan added to this in a sense that boundaries were not given, but they were asked for when outlining the spaces. Also, the precision in proportioning the spaces and drawing the path of movement was not asked for, however, coding demanded strict grading using the tolerance levels, which sometimes yielded lower scores.

5.7 Limitations

Considering that this was a screening experiment for detecting trends, many more relationships can be explored and elaborated upon. We did not expand on them since a follow-up study is intended to be done at a later time, which will yield data for another 80 participants and increase the statistical power of the study, closing the full factorial 2⁵. This would possibly identify significant effects that were missed in the first wave of data collection, and confirm or refute the conclusions and identified tendencies in this study. The role of presence will also be further examined and the relationship it establishes with the system variables to help create a stronger impact on spatial comprehension.

There are a few limitations of the current experiment especially regarding the hardware and software used. This might have affected the results as well and should be corrected in the following research done with these parameters.

When comparing large display with small screen resolution, the images presented were slightly dimmed with weakened colors on the large display due to resolution differences. This resulted in the image perceived not to be exactly the same between these two conditions in view of their illumination and sharpness of colors. This is expected to be corrected with the new generation of projectors intended for the improvement of the Immersive Environments Lab.

Compromise made for the wide field of view conditions taking into account the software limitations (Stereoscopic PlayerTM) was previously mentioned in the explanation of the stimulus material (please refer to **Chapter 3**). The image resolution for the movies rendered for the wide field of view had to be lowered by 25% in order to comply with the length and speed of the movies rendered for the narrow field of view. This primarily

affected the visual quality of the stimulus not the frame rate of 30/s, whereas the experience of the walkthrough considering its pace and smoothness stayed the same.

Another observation we can make after conducting the experiment is that the sixminute walkthrough might have been too long for the subjects taking into consideration that they were passive observers and not active participants (no navigability or interactivity), and that the stimulus was seen twice in a row; the second time with pauses. This might have led to subjects being tired by the length of the stimulus and not paying as much attention as they did the first time, missing some important information on spatial organization, and perhaps impacting perceptions of presence.

There were two additional shortcomings of the experiment that were noticed after its execution. The perspective on the image with wide field of view is not entirely analogous with the image with narrow field of view. This is likely due to the different camera lenses used to render these images, 13 and 28 mm respectively. This could have been avoided if all the conditions were rendered for three screens and side screens were shut off for presenting the single screen conditions. Also, that approach would nullify the differences in speed, resolution or perspective between one and three screen conditions. Another drawback noticed later is that two independent variables – field of view and level of detail – overlapped in certain conditions. The wide screen condition may have offered significantly more depth cues as part of level of detail than intended. This observation combined with the previous one brings some doubts to the interpretation of the results considering these two variables when their interactions were significant. Since we cannot be completely sure, future research is needed for clarification of how these variables work with or against each other.

5.8 Conclusion

The starting point of this study was to evaluate the relative impact of VR variables on spatial comprehension and presence. VR in architectural design setting demonstrated to be a great addition and instrument for presenting and evaluating design spaces. The challenge was to determine how VR can enhance and support spatial comprehension as a step toward design comprehension.

In general, our results demonstrated benefits for the designers working on a large display with wide field of view, and stereoscopic viewing, but we should be aware of overestimating dimensions in a virtual environment as a consequence of these variables on spatial comprehension of design. The results extend previous findings by Tan et al. (2003) and Patrick et al. (2000) showing increase in performance in 3D tasks due to display size. Large displays afford cognitive aids that help involvement and focus of attention which is powerfully tied to sense of presence. This can be explained by field of view and the connection is that wide field of view increases immersion and immersion sense of presence. This is supported by our study as well.

Compared to Patrick et al. (2000), the authors explain their findings by large display providing a greater absolute difference in scale and creating more immersive environment. Also, the images seen by participant are comparable to the ones seen in real-life and provoke more precise dimension estimations. This interpretation would confirm the assumptions and the interpretation of the results from this study that the subjects perceived dimensions of the space to be close or exact to the human scale and may have used themselves as scale figures to estimate the sizes or distances.

The results from our experiment indicated the general tendency that spatial comprehension and sense of presence increased as display size and/or field of view increased. Subjects exhibited higher immersion and presence scores with increasing field of view and/or display size. This implies students achieved better spatial comprehension of a virtual environment when they had a stronger sense of presence, though the correlation between comprehension and presence cannot be positively confirmed. On the other hand, stereoscopy did not demonstrate a strong impact on dependent variables, in fact, monoscopy proved to be better solution for estimating tasks, which cannot be supported entirely by gathered data since there is a possibility that stereo illusion was not

completely analogous between large and small screen (see Limitations). Since stereoscopy is adding additional depth cues, it might be advisable that is combined with low level of detail not to incite the information overload.

Another recommendation to make is to consider content variables - level of detail and level of realism - for the task at hand. If the design is at development stage, high levels of detail and realism would be well received and effective even on one small display, though large screen with wide/narrow field of view can be also combined successfully. Conversely, when large display with wide field of view is used for assessment of spaces in schematic design stage in terms of size and scale or for design evaluation, might be advisable to keep content variables at low levels, not to hinder the spatial perception. The right balance should be achieved between display and content variables depending on the task at hand. This recommendation can be summarized in the following table:

Stage of design	Schematic design	Design development
Display variables	Large screen Wide field of view	Large/small screen Wide/narrow field of view
Content variables	Low level of detail Low level of realism	High level of detail High level of realism

Table 5.13: Recommendation for configuration of variables depending on stageof design

It is important to mention that the results of our study cannot be generalized, since the experiments carry internal validity, but not external validity, or in other words, the findings of the experiments cannot be generalized to the entire population, or applied to situations that were not tested directly. This brings us to the final conclusion that one ideal configuration of the VR system is not possible. Fine tuning of the system is demanded depending on the task and context. Virtual reality variables verified their impact of fluctuating magnitudes on spatial comprehension and sense of presence and VR confirmed its complex nature that needs to be further explored and elaborated. Furthermore VR potentials are not even close to be fully discovered.

5.9 Future Research

Based on the research findings, future studies in the Immersive Environments Lab can benefit in adding other potentially interesting variables i.e. luminosity, screen resolution, viewer-centric against object-centric representation, navigability and interactivity, and eliminating less or non-significant factors. Once the significant factors are identified, a full factorial experiment, particularly with more levels for each factor, instead of a fractional or screening experiment, could discover higher order interactions between the variables. Another approach to take to build on these findings would be to diversify the subject pool by comparing the variations between related design majors i.e. architecture and landscape architecture, among design majors and non-design majors, and between student designers and established professionals. VR is expected to be used as a connecting link between these groups in the future.

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APPENDIX A

IRB APPROVAL

INFORMED CONSENT FORM FOR SOCIAL SCIENCE RESEARCH The Pennsylvania State University

ORP USE ONLY: IRB#22310 Doc.#1 The Pennsylvania State University Office for Research Protections Approval Date: 02/02/06 JKG for DWM Expiration Date: 01/23/07 JKG for DWM Social Science Institutional Review Board

Title of Project:	Effect of virtual reality system variables on architectural design comprehension
Principal Investigator:	Loukas N. Kalisperis Professor Department of Architecture College of Arts & Architecture Pennsylvania State University 206 Engineering Unit C University Park, PA 16802
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	Nevena Zikic Graduate Student, Dept. of Architecture Pennsylvania State University 128 Stuckeman Family Building University Park, PA 16802
	Telephone: (814) 865-4209 E-Mail: nuz102@psu.edu
1. Purpose of the Study make a significant in	y: The purpose of the project is to identify which virtual reality system variables mpact on architectural design comprehension and in creating a sense of presence.

2. Procedures to be followed: You will be presented with a series of computer images of a building on the display screens in the Immersive Construction Lab (iCon lab). You will be asked to complete a

Page 1 of 2

questionnaire which would have questions pertaining the space /building you were shown such as to estimate the size of the room, which rooms are adjacent to each other, etc.

- 3. Discomforts and Risks: There are no risks in participating in this research beyond those experienced in everyday life.
- 4. Benefits:

a. You might learn more about architectural presentation using virtual reality.b. This research might provide a better understanding of how each of the virtual reality system components such as screen size, stereoscopy etc affect ones understanding of architectural.

- 5. Duration: It will take about 30 40 minutes to complete the study.
- 6. Statement of Confidentiality: Only the person in charge, and his/her assistants, will know your identity. If this research is published, no information that would identify you will be written. Your name will not be associated with any of the data collected in any manner. Only the principal investigator and the co-investigators will have access to the data collected and the data would be stored securely in a locked file cabinet in the co-investigator's office.

The following may review and copy records related to this research:

- The Office of Human Research Protections in the U.S. Department of Health and Human Services
- Penn State University's Social Science Institutional Review Board
- Penn State University's Office for Research Protections
- Right to Ask Questions: You can ask questions about the research. The person in charge will answer your questions. Contact Loukas Kalisperis at 865-0877 or Bimal Balakrishnan at 814-777-0616 with questions. If you have questions about your rights as a research participant, contact Penn State's Office for Research Protections at (814) 865-1775.
- 8. Compensation: There is no compensation for the study and participation is completely voluntary. You may withdraw your participation at anytime without penalty.
- 9. Voluntary Participation: You do not have to participate in this research. You can end your participation at any time by telling the person in charge. You do not have to answer any questions you do not want to answer.

You must be 18 years of age or older to consent to participate in this research study. If you consent to participate in this research study and to the terms above, please sign your name and indicate the date below.

You will be given a copy of this consent form to keep for your records.

Participant Signature

Date

Investigator Signature

Date

Page 2 of 2

APPENDIX B

QUESTIONNAIRE

Subj	ect No.					
SS	NoS	D	R	Str		
Please do not write in this box						

GENERAL INFORMATION

1. Age			
years			
2. Gender			
Male	Female		
3. Height			
Height ft -	in		
4. Academic Major			
5. Academic Standing			
1^{st} year			
3 rd year			
4 th year 5 th year			
Other	If other,	please specify	

When you have finished the section, **NOTIFY** the research assistant. Please **DO NOT** proceed to the next section until the research assistant asks you to.

Subj	ect No.					
SS	NoS	D	R	Str		
Please do not write in this box						

IMMERSIVE ENVIRONMENTS LABORATORY RESEARCH

Thank you for your help to make this research a success! Your participation will help us improve the Immersive Environments Laboratory now being built in the new School of Architecture and Landscape Architecture, the Stuckeman Family Building.

SECTION 1

Based on the presentation you just saw, please mark your answer to the following question by circling a number on a scale 1 to 8.

1. To what extent did you feel you were physically in the house?

Not									A great
at all	1	2	3	4	5	6	7	8	deal
2. To what	t extent wa	as it easy	for you t	to get use	ed to the	house?			
		-	-	-					
Not									A great
at all	1	2	3	4	5	6	7	8	deal
3. To what	at extent d	lid you l	have to p	ay a lot	of attent	tion about	t what wa	as going	g on in the
house?									
Not									A great
at all	1	2	3	4	5	6	7	8	deal
4. To what	it extent di	d you fe	el that wh	nat you sa	aw in the	house wa	s similar	to realit	ty?
Not		_	_				_	-	A great
at all	1	2	3	4	5	6	7	8	deal
D1 ==	0.0555								
Please PR	OCEED to	the nex	t page.						

Subj	ect No.				
SS	NoS	D	R	Str	
Please do not write in this box					

5. How easy was it for you to get a good feel of the spaces in the house?

Not									Very
at all	1	2	3	4	5	6	7	8	easy
		• 1	•	• 4 1		•	4		
6. HOW	much d	ia your exp	erience	in the h	iouse see	m consis	tent with	i your	real world
experience	ce:								
Not									A great
at all	1	2	3	4	5	6	7	8	deal
7. How c	ompellii	ng was your	sense of	moving a	round in	side the h	ouse?		
Mat									Acusat
not at all	1	2	3	4	5	6	7	8	A great
ut un	-	2	5	·	5	0	,	0	ucui
8. How r	ealistic o	lid the house	e appear	to you?					
Not at all	1	2	2	Λ	5	6	7	0	Highly
realistic	1	2	3	4		0	/	8	realistic
9. To wh	at exten	t did you fee	l you cou	ıld reach	into the	house and	l grasp a	n object	?
		-	-					-	
Not		_				_		-	A great
at all	1	2	3	4	5	6	7	8	deal
10. To w	hat exte	nt did the oh	iects an	near to b	e nronerl	v sized re	lative to	other of	viects?
10.10			Jeeus ap		c properi	y sizeu i e	141110 10	ounci or	Jeeus.
Not									A great
at all	1	2	3	4	5	6	7	8	deal

Subj	ect No.				
SS	NoS	D	R	Str	
Plea	Please do not write in this box				

11. How real did the objects in the house appear to you?

Not at all realistic	1	2	3	4	5	6	7	8	Highly realistic
12. To w	vhat exten	t did you f	eel you w	<i>ent int</i> o t	the house	?			
Not									A great
at all	1	2	3	4	5	6	7	8	deal
13. To w	vhat exten	t did the ex	xperience	e require	a menta	l effort fro	om you?		
Not									A great
at all	1	2	3	4	5	6	7	8	deal
When yo	ou have fin	ished the so	ection, N	OTIFY tł	ne researc	h assistan	t.		

Subj	ect No.				
SS	NoS	D	R	Str	
Please do not write in this box					

Answer the following questions as best as you can by marking an " \mathbf{x} " next to the appropriate answer.

Estimate the following if you know that the height of the SUV (sport utility vehicle) in front of the garage is 6 feet. Please refer to the sketch for all dimensioning.



1. The height of the highest roof point of the house excluding the chimney.

19	ft
21	ft
25	ft
29	ft
31	ft

2. The shortest horizontal distance from the SUV to the foot of the chimney.

22	ft
26	ft
30	ft
34	ft
38	ft

3. The overall width of the house.

37 ft
41 ft
45 ft
49 ft
53 ft

Please **PROCEED** to the next page.

Subje	ect No.				
SS	NoS	D	R	Str	
Please do not write in this box					

4. The length of the path from the sidewalk to the door.

22 ft
26 ft
30 ft
34 ft
38 ft

5. How many footsteps would it take you to get from the sidewalk to the door?

3 - 7
8 - 12
13 - 17
18 - 22
23 - 27

When you have finished the section, **NOTIFY** the research assistant. Please **DO NOT** proceed to the next section until the research assistant asks you to.

Subj	ect No.			
SS	NoS	D	R	Str
Please do not write in this box				

6. How well furnished do you think the LIVING ROOM is?

Not at all									Highly
furnished	1	2	3	4	5	6	7	8	furnished

7. Estimate the dimensions of the LIVING ROOM. Please round off dimensions to the nearest 3 inches.



8. How many people do you think can be in the LIVING ROOM without feeling crowded if all of them are standing?

3 -	7
8 -	12
13 -	17
18 -	22
23 -	27

Estimate the following. Please round off dimensions to the nearest 3 inches. 9. The width and height of the shelf.

Width	ft -	in
Height	ft -	in

Please **PROCEED** to the next page.

Subj	ect No.						
SS	NoS	D	R	Str			
Please do not write in this box							

10. The shortest distance between the shelf and the coffee table.

Distance	ft	-	in
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11. The shortest distance between the coffee table and the fireplace.

12. The shortest distance between the fireplace and the perpendicular outside wall.

		1	
Distance	ft	-	in

13. How photorealistic do you think the LIVING ROOM is?

Not at all									Very
realistic	1	2	3	4	5	6	7	8	realistic
When you	have finis	shed the s	ection, N	OTIFY th	ne researc	h assistan	t.		
Please DC	NOT pro	oceed to th	ne next se	ction unti	l the resea	arch assist	tant asks y	ou to.	

Subje	ect No.					
SS	NoS	D	R	Str		
Please do not write in this box						

14. Estimate the dimensions of the DINING ROOM. Please round off dimensions to the nearest 3 inches.



Mark the difficulty to estimate the dimensions of the **DINING ROOM**:

Easy to									Difficult to
estimate	1	2	3	4	5	6	7	8	estimate

15. How many people do you think can sit at the dining table?



Estimate the following. Please round off dimensions to the nearest 3 inches. 16. The width and length of the dining table.



17. The shortest distance between the dining table and the kitchen entrance.

Distance ft - in

Please **PROCEED** to the next page.

Subj	ect No.					
SS	NoS	D	R	Str		
Please do not write in this box						

18. The shortest distance between the dining table and the shelf.

Distance ft - in

When you have finished the section, **NOTIFY** the research assistant. Please **DO NOT** proceed to the next section until the research assistant asks you to.

Subj	ect No.					
SS	NoS	D	R	Str		
Please do not write in this box						

19. How well furnished do you think the KITCHEN is?

Not at all									Highly
furnished	1	2	3	4	5	6	7	8	furnished

20. Estimate the dimensions of the KITCHEN. Please round off dimensions to the nearest 6 inches.



Mark the difficulty to estimate the dimensions of the KITCHEN:

Easy to									Difficult to
estimate	1	2	3	4	5	6	7	8	estimate

Estimate the following. Please round off dimensions to the nearest 3 inches. 21. The height of the breakfast counter.

Height ft - in

22. The height of the fridge.

Height ft -	in	
-------------	----	--

23. The shortest distance between the fridge and the oven.

Distance ft - in

Please **PROCEED** to the next page.

Subject No							
SS	NoS	D	R	Str			
Please do not write in this box							

24. How photorealistic do you think the KITCHEN is?

Not at all									Very
realistic	1	2	3	4	5	6	7	8	realistic

When you have finished the section, **NOTIFY** the research assistant. Please **DO NOT** proceed to the next section until the research assistant asks you to.

Subje	ect No.					
SS	NoS	D	R	Str		
Please do not write in this box						

25. Estimate the dimensions of the STUDY ROOM. Please round off dimensions to the nearest 3 inches.



Mark the difficulty to estimate the dimensions of the **STUDY ROOM**:

Easy to									Difficult to
estimate	1	2	3	4	5	6	7	8	estimate

26. How many people do you think can be in the STUDY ROOM without feeling crowded if all of them are standing?

3 - 7
8 - 12
13 - 17
18 - 22
23 - 27

Estimate the following. Please round off dimensions to the nearest 3 inches. 27. The height of the stair landing from the floor level.

28. The depth of the laundry room.



Please **PROCEED** to the next page.

Subj	ect No.						
SS	NoS	D	R	Str			
Please do not write in this box							

29. Rank each space from the smallest size to the largest one. Attribute a 1 to the smallest, a 2 to the next largest and so on. If two spaces are the same size in square footage, give each one the same value.

LIVING ROOM	
DINING ROOM	
KITCHEN	
STUDY ROOM	

When you have finished the section, **NOTIFY** the research assistant. Please **DO NOT** proceed to the next section until the research assistant asks you to.

Subje	ect No.					
SS	NoS	D	R	Str		
Please do not write in this box						

Estimate the following.

30. The width of the HALLWAY between the MASTER and GUEST bedroom on the second floor.

2 ft – 6 in
3 ft – 0 in
3 ft – 6 in
4 ft – 0 in
4 ft – 6 in

31. The distance between the doors of the MASTER and GUEST bedroom on the second floor.

9 ft – 6 in
10 ft – 0 in
10 ft – 6 in
11 ft – 0 in
11 ft – 6 in

32. How many footsteps would it take you from the MASTER bedroom door to the GUEST bedroom door?



When you have finished the section, **NOTIFY** the research assistant. Please **DO NOT** proceed to the next section until the research assistant asks you to.

Subje	ect No.				
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Please do not write in this box					

33. Which space is below the MASTER bedroom on the second floor?



34. Which space on the second floor is above the KITCHEN?



35. Which space is below the GUEST bedroom on the second floor?



Please **PROCEED** to the next page.
Subj	ect No.			
SS	NoS	D	R	Str
Plea	ase do r	ot write	e in thi	s box

36. On the sketch of the first floor plan shown below draw the OUTLINES of the spaces the way they are organized and LABEL them.

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1	50	62	22	12	22		12	10	50	62	82	22	12	32	28	22	82	10	100	50	12	22	100	10	32	12

37. On the sketch of the first floor plan shown above draw a line showing the PATH of your visit through the spaces. Place ARROWS on the line to show the direction of movement.

When you have finished the section, **NOTIFY** the research assistant. Please **DO NOT** proceed to the next section until the research assistant asks you to.

Subje	ect No.				
SS	NoS	D	R	Str	
Plea	ase do n	ot write	e in thi	s box	

SECTION 9

1. Have you used the Immersive Environments Lab (IEL) before?



If NO, please skip to question 2.

a. If yes, how often did you use the Immersive Environments Lab (IEL) before?

Very									Very
rarely	1	2	3	4	5	6	7	8	often

b. If yes, how would you rate your experience with the Immersive Environments Lab (IEL)?

Very									Very
poor	1	2	3	4	5	6	7	8	good

c. If yes, how was your overall comfort level in using the technology in the Immersive Environments Lab (IEL)?

Not at all									Highly
comfortable	1	2	3	4	5	6	7	8	comfortable

Please **PROCEED** to the next page.

Subj	ect No.			
SS	NoS	D	R	Str
Plea	ase do r	not write	e in thi	s box

2. Estimate the average hours per week during this term that you spent using the computer for course related activities.

This term, on average I spent hours per week using a computer on all course related activities.

3. Estimate the average hours per week during this term that you spent using the computer for personal or leisure related activities.

This term, on average I spent hours per week using a computer for personal or leisure related activities.

4. Estimate your experience with 2D-graphics software in general (Photoshop, Illustrator, InDesign, QuarkExpress, etc).

I have months experience in using 2D-graphic design software.

5. Estimate your experience with 3D-modelling with computer aided design software in general (Form.Z, AutoCAD, SketchUp, 3DStudio Max, etc).

I have months experience in 3D-modelling with computer aided design software.

THANK YOU for taking the time to complete the questionnaire. We need and value your participation in our research to make the future Immersive Environments Lab even better!

APPENDIX C

STIMULUS MATERIAL

KEY STOP 1 – EXTERIOR





1 SCREEN AND 3 SCREENS – High Detail and High Realism





1 SCREEN AND 3 SCREENS – High Detail and Low Realism

KEY STOP 1 – EXTERIOR





1 SCREEN AND 3 SCREENS – Low Detail and High Realism





1 SCREEN AND 3 SCREENS – Low Detail and Low Realism

KEY STOP 2 – LIVING ROOM





1 SCREEN AND 3 SCREENS – High Detail and High Realism





1 SCREEN AND 3 SCREENS – High Detail and Low Realism

KEY STOP 2 – LIVING ROOM





1 SCREEN AND 3 SCREENS – Low Detail and High Realism



1 SCREEN AND 3 SCREENS – Low Detail and Low Realism

KEY STOP 3 – DINING ROOM





1 SCREEN AND 3 SCREENS – High Detail and High Realism





1 SCREEN AND 3 SCREENS – High Detail and Low Realism

KEY STOP 3 – DINING ROOM





1 SCREEN AND 3 SCREENS – Low Detail and High Realism





1 SCREEN AND 3 SCREENS – Low Detail and Low Realism

KEY STOP 4 – KITCHEN





1 SCREEN AND 3 SCREENS – High Detail and High Realism



1 SCREEN AND 3 SCREENS – High Detail and Low Realism

KEY STOP 4 – KITCHEN





1 SCREEN AND 3 SCREENS – Low Detail and High Realism



1 SCREEN AND 3 SCREENS – Low Detail and Low Realism

KEY STOP 5 – STUDY ROOM





1 SCREEN AND 3 SCREENS – High Detail and High Realism





1 SCREEN AND 3 SCREENS – High Detail and Low Realism

KEY STOP 5 – STUDY ROOM





1 SCREEN AND 3 SCREENS – Low Detail and High Realism





1 SCREEN AND 3 SCREENS – Low Detail and Low Realism

KEY STOP 6 – HALLWAY





1 SCREEN AND 3 SCREENS – High Detail and High Realism



1 SCREEN AND 3 SCREENS – High Detail and Low Realism

KEY STOP 6 – HALLWAY





1 SCREEN AND 3 SCREENS – Low Detail and High Realism



1 SCREEN AND 3 SCREENS – Low Detail and Low Realism

APPENDIX D

TECHNICAL DETAILS

TECHNICAL DETAILS

HARDWARE SYSTEM SPECIFICATIONS

Windows XP Workstation

- Dell Precision 650 workstation
- triple-head Matrox Parhelia 256 graphics card
- dual Intel Xeon 2.4 GHz
- 2 GB RAM
- CompactFlash/SD/MMC reader/writer
- DVD-RW
- Gyration wireless GyroMouse Pro
- Sidewinder wireless joystick
- Wireless computing RF-220 Compact Keyboard
- 4 input video capture card
- 19" diagonal analog RGB monitors

Linux Workstation & Cluster Nodes

- 4x Dell Precision 650 workstations
- PNY NVIDIA Quadro 900 XGL
- Intel Pentium 4 Xeon 2.8 GHz
- 2 GB RAM
- DVD ROM
- wireless Sidewinder joystick
- Intel PRO/1000 MT Server Adapter

Projectors

- 6 x Infocus Proxima Ultralight x350 1200 lumen DLP projectors
- controlled by Niles IRP6+ infrared remote extender & switch panel

Video Switching

- custom Rossman Audio 3x3x1 video switch with remote button panel
- HD-15 pin 12 routed for stereo sync capability
- selects between Windows desktop, Linux cluster, and external laptop port video sources

Passive Stereo

- Cyviz XPO2 Stereo 3D Converters
- linear polarized filters and glasses
- NuVision 60 GX Wireless Stereoscopic LCD glasses & emitter

Screens

- three frustum panorama
- purchased from VREX
- 6' x 8'; resolution XGA 1024x768 /screen
- 1/4" thick rigid acrylic substrate with polarization preserving rear-projection surface
- custom screen, projector and mirror mounts designed and constructed by Jamie Heilman

Wireless Networking

- LinkSys 54G wireless access point
- 802.11b & 802.11g
- used for wireless multimodal tablets & handheld devices