UNDERSTANDING THE IMMERSIVE EXPERIENCE: EXAMINING THE INFLUENCE OF VISUAL IMMERSIVENESS AND INTERACTIVITY ON SPATIAL EXPERIENCES AND UNDERSTANDING

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by

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LIST OF ABBREVIATIONS

α Cronbach's index of internal consistency

df Degrees of freedom: the number of values free to vary after certain restrictions have been placed on the data

F F distributions: Fisher's *F* ratio of two variances

M Sample Mean: the sum of a set of measurements divided by the number of measurements in the set

p Probability of a success in a binary trial

r Estimate of the Pearson product-moment correlation coefficient

SE Standard error

$<$ Less than

$>$ Greater than

$=$ Equal to

λ Wilk's Lambda: test to see differences between the means of identified groups of subjects on a combination of dependent variables

η_p^2 Partial eta squared: The proportion of variance associated with or accounted for by each of the main effects, interactions and error.

β Beta coefficient: estimates resulting from an analysis carried out on independent variables that have been standardized so that their variances are 1

CHAPTER 1: INTRODUCTION

1.1 Introduction

Advances in computer graphics enable us to represent space and 3-dimensional (3D) objects in a better and more realistic manner. Technology resulting from these advances can accurately recreate a number of monocular depth cues and binocular depth cues such as stereoscopy. Popularity of this 3D technology has been steadily increasing as the entertainment field continues improvements for hardware and display devices to enhance the 'immersive experience'. This experience refers to ways in which users are able to become part of the presented content. With the introduction of the 3D televisions, 3D gaming consoles, and a focus on 3D movies – both live action and animated – new possibilities and techniques are becoming available to fields outside of the entertainment industry. These new possibilities and techniques offer much to other fields which are adopting 3D technology such as architecture, interior design, and training programs. All of which seek to gain a better understanding of aspects of spatial information and performance within a simulated environment. Despite the adoption of techniques and 3D technology by fields outside of the entertainment industry, the impact of 'immersive experience' on spatial understanding and the mechanism underlying it still remains unclear.

As many have argued, 3D technology is only one contributor to the 'immersive experience', several other factors pertaining to the user also play a role in creating a sense of immersion (Ermi & Mäyrä, 2005; Tijs, 2006; Witmer & Singer, 1998). These factors have ranged from the specific type of medium (virtual reality, gaming, movie, etc.) to the presentation of information (visual, tactile, auditory, etc.) to the subjective perceptions of the people using the technology. In addition to the multitude of factors that comprise the immersive experience, there is theoretical ambiguity that occurs due to conceptual overlap with related concepts like presence. Considering these two main issues, further study of the immersive experience is necessary in order to improve both. This leads into two concepts for study: immersion and presence.

Fields outside of entertainment have been slowly incorporating 3D technology in an attempt to help in understanding space and performance. Disciplines like architecture and interior design for instance seek to help designers and clients to better evaluate space through various tools including renderings and physical models. These tools are used in order to help both the designers and clients to make more informed design decisions (Okeil, 2010). With the aid of drawings, plans, renderings, and physical models, designers are able to 'walk' through their designs but, not necessarily experience them (Okeil, 2010). Walk-throughs and other digital design representations have been increasingly used in architecture providing a much richer experience of the designed spaces at a more realistic scale. By capitalizing on the immersive experience from various types of 3D technology, design disciplines can gain a better sense of architectural spaces through simulated experiences.

Despite the benefit to the design disciplines, there are several barriers that impact the adoption of these 3D technology including (Calado, Soares, Campos, & Correia, 2013): cost of technology, skills needed to use the technology, and identifying the actual impact of the technology on users. Looking specifically at virtual reality systems, possibly one of the most sophisticated forms of 3D technology with applications across multiple disciplines, they are often sold as a comprehensive technological package for a premium price. Gaining a better understanding of the immersive experience will help to inform which aspects of 3D technology are more critical for evaluating the experiential qualities of space. This in turn could help with the development of more cost-effective and more customized systems which, focus more on the qualities of the system that benefit the design fields more.

Design fields are not the only discipline outside of entertainment adopting 3D technology. Training programs from all different areas (i.e. fire-fighting, military, airline pilots, etc.) are also adopting various 3D technologies to help train individuals to respond to specific environments or, to simulate how individuals would respond to specific changes to an actual environment. The challenge of understanding simulated space in design fields are therefore also applicable to training simulators.

Simulated training programs have continued to rely on the "immersive experience" to aid trainees in understanding material which was either very costly or in some cases too dangerous to simulate in the real world (Tate, Sibert, & King, 1997). These simulated training programs tended to incorporate a "hands-on" learning experience where focus was usually on the context of the training curriculum and how that would transfer to the real-world (Bossard, Kermarrec, Buche, & Tisseau, 2008). Little focus is usually given to the technology that facilitates the 'immersive experience' which, could be inhibiting the simulation from performing in the intended way. The fields that utilize these training programs tend to have a highly specialized focus (e.g.

medical, fire-fighting, military, etc.) and provide a great need for a better understanding of what the 'immersive experience' is and what it truly is doing to help trainees. This consideration suggests a need to examine the spatial experiences of users.

When using 3D technology to create an 'immersive experience' in areas outside of entertainment, it is important to distinguish how that technology is facilitating the experience. Virtual reality, in particular, has allowed for users to experience a 3D world through the use of an "experiential interface" which contains content with which users could interact as if they were truly there (Gorini, Capideville, Leo, Mantovani, & Riva, 2011, p. 99). This indicates the importance of 3D technology in terms of experiential components and what those components comprise of to create the 'immersive experience'. Using an experiential method alludes to the need to understand not only the way in which a user perceives a virtual space using the technology but, also how the user is actually interacting with the virtual space. Dalgarno and Lee (2010) suggested that immersion itself was a product of fidelity and interactive capabilities of the simulated environment. Adversely, Bowman and McMahan (2007) stated that while immersion and interaction are important to consider together, that immersion was not increased by more realistic methods of interaction with the environment. This is only a small indication of the lack of clear understanding of the joint impact of immersion and interactivity. As a whole these two concepts work together to allow users to actually participate in an experiential interface generated through technology. This suggests looking at the concepts of immersion and interactivity and how they work together.

To understand the benefits of the immersive experience, it is necessary to identify what could be learned from an immersive environment. With any virtual environment, space must be considered – for example, how one interacts with the space or how one comprehends the content of the space. One could broadly classify virtual environments into two categories: active and passive. To further contextualize the difference, active virtual environments could be considered more “interactive” (i.e. video games, computer games, etc.) whereas passive virtual environments are more static – less interactive (i.e. IMAX movies, 3D movies, etc.). The spatial aspects of user participation could be considered highly linked to the “immersive experience” depending on whether a medium is presenting active or passive virtual environments. Meijer, Geudeke, and van den Broek (2009) stated that spatial learning occurred from navigation based on their study of the three types of spatial knowledge: landmark, route, and survey. They further stated that learning in a virtual environment was similar to that of the real-world as similar spatial knowledge was used when performing tasks in the real-world. This suggested that spatial aspects of a virtual environment could be measured in a similar way to those of the real-world. As a result of an indicated relationship between spatial learning and navigation, it was also important to examine the construction of spatial understanding in virtual environments.

Overall, this dissertation investigates the relative contributions of the immersive experience through manipulations of immersion and interactivity on spatial experience and understanding. To do this, immersive experience was explicated to help bring conceptual clarity to each of the manipulations of immersion and interactivity. This clarity helped in better identifying the relative impact of the manipulations on spatial experience and understanding; aiding in addressing the overall research question, what is the influence of the immersive experience on spatial experience and understanding. Through the exploration of the theoretical ties between immersion and interactivity on spatial understanding, this study looked at isolating individual components of the virtual environment to better identify the relative contributions of each in aiding a user's experience within a simulated environment. The constructs of spatial experience and spatial understanding were broken into common concepts. Spatial experience consisted of concepts of spatial presence, vection and reality judgment. Spatial understanding consisted of concepts of spatial task performance and spatial recall.

To evaluate the impact on the measures of spatial experience and understanding, a simulation was developed and tested. Specifically, a simulation for a search task and report of findings task from a building that was recently on fire was developed. A narrative provided instruction for the combination of tasks in order to help provide motivation for users to not only complete the tasks but, to actively explore the space, gaining spatial knowledge through experience. This introductory chapter further explains the rationale for the study and introduces the key concepts in the study. Chapter two starts with a focused literature review to explicate key concepts in this study. Then research questions and hypotheses regarding the impact of immersiveness and interactivity on spatial experience and understanding are discussed. Chapter three describes the research design and provides details of the controlled experiment carried out to address the research question and hypotheses. Chapter four details the data analysis including the data screening for assumptions. Chapter five concludes the study with a discussion on the findings and how they related back to previous findings from the literature.

1.2 Rationale

The findings from this study should help to improve the overall understanding of the immersive experience and how it relates to both spatial experience and understanding in virtual environments. This project thus has important theoretical, methodological, and practical implications. These implications form the overall rationale for conducting this research on the immersive experience influencing spatial experience and understanding.

This study intended to clarify the concept of immersion and distinguish it from related theoretical concepts such as presence, involvement and engagement. Currently, a clear theoretical definition does not exist for the concept of immersion. Studies conducted in human-computer interaction and entertainment have utilized varying research approaches which have further muddled the definition. For the most part, human-computer interaction research has focused on the definition provided by Slater (1999) (i.e. immersion refers to the technology of the virtual system). The use of the technology-focused definition of immersion has helped in distinguishing it from presence but, seemingly ignores the concepts found in psychological immersion by simply labeling them as presence. This again causes confusion in the conceptual clarity of presence and how manipulations of immersion may or may not influence user perceptions of presence. Nor did the definition provided by Slater (1999) rationalize links between immersion and other user experience factors. Slater and Wilbur (1997) did attempt to create a framework of immersion which, addressed some issues of linking immersion with other concepts.

However, like other established frameworks for immersion (Witmer & Singer, 1998) subsequent research on immersion has turned to other operationalizations of immersion in order to better fit the needs of the research. In particular, studies looking at human-computer interaction of video games have added to the confusion by suggesting immersion was different for video games than for virtual environments (Ermi & Mäyrä, 2005).Therefore, it was important to look at the theoretical ties between immersion and other factors related to immersion.

More specifically, this study sought to gain an understanding of the concepts that formed the construct of immersion. In order to do this, conceptual overlap with related concepts were explored through a formal literature review and concept explication. One of the key theoretical implications was the operationalization of immersion and the systematic assessment of its impact on different user experience dependent variables (i.e. spatial presence and spatial understanding). This study therefore sought to provide a clearer understanding of the concept of immersion through the process of explication elaborated by Chaffee (1991) and, by systematically assessing the relative impact on concepts related to spatial understanding and experience.

Distinguishing immersion from spatial presence is important for virtual reality research. This study builds on existing theoretical distinctions between immersion and presence (Wirth, et al., 2007) in order to compare them at the level of measurable dimensions. Providing a theoretical framing of the relationship between immersion and presence could better test the role of immersion on presence measures. Similarly, immersion was theoretically linked to spatial understanding in order to better establish ‘if’ and ‘how’ the influence of immersion occurred.

This study also intended to make a methodological contribution by adopting a media effects approach to studying the impact of virtual reality system components. Studies on technology and related concepts often treat technology as a monolithic entity, limiting the ability to transfer methods and findings across different technologies. This study used an approach which looked at technology in terms of its affordances in order to determine how specific features and settings independently influenced measures of spatial experience and understanding. This variable-centered approach proposed by Nass and Mason (1990) was previously demonstrated within the context of virtual reality technology by Balakrishnan and Sundar (2011).

The idea behind the variable-centered approach was not entirely new to the study of virtual reality technology or the concept of immersion but, it can provide insight that current methods do not yet cover. Laha, Bowman and Schiffbauer (2013) discussed a similar approach, the mixed reality (MR) simulation approach, to studying immersion and virtual reality technology. The MR simulation approach breaks immersion into a taxonomy of sensory fidelity attributes to be varied using a single system. This study combined the taxonomy of immersion of virtual reality technology from an affordance perspective to explore the relative impacts of each specific affordance. The implications of combining both approaches provided a more reliable way to test concepts like immersion across the spectrum of virtual reality systems.

The study's manipulations of the independent variables focused on specific aspects of visual and interactive aspects independently. As McMahan, Gorton, Gresock, McConnell, & Bowman (2006) pointed out, there needs to be a distinction between immersion and interactivity influences within virtual environments to gain a better understanding of the impact of each independently. This allows for better control over correcting issues found with a simulation if individual components could be isolated and addressed. To follow along these lines, the visual aspects would be investigated separately from the interactive ones. The visual aspects dealt with how well the user saw what was going on. While this could include multiple combinations of display features of a virtual reality system, this study looked to start with just two features. This would provide better information about the two display features than if they were grouped with three or more. Ragan, Sowndararajan, Kopper and Bowman (2010) explained this approach allowed for immersion to be identified in 'levels' as opposed to the immersive or non-immersive approach (a common method for exploring immersion). Similarly, the interactive aspect investigated the degree to which a user could interact in the simulation. This was done by investigating a feature of the input device used by the participant. The study sought to utilize two levels of a specific input device's attributes. The features of the input device would then be transferrable across different types of input devices and not specific to just the one used in this study. The end benefit would be to have an understanding for different levels of interaction capabilities and how that influences a user's understanding of the virtual environment.

Second, the key goal of this study was to establish the role of the technology components in how users experience a virtual environment. Specifically, the study sought to see how technology components influenced user experience, performance and ultimately memory of experiences based on their understanding of the simulated space. The findings of this study could then be used to inform disciplines interested in using virtual environments to enhance understanding of space.

In most cases where users were asked to interact with a virtual space there would be a degree of spatial presence experienced while in that space (Witmer & Singer, 1998). Spatial presence has been generally defined as 'feeling present in a space'. This definition tied into the idea that if one felt present in a virtual space, they were more attentive to that space and less attentive to the surrounding real-world (Wirth, et al., 2007). So when simulations aimed at accomplishing a certain purpose was used, users should have felt as if they were in the space experiencing the events in order to react in a more realistic manner. Understanding the influences of different technology components on the sense of presence would provide better insight into how to improve technology to better aid in spatial understanding.

Performance within a simulated environment has been another concern for two reasons. First, simulations are similar to virtual learning environments where users are expected to learn by doing or experiencing content. Secondly, the information learned in the simulated environment should transfer to real-world knowledge. In approaching these two concerns of performance, Roussou (2004) discussed the importance of interaction and other virtual environment aspects (i.e. presence, immersion, etc.) from a learning perspective. How a learner interacted and received feedback from the simulated space played a role in not only how the learner performed but, ultimately what would be learned. In this case, different technologies could potentially influence how a user/learner may make decisions due to the influence of a number of different factors (i.e. skill level, novelty, etc.).

As simulations focused on transferring spatial knowledge to users are generally situated within a context (i.e. a burning building for fire-fighters, a new renovation for architectural designers, etc.), it is important to make sure the technology facilitates that transfer of knowledge. Testing how the technology specifically influences performance would provide better insight into how spatial understanding could be improved as a function of different technology components.

Lastly, the study looked at the influences on memory of the experience with a particular focus on the transfer of spatial information. The purpose of most simulations for training has been to teach users about something with the understanding that knowledge would transfer from their experiences in the simulation to the real-world. This same idea pertains to information learned from the exploration of a designed space where knowledge of layout and the relationships of designed elements should be remembered in order to evaluate the spaces. Transfer occurs due to processes related to memory of aspects of what was previously learned (Bossard, et al., 2008). Understanding again how the technology facilitates a user's ability to remember specifics about an experience after performing tasks could provide information into which aspects really would benefit disciplines focused on spatial comprehension more.

CHAPTER 2: LITERATURE REVIEW

This chapter discusses the key concepts related to the immersive experience in virtual reality systems. The first section explicates the key concepts in this study – immersion, interactivity, then spatial experience and understanding. The last section will examine the theoretical model to pose the overall research question and generate specific hypotheses for conducting the study.

2.1 Virtual reality systems and the immersive experience

Virtual reality systems are simply a technological medium which offer the opportunity for users to experience and interact with 3-dimensional computer-generated content. Gorini et al. (2011) noted that virtual reality systems comprise of several components: hardware, software, a user interface, and human factors like perceptions, cognition, and emotions (p. 99). Considering all the components involved in a virtual reality system adds to the complexity in understanding how the immersive experience occurs. But the complexity of the systems is not the only challenge in understanding virtual reality system technology.

The landscape of virtual reality technology is broad, diverse and constantly evolving. Different types of virtual reality systems exist. One can go from very costly systems like a CAVE (i.e. a four to six screen projection system), to slightly less costly systems like head-mounted displays (HMDs) (i.e. personal viewing systems), to more cost effective systems like desktop-VR systems. Each type of system affords different benefits particularly, in terms of generating an immersive experience. With the vast diversity of these constantly evolving systems, one of the key challenges for research on virtual reality systems is to be able to assess the impact of such systems on user experiences (Steuer, 1992). In order to assess the impact of technology components used in creating an immersive experience, it was important to explore commonalities and distinctions.

Virtual reality systems capture user attention primarily through a display device and involve users in the displayed content through an input device (Bowman & McMahan, 2007). These common features of a virtual reality system relate directly to the immersive experience found in all types of virtual reality systems. Distinctions of features in a virtual reality system comes more in the form of the content and individual user differences (Steuer, 1992). Based on this understanding of virtual reality systems and the immersive experience, it was necessary to look in-depth at the concepts that comprise the immersive experience in terms of the technology components in a virtual reality system: immersion and interactivity.

2.2 Immersion

Immersive experience stems from a more complex concept, ‘immersion’. Immersion itself is not a new concept and has been highly studied in the context of virtual reality research. Its original meaning related to the actual submersion of an object in water which, has later been translated to many fields pertaining to experience, particularly simulated experiences (Murray, 1997). In terms of technology, a user is submerged in a simulated experience generated by the technology.

Historically, immersion has been studied from a variety of disciplinary perspectives including but not limited to that of education, media studies, communication, and psychology. Research on immersion performed in the field of education focused more on second language learning and later experiential learning (Curtain, 1986). Cognitive psychologists researched immersion as a phenomena which occurred with the introduction of new technology (Agarwal & Karahanna, 2000). The majority of recent research has centered on video games and virtual environments (Brown & Cairns, 2004). Many fields now rely on technology to envelop the user in a specific experience. Murray (1997) indicated the idea of immersion is both physically and psychologically experienced by users. While Murray (1997) determined the dichotomy within the area of immersion, Biocca and Delaney (1995) furthered the distinction by indicating the physical aspects being related to perception of sensory engagement. This furthered the original understanding of the dichotomy that immersion occurred on both a perceptual (sensory) and psychological (affective) level as shown in Fig. 1. Immersion therefore, could be seen as an outcome of both sensory and affective factors. Sherman and Craig (2003) supported this dichotomy within the concept of immersion by labeling the two sides as physical (perceptual) and mental (psychological) immersion.

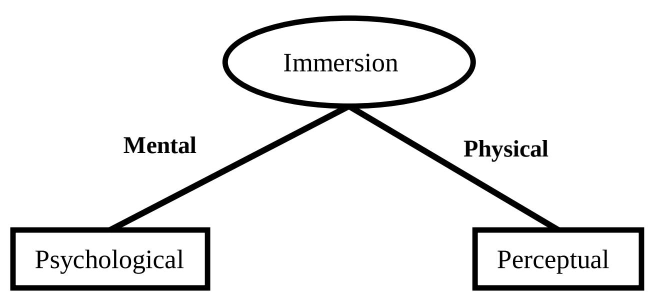

Figure 1: The dichotomy of immersion.

This dichotomy of immersion has led to differences in how it is defined in the literature. This issue with defining immersion could be attributed the retro-fitting the concept had undergone to be applied to technology (Murray, 1997). Several studies have attempted defining and explicating the concept of immersion (Robertson, Czerwinski, & van Dantzich, 1997; Slater & Wilbur, 1997; Witmer & Singer, 1998). Despite these attempts, immersion still remained an ill-defined term.

The concept of immersion continues to be relevant for newer technology. With the improvements to user experiences, immersion as become more difficult to distinguish from other related concepts like presence, engagement and involvement (Schuemie, Van Der Straaten, Krijn, & Van Der Mast, 2001). To distinguish immersion from other known concepts, studies have been conducted to measure both immersion as well as presence, a concept that is often confounded with immersion. These studies led to debates on what attributed to the distinction between the two concepts. Presence is a concept commonly found in research dealing with virtual reality technology and, refers to the feeling of being in a simulated or mediated space (Schubert, Friedmann, & Regenbrecht, 1999a). Witmer and Singer (1998) developed a commonly used questionnaire in which presence could be measured based on exposure to a virtual environment. In addition to measuring the concept of presence, Witmer and Singer (1998) distinguished immersion from presence by developing a second portion to their questionnaire which, focused on measuring a user's immersive tendency. It was from this second section that Witmer and Singer (1998)'s definition of immersion became clear; that of a user-focused sensation based on responses to the virtual environment, similar to that of presence. Slater (1999) countered this definition suggesting that immersion was technology-focused causing the user to experience a sense of presence. In this way, immersion and presence were more clearly distinguished; immersion being objective and presence as a subjective measure. Other studies have furthered the debate through other known mediating variables (e.g. involvement, engagement, etc.), which have muddled the conceptual clarity of immersion.

As immersion has been referred to as having both a perceptual and psychological aspect, it was important to define it as such and to try to remain consistent across the different domains that used the concept. Therefore, immersion could be theoretically split into its two parts accordingly: perceptual immersion and psychological immersion. In explicating both perceptual and psychological immersion, the foci were different. In looking at the immersive experience as a product of technology generating a sense of immersion, perceptual immersion was explicated with the intention of listing technological affordances. The focus of the explication of psychological immersion was to understand the attributes it comprised of, in order to better distinguish them to serve as control variables.

2.2.1 Perceptual Immersion

Immersion could be seen as a sensation similar to submersion in water, in that users perceive their senses being physically engaged through various types of technology. It leads user to perceive themselves as being engulfed in the media content as a function of technology used. Immersion here is seen as a technology-based phenomenon. Therefore, perceptual immersion is purely the objective aspect of a virtual reality system that could stimulate user senses through various types of technology attributes. This is in line with the definition provided by Slater and Wilbur (1997) that immersion was the objective measure of the technology being used in a system. This definition is useful as it distinguishes immersion from the more subjective aspect of presence (Schuemie, et al., 2001). The challenge then became understanding how immersion theoretically influenced user performance in context-based tasks within a simulation and, how that is translated to the real world (Gorini, et al., 2011).

According to Slater and Wilbur (1997), immersion was an objective aspect that described technology and the degree a display was able to involve the user's senses. Bowman and McMahan (2007) refined the need to distinguish immersion based on the senses. Bowman and McMahan (2007) suggested this refinement was due to a link between immersion and stimulation of the senses. Several studies have considered the various senses that could be simulated through techonology as shown in Fig. 2. Here, perceptual immersion is seen as an outcome from experiencing the different types of sensastions.

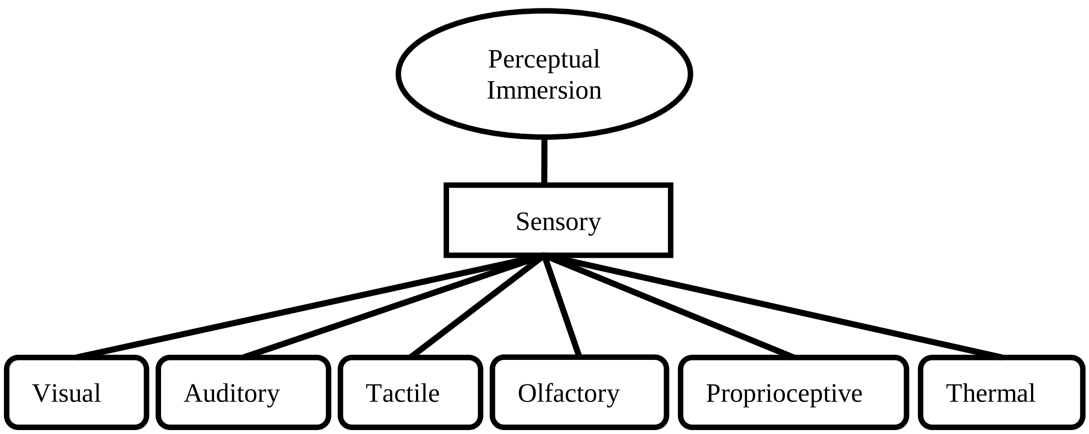

Figure 2: Perceptual immersion as sensory factors.

Visual immersion was the most prominent type as all immersive virtual reality systems contain some aspect of visual stimuli. In other words, display technology could be found in most immersive systems. Thinking about immersion in this way allowed for a suitable decision to be made on which type of immersion was most useful. For this specific study, visual immersion would be considered sufficient for exploring the effects on spatial tasks as many aspects of display technology have been found to influence immersion (Bowman & McMahan, 2007). These aspects shown in Fig. 3 are not exhaustive, but cover most common display attributes associated with visual immersion. To better clarify the focus, visual immersion suggests a state and not a variable aspect of the immersive experience. Therefore, the concept of visual immersion in this study was recast as visual immersiveness. Treating it as an affordance of display technology allows it to be varied at different levels and systematically study its impact.

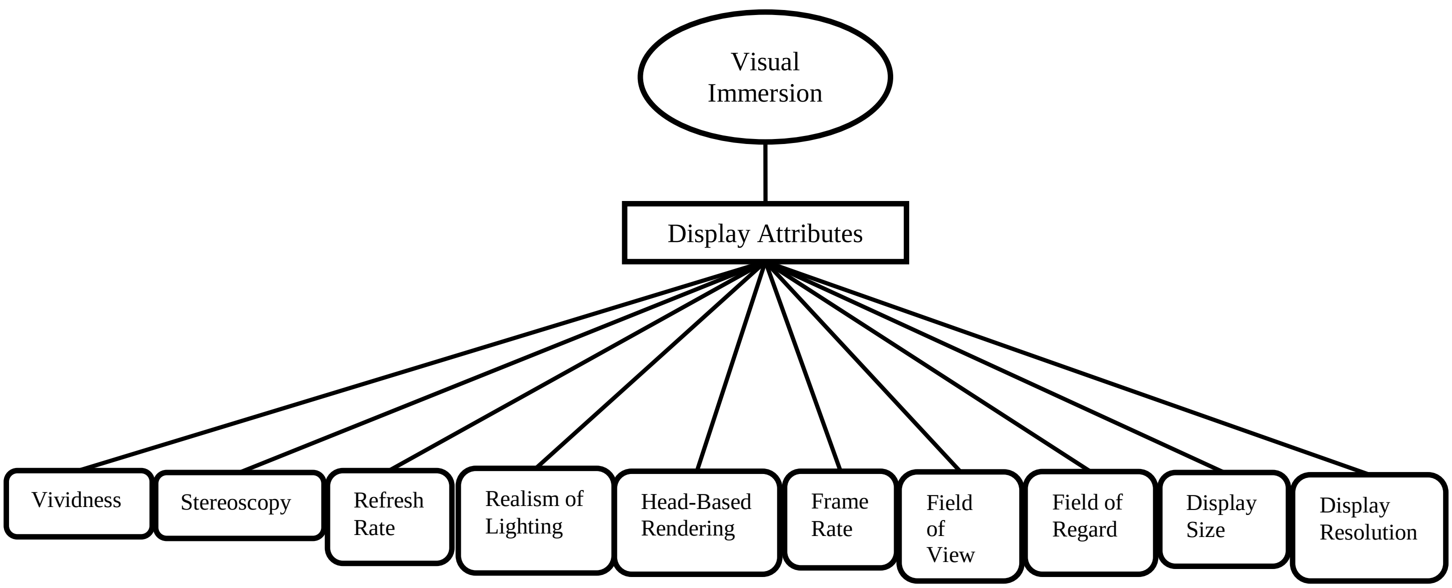

Figure 3: Display attributes related to visual immersion.

2.2.2 Psychological Immersion

Psychological immersion deals with the aspects of engulfing a user in content which pertained to the user's ability to experience such sensations. Whereas perceptual immersion was based on the use of technology to simulate an experience, psychological immersion dealt with playing off of a user's mental ability to be immersed, i.e. a user's emotional response. In some regard, perceptual and psychological immersion work hand-in-hand. This was not always the case though as other media studies have proven that immersion could occur without the use of a perceptual medium, as in the case of reading books. When reading books, individuals have claimed to be immersed in the storyline and yet no imagery, audio, tactile, or olfactory mechanisms were used to create such an experience (Ryan, 1999). This suggested that individuals were capable of experiencing immersion without the need of sensory input from outside sources. The issue was that not all users were easily immersed in different mediums. It has been argued that in many cases this was mislabeling of other psychological concepts including imagination (Baños, et al., 2008) and narrative transportation (Green, Brock, & Kaufman, 2004). Aside from the issues in distinguishing psychological immersion from other psychological concepts, this was one of the larger distinctions between perceptual and psychological immersion.

Psychological immersion could be defined as the user's perceptual and cognitive ability to focus on the content being visualized. Three main dimensions could be formed for psychological immersion: involvement, attention, and affect, see Fig. 4. Involvement was the degree to which a user could become engulfed by an activity (Schuemie, et al., 2001). Attention was the degree to which a user could focus on a task, dedicating full concentration to working through a problem (Ermi & Mäyrä, 2005). Affect was the emotion or experience of feeling a user had while being engrossed in an activity (Robertson, et al., 1997).

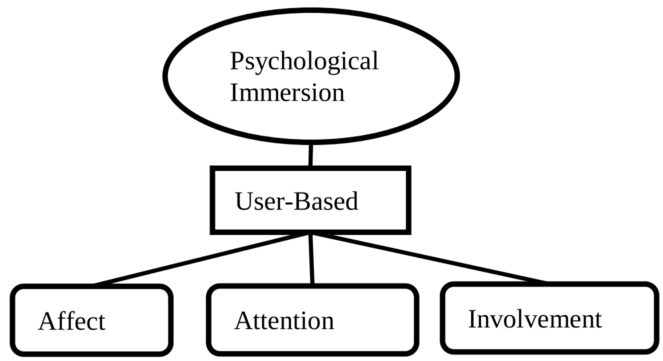

Figure 4: User-based factors related to psychological immersion.

2.3 Interactivity

Interactivity refers to how and to what degree people interact with a virtual system (Bucy & Tao, 2007). While interactivity has been studied from various perspectives in relation to technology (e.g. websites) the focus on 3D environments has been limited (Yun, 2007). Interaction has often been seen as the concept relating to active participation in a virtual environment (Bucy & Tao, 2007). Sundar (2004) clarified that interaction was a function of the user. With a focus on the user as the determinant of interaction, manipulating interaction in an experimental setting became difficult. Therefore, interaction needed to be considered a function of media technology as suggested by Sundar (2004). This led to a distinction in terminology: interactivity and interaction. Interactivity here is viewed as an affordance of the technology while interaction is treated as resident in the user.

Like many concepts in virtual environment research, interactivity was adopted from the communication field where the meaning pertained to interactions between people (i.e. human-to-human interaction) or people and content (i.e. human-to-content interaction). Communication-based interactivity was essentially the sequential messaging in response to previous messages (Rafaeli, 1988 in Yun, 2007). The key to interactivity for technology lies in response time (Steuer, 1992; Yun, 2007), and is due to the form of involvement of the user

– active or passive. Andersen (1997) in Yun (2007) indicated this had to do with the level of control over the interaction that was necessary to become a part of the content.

2.3.1 Navigation as a type of interaction

Interactivity has been widely accepted as a form of communication with a synthetic environment (Bucy & Tao, 2007). In virtual environment research, interactivity is heavily focused on the technological aspects of the virtual environment system. Bowman and Hodges (1999) classified interaction in terms of technology. Steuer (1992) generated a list of three categories based on their research where interactivity consisted of: a focus on speed – the rate input could be assimilated (i.e. Response time), a focus on range - the number of possible actions at a given time, and a focus on mapping - the ability of a system to map its controls to changes in a natural/predictable manner.

Bowman, Kruijff, LaViola Jr., and Poupyrev (2005) later defined interactivity in terms of technology, specifically input devices for particular types of interaction. Bowman et al. (2005) divided interaction into two main components: manipulation/selection and navigation. The operationalization of manipulation/selection encompassed three basic actions: selection, manipulation, and release. These three actions could be performed with objects within a 3D virtual environment. Within navigation, Bowman et al. (2005) added that travel and wayfinding were essential parts of navigation. This led to the issue of differentiating interactivity from navigation. Sundar (2004) furthered this idea of interactivity as different from navigation but, only so far that navigation was considered a type of interactivity. In considering navigation as part of interactivity, the operationalizations of travel and wayfinding also became a sub-component of interactivity.

Navigation presented similar complications in its definition as interactivity in that it was commonly associated with the user rather than the technology (Balakrishnan & Sundar, 2011). Balakrishnan and Sundar (2011) re-conceptualized it as navigability, i.e. the affordance for navigation thus recasting it from a user-centric to technology-centric perspective. In their study, navigability was further broken down into two main technology-based aspects: traversability and guidance, which enabled travel and wayfinding respectively. Balakrishnan and Sundar (2011) explained that "traversability is defined as the affordance to move large distances in a virtual environment as a function of (1) environmental constraints and (2) steering control" (p. 164). It was found that steering control had significant influence on spatial presence. Similarly, this study looked at the technology aspects of navigation to represent interactivity with a specific focus on traversability.

2.3.2 Interactivity & immersion as defining characteristics of VR

Several studies have suggested that both immersion and interactivity were crucial to spatial performance measures and user experience (Bowman & McMahan, 2007; Steuer, 1992; Zeltzer, 1992). Although no direct connection between immersion and interaction had been identified, Zeltzer (1992) generated a taxonomy for exploring virtual reality systems consisting of three characteristics: autonomy, interaction, and presence. As with many studies, the term 'presence' was used by Zeltzer (1992) in an encompassing manner. As Schuemie, Van Der Straaten, Krijn, & Van Der Mast (2001) stated, Zeltzer's 'presence' was more closely related to immersion as defined by Slater and Wilbur (1997). Therein, the taxonomy for exploring virtual reality systems could be recharacterized as: autonomy, interaction, and immersion. This showed the importance of considering immersion and interactivity as viable virtual environment attributes which, could be implemented to influence the relationship with spatial performance measures and user experience. Following the same idea of exploring virtual reality systems, the same taxonomy could be considered as immersiveness and interactivity. With this model for exploring virtual reality systems, the impact on user experience measures, spatial presence in particular, could be examined.

Another more direct connection for looking at 3D virtual enviornment attributes from the concepts of immersion and interaction came from the “human-VE interaction loop” model developed by Bowman and McMahan (2007). In this loop, a model was sent to the computer where rendering software delivered it to display devices for a user to view. The user then utilized an input device sending a message back to the computer system to update the rendering software. In considering this model, immersion and interaction were central to user participation. Despite the inclusion of some form of interaction in their model, the concept of interactivity was intentionally left out of the Bowman and McMahan (2007) analysis. While their findings provided great insight into the relationship between virtual environments attributes of immersion on spatial performance measures, it did not consider interactivity as having any direct contribution to the overall outcome.

2.4 Spatial Experience

Spatial experience comprised of numerous concepts related to an individual’s experiences in a space; regardless of whether it was simulated or real. In this section, key aspects of spatial experiences in virtual reality environments are identified and discussed in-depth. Spatial experience in virtual reality specifically pertains to an individual feeling present within a space. This feeling of presence within a space comes from several factors including the illusion of self-motion, vection, and the perception the simulated space as ‘real’ known as reality judgment. For spatial experience, three main concepts are discussed: spatial presence, vection and reality judgment.

2.4.1 Spatial Presence

Presence is a complex concept representing “the sense of being in a place” (Schubert, Friedmann, & Regenbrecht, 1999a). Often considered a multidimensional variable comprising of several subjective factors, there are numerous types of presence: telepresence, spatial presence, social, mediated presence, and so on (IJsselsteijn, de Ridder, Freeman, & Avons, 2000).

Spatial presence has been related to the larger concept of presence in a number of ways. Schubert et al. (1999b) explained a basic model of presence which consisted of two main components: spatial presence and involvement. The idea behind this basic model stemmed from previous studies which aimed to identify presence based on key factors which Schubert et al. (1999b) deemed necessary to distinguish: spatial presence and attentional allocation.

Wirth et al. (2007) explained that “spatial presence is a binary experience, during which perceived self-location and, in most cases, perceived action possibilities were connected to a mediated spatial environment, and mental capacities are bound by the mediate environment instead of reality” (p. 497). Prior work by Vorderer et al. (2004), a precursor to the Wirth et al. (2007) work, defined spatial presence similarly in their development of the MEC spatial presence questionnaire (MEC-SPQ). In their model for setting up the questionnaire, Vorderer et al. (2004) defined spatial presence as a construct consisting of two parts: self-location and possible action. These two parts were the result of both attention allocation and the spatial situation model (SSM). In addition, two other factors were included: cognitive involvement and suspension of disbelief. Combined, these factors could generate spatial presence. Wirth et al. (2007) used this same idea in the development of their model of spatial presence. In addition to including the major factors from Vorderer et al. (2004)'s model, location of the primary ego reference frames (PERF) was introduced as the explanatory mechanism for how the SSM facilitates the experience of spatial presence.

The spatial situation model was a mental model or representation which a person forms of a space. This model was always in complete form though it was continually updated (Wirth, et al., 2007). The model was highly dependent on user attention. Without attention, the spatial situation model could not occur and spatial presence then becomes highly unlikely. In addition to attention, the spatial situation model was also dependent on spatial cues. These cues were used to not only grab a user's attention but to also provide a basis for the formation of a mental representation of the space. Once a user established a spatial situation model, he/she then compared it to the mediated space to gain confirmation of the PERF. This confirmation that a user's PERF fit the spatial situation model was what increased the perception of spatial presence. Wirth et al. (2007) presented a two level model of spatial presence formation. The first step was based on attention and how it led to the development of the spatial situation model. The second step was when confirmation of a user's PERF occurred, inducing a sense of spatial presence. Wirth et al. (2007) also noted that several media factors and user differences may impede the process. Contrary to the Wirth et al. (2007)'s model of spatial presence, Balakrishnan and Sundar (2011) found that for virtual environments the formation of spatial presence can occur without the formation of a spatial situation model. This occurred through the use of a bottom-up process as opposed to

Wirth et al. (2007)'s top-down process, suggesting that different mechanisms may impact spatial presence.

Two related concepts, vection and reality judgment, can also aid in indirectly assessing spatial presence. Vection, the perceptual illusion of self-motion, occurs when an individual feels present and moving within a simulated space. This indicates how vection indirectly measures presence. The other concept, reality judgment, is the acceptance of what is being perceived as 'real'. When an individual feels present within a simulated space, the simulated space should become easier to accept as real. This illustrates how reality judgment can also indirectly measure spatial presence.

2.4.2 Vection

Vection is the perception that motion occurs around a stationary observer, otherwise referred to as illusory motion or self-motion. To gain a sense of self-motion, typically vestibular cues were considered but, they have also proven to not be completely necessary as both visual and auditory stimuli have reported instances of inducing vection (Larsson, Västfjäll, & Kleiner, 2004). The instances of self-motion occurring from visual stimuli suggested a link between vection and presence, particularly spatial presence (Schulte-Pelkum, Riecke, von der Heyde, & Bülthoff, 2003). When an observer feels present in a space, the potential for self-motion has been reported as higher, increasing the sense of vection (Schulte-Pelkum, et al., 2003). The link between vection and spatial presence has been explained in two ways. First, when an observer felt present in a space, he/she was able to use that space as a 'stable reference frame' as would normally happen in the real-world (Riecke, Schulte-Pelkum, Avraamides, von der Heyde, & Bülthoff, 2005). Essentially, an observer needed to overcome a conflict between sensory information received from a simulated space while remaining physically stationary (Riecke, 2011). To account for this conflict, the simulated space should be able to increase the observer's perception of being in the space to make the visual cues of motion more 'believable'.

Second, vection was impacted by similar display parameters such as field of view and content of a visual stimulus with the exception of stereo (IJsselsteijn, de Ridder, Freeman, Avons, & Bouwhuis, 2001). The added perception of depth related to stereoscopic imagery had not been found to consistently impact vection (IJsselsteijn, et al., 2001) but, had been considered to help facilitate self-motion through depth cues (Riecke, 2011).

Studies on self-motion have focused on highly controlled experimental stimuli which, allowed for precise settings on velocities and acceleration effects (Riecke, et al., 2005). In these experimental settings, vection had typically been measured through either self-report items (IJsselsteijn, et al., 2001) or direction indication exercises such as pointing tasks (Riecke, et al., 2005).

2.4.3 Reality Judgment

In virtual environments, users are expected to accept what they perceive as real (Baños, et al., 1999). Reality judgment was the outcome of a number of variables that users collectively perceived as real. Baños et al. (2000) noted that reality judgment is not about "sensorial or pictorial realism" (p. 328). Instead, reality judgment was more about an individual's "willingness to interpret virtual experiences as if they were veridical" (Baños, et al., 2000, p. 328).

Presence has been considered a related but not always necessary factor in establishing higher degrees of reality judgment by users (Baños, et al., 2000). The relationship between reality and judgment could be linked through the concept of absorption. When an individual became so absorbed in a virtual environment, he/she became more present in the virtual space allowing the user to focus his/her perceptions on the simulation as if it were real. The user's focus on his/her perceptions from the simulation then led to higher degrees of reality judgment. Reality judgment was evaluated primarily through self-report items after being exposed to a stimulus (Baños, et al., 1999).

2.4.4 Immersion and Presence

When considering the concept of immersion, it was also important to consider the concept of presence. Presence and immersion have had a fairly long history of being mislabeled (Schubert, Friedmann, & Regenbrecht, 1999a). Many followed the logical distinction made by (Slater & Wilbur, 1997) where presence represented the subjective psychological feeling of "being in a space" and immersion represented the objective technology which allowed for presence to occur. Baños et al. (2004) agreed with the original statement made by Schubert, Friedman, and Regenbrecht (2001) and pointed out it would be "misleading to assume a one-to-one relationship between immersion and presence" (p. 735). As Schubert et al. (2001) further explained this idea being due to "cognitive processes leading from stimuli perception to presence" (p. 267). This idea by Schubert et al. (2001) sets up how the relationship between immersion and presence should be considered, with immersion influencing presence. To better gauge how this influence occurs, it was important to consider the theoretical links between immersion and presence.

At the theoretical level, presence and immersion were related through two different concepts: involvement and engagement. Schubert et al. (1999a) found that involvement linked to presence through attention and awareness processes. Sherman and Craig (2003) in Gorini et al. (2011) furthered the notion of the relationship "narratives are responsible for mental immersion, through which users can be deeply engaged and involved in the experience, increasing their sense of mediated presence" (p. 100). From the narrative stemmed motivation which, became the causal factor between immersion and engagement. From this perspective, the relationship between presence and immersion could be seen as a product of other mediating variables, specifically those of involvement and engagement. This study looked at the influence of immersion on presence and, explored the theoretical relationship between immersion and presence through mediating variables.

Thinking first about immersion and presence and the initial exploration, each construct was defined in terms of less abstract concepts. Immersion was defined as a dichotomy consisting of psychological and perceptual immersion (Sherman & Craig, 2003). Presence was defined as consisting of a spatial constructive and attentional allocation (Schubert, Friedmann, & Regenbrecht, 1999a). From these definitions, the distinction between the two constructs could be derived. Both perceptual and psychological immersion were each split into different dimensions: sensory dimensions and involvement, attention, and affect dimensions respectively. From this split of the two types of immersion, the use of narrative was found to increase motivation which establishes engagement. For presence, attentional allocation was found to be formed from involvement which establishes a sense of presence (Lessiter, Freeman, Keogh, & Davidoff, 2001). These two findings for each of the concepts called for a need to look at the relationship between engagement and involvement.

Wirth et al. (2007) explained involvement as being a “motivation-related meta-concept” containing numerous forms of interaction with a simulated environment. Involvement itself was considered the “active and intensive processing of the mediated world” (Wirth, et al., 2007, p. 513). The ‘intensive processing’ was what Wirth et al. (2007) used to distinguish involvement from spatial presence. Intensive processing referred to the level of information processing occurring: thinking, interpreting, elaborating, appraising and assigning relevance to content within the media (Wirth, 2006). Schubert et al. (1999a) further added to the definition of involvement by suggesting it was linked to both awareness and attention processes of users thus, adding to the idea of active information processing. Witmer, Jerome, and Singer (2005) supported this view by stating “involvement is a psychological state experience as a consequence of focusing one’s mental energy and attention on a coherent set of stimuli or meaningfully related activities or events” (p. 299). In all of the definitions, no direct relationship existed between involvement and immersion, only indirect ones. As such, to see the connection back to immersion, a similarly related concept, engagement, should be defined differently.

Dede (2009) suggested that immersion influenced engagement in virtual environments. This inferred a relationship between immersion and engagement. Sherman and Craig (2003) further noted the relationship between immersion and engagement by stating that immersion indicated a level of engagement while engagement indicated the success of communicating the virtual environment to the user (p. 383). Frequently referred to in education, "engagement predicts important outcomes (e.g. learning, development) and because it reveals underlying motivation" (Reeve, Jang, Carrell, Jeon, & Barch, 2004, p. 148). Also, having a link to motivation suggested a possible relationship between engagement and involvement. Lessiter et al. (2001) suggested engagement as a measure of both a user's interest and involvement in the virtual environment's content along with the user's general enjoyment of the experience (p. 293). This understanding of engagement inferred that involvement was necessary for engagement to occur. Further presenting this line of thinking, Reeve et al. (2004) explained "engagement refers to the behavioral intensity and emotional quality of a person's active involvement during a task" (p. 147). Considering the relationship between engagement and involvement as one leading to the other, it was possible to think of involvement being nested within engagement. As involvement was found to be nested in engagement with user interest, the link between presence and immersion was seen.

Murray, Fox, and Pettifer (2007) indicated that involvement and engagement were related through the concept of absorption. Absorption was defined as "a disposition for having episodes of 'total' attention that fully engage one's representational (i.e., perceptual, enactive, imaginative, and ideational) resources" (Tellegen & Atkinson, 1974,

p. 268). Based on this definition, absorption links involvement and engagement. Murray et al. (2007) established the indirect relationship between presence and absorption stating that involvement was coupled with absorption, forming a sense of presence. This addition of absorption to the model of involvement and engagement added to the relationship between presence and immersion; theoretically linking the two constructs together, see Fig. 5.

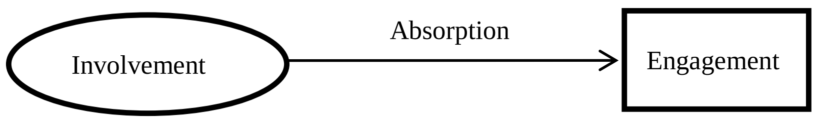

Figure 5: The relationship between involvement and engagement.

Dalgarno and Lee (2010) established that immersion (e.g. perceptual) was a product of ‘fidelity’ and ‘interactive capabilities’ and presence was a product of immersion. This particular explanation fell in line with this study, suggesting that interactivity played a partial role in linking immersion and presence together. Considering this link between immersion and interactivity, the relationship between immersion and presence can be viewed in light of contributions made by interactivity. Wirth et al. (2007) cautioned though that “spatial presence can be enriched by” but not dependent on perceptual immersion (p. 496). This again indicated that interactivity may play a role in the relationship between immersion and presence.

To start, perceptual immersion was split into different sensory dimensions (i.e. visual, auditory, olfactory, and tactile). From those dimensions, visual immersion was chosen for this study as it is a critical aspect of virtual reality systems. Specifically for this study, visual immersiveness was operationalized as stereoscopy and field of view (FOV).

2.4.5 Visual Immersiveness and Spatial Presence

Presence, specifically spatial presence, in this study was established as perceived self-location and perceived action possibilities (Wirth, et al., 2007). Perceived self-location was defined as the feeling of being located in a simulated space (Wirth, et al., 2007). This definition could pertain to not only virtual environments but, other types of media which provided descriptive information about spaces, like books. The measure of self-location was analogous to the concept of embodiment described by Biocca (1997). Embodiment occurs in virtual environments because of sensory engagement on different channels (Biocca, 1997). In the article, Biocca explained the human mind perceived different senses (i.e. vision, hearing, feeling, etc.) as channels which could be addressed by different aspects of a virtual interface. This process was speculated to be related to instantiating 'image schemata' with objectified metaphors and analogies presented by virtual environments through the senses. This presentation by virtual environments through the senses was also recognized as sensory engagement. The indicated image schemata created from the sensory information became a mental representation of one's sensory engagement with a virtual environment. Visual immersion was one dimension of perceptual immersion which, provided the visual senses with information about the virtual environment. Based on the relationship of visual immersion and self-location, coupling visual immersion with other sensory technologies like auditory immersion should provide a higher sense of self-location based on the mechanisms suggested by Biocca (1997) and Wirth et al. (2007), see Fig. 6.

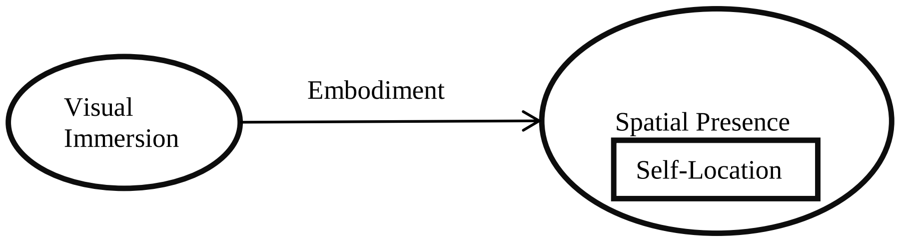

Figure 6: Mapping self-location to visual immersion.

Embodiment also plays a role in perceived possibility for actions, the other dimension of spatial presence (Wirth, et al., 2007). Glenberg (1997) began defining possible actions as "patterns of action derived from the projectable properties of the environment" (p. 4). Projectable properties related to visible properties of the virtual environment. The initial part of the definition continued stating these properties (e.g. projectable) were combined with patterns of remembered interactions with similar situations/objects. These patterns were 'embodied' as they were constricted to "how one's body can move itself and manipulate objects" (Glenberg, 1997, p. 4). Embodiment therefore related to how one restricted memories of interactions and visual information to what he/she knew they could physically/mentally do. Possible actions were established based on the definitions of these patterns (i.e. objects or situations) from a source's memory of actually enacting similar situations in the past. The idea presented in Glenberg's definition related to embodiment, but more specifically embodied cognition. Embodied cognition was defined as "the outcome of the active interpretation of a virtual environment" (Schubert, Friedmann, & Regenbrecht, 1999b, p. 270). Schubert et al.

(1999b) speculated that for possible actions to occur two actions must take place: 1) "projectable properties are actively created by the individual agent" and 2) "non-projectable properties are retrieved from memory" (p. 271). Together these two actions represented the patterns in Glenberg's definition of possible actions. Schubert et al. (1999b) rationalized that while Glenberg's definition was highly dependent on memory, that many decisions made were based on what was initially experienced, the projectable properties. This occurs in an environment because the human mind is wired to react first rather than to consider past experiences of similar situations before acting.

Schubert et al. (1999b) then related possible actions back to virtual environments stating that during the act of combining the two patterns (i.e. initial experience and memory of experiences), suppression of outside properties must occur. Suppression in this case meant to reduce the amount of influence of the immediate real world on the perceptions of the virtual space. In other words, it was important to keep an individual focused on the virtual environment so he/she did not notice what was going on in the room where the equipment was housed. This process of suppression allowed for more focused attention on the virtual stimuli in the virtual environment which, related back to the definition of presence including attention allocation. More focused attention then allowed for the "construction of meshed sets of patterns of action" to occur based only on the virtual environment (Schubert, Friedmann, & Regenbrecht, 1999b, p. 272). Different features of a virtual reality system like field of view and stereoscopy are known for helping users focus attention on the simulated environment by filtering out the immediate physical environment (Hendrix & Barfield, 1995). From the perspective of embodied cognition and its relationship with possible actions, the relationship with immersion then became less clear. Possible actions was based on the two aspects of Glenberg's definition (projectable -initial experience and non-projectable properties - memory) pertaining to movement of the body. While visual immersion aided in providing a visual representation (similar to image schemata) of the virtual objects and situations, it did not provide all information necessary to be actively participating. This followed along the earlier established rationale that interactivity plays a role in the relationship between immersion and presence. Therefore, the combination of immersiveness and interactivity, see Fig. 7 can be seen as influencing the possible actions dimension of spatial presence.

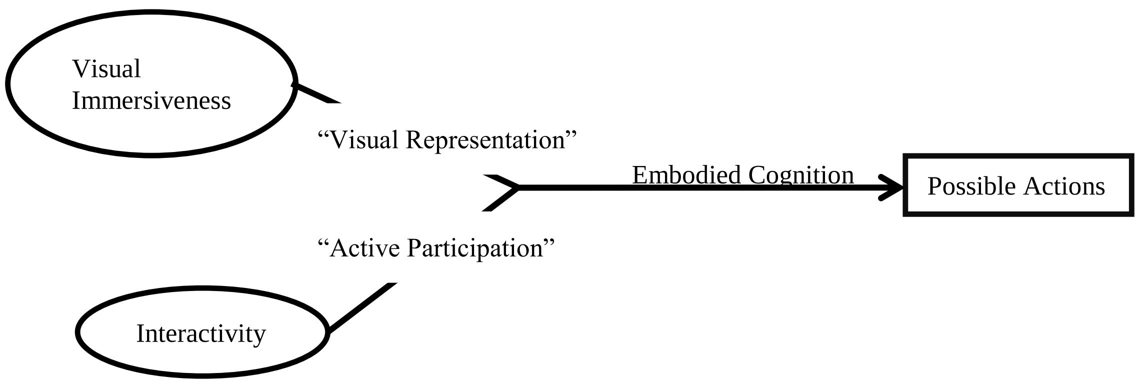

Figure 7: Visual immersiveness, interactivity and spatial presence.

Visual immersion linked to both self-location and possible actions by providing a visual representation. The visual representation provided in VR environments is based on a variety of visual information presented in the form of cues (i.e. color, depth, shape, etc.). For self-location visual immersion provides visual engagement which, helps to form image schemata. Visual cues could provide more information to develop more detailed image schemata, increasing the sense of self-location. For possible actions, visual immersion provided a mental representation or projectable objects which informed action. Combining visual immersion with interactivity could increase perceptions of possible actions as interactivity provided information on being an active participant. Looking at the two features of a virtual reality system that led to visual immersion (stereoscopy and field of view), each contributed to the spatial presence measures. IJsselsteijn et al. (2001) established the relationship between stereoscopy and field of view on factors of presence. This confirmed that some aspect of stereoscopy and field of view were related to presence. So rationally, stereoscopy and field of view should be linkable to the two factors of spatial presence.

Stereoscopy is defined as a technique which simulates the illusion of depth (Baños, et al., 2008). Stereoscopy provides depth cues to existing images which, increases the amount of visual cues (Crone, 1992). So, the relationship between stereoscopy and self-location could be seen as the improvement of image schemata through the use of visual depth cues. Similarly, stereoscopy could be related to possible actions by improving the visual representation through visual depth cues. Visual depth cues provided more information on which decisions on actions could be made. Finally, when coupled with interactivity, stereoscopy should then show increased possibility for actions, see Fig. 8.

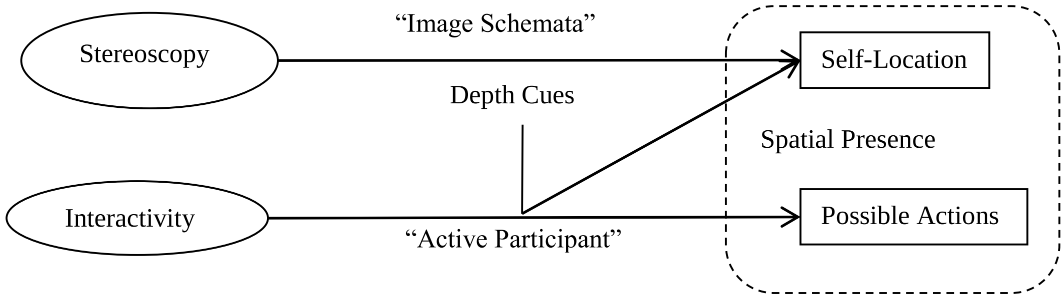

Figure 8: Stereoscopy, interactivity and spatial presence.

Field of view contributed to visual cues in two ways regardless. Wider field of view provides more visual cues by encompassing greater peripheral view in the virtual environment. Increasing peripheral views increases the amount of visual cues presented at any given time. Increasing the amount of visual cues therefore could increase the development of image schemata, increasing the sense of self-location. In addition to providing more visual cues, wide field of view also helps to better suppress the outside world. With more peripheral vision filled by a virtual environment, less of the real-world could disrupt the visual immersion experienced. Reducing the amount of disruption from the real-world could help increase embodiment within the virtual environment. Increased suppression of the real-world helps increase the focus on the virtual environment which, increases the amount of visual information processed by an individual (Wirth, et al., 2007). It can then be speculated that increased visual information provides knowledge needed to act in the virtual space thus increasing perceived possibility for action. Again, perceived possibility for actions is increased by both field of view and interactivity to as shown in Fig. 9.

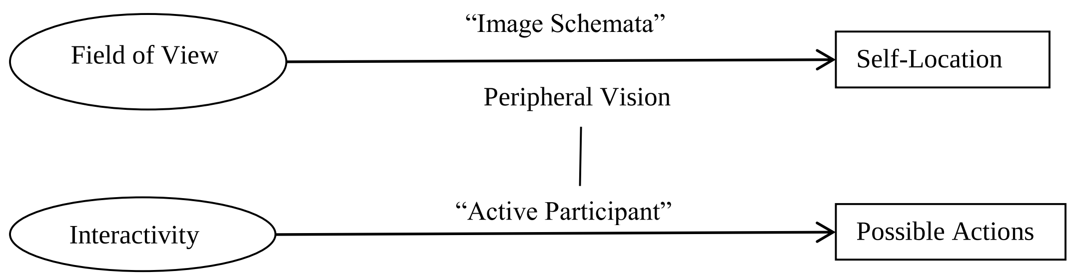

Figure 9: Field of view linked to spatial presence.

2.5 Spatial Understanding

At any given time, a person is usually aware of and learning about the surrounding space. That awareness translates into an understanding of the space through contributions of sensory information, internal cues, and context. This information is derived from experiences of moving through a space (Waller & Hodgson, 2013). The way an individual understands space pertains to the individual's cognition of the space coupled with experiencing a space. Spatial understanding refers to how one comprehends the space surrounding them. Spatial understanding comprises of two main components within the construct of spatial cognition: spatial task performance and spatial recall.

2.5.1 Spatial Task Performance

Spatial task performance can roughly be identified as one aspect of spatial cognition (Witelson & Swallow, 1988). Several definitions exist for spatial cognition in the literature, some of which focused on first breaking down the comprising terms: 'spatial' and 'cognition'. Mark (1993) explained that cognition roughly referred to mental processes including those of perception and recognition. 'Spatial' was explained as consisting of two parts, a conscious portion referred to as 'spatial' and an unconscious part related to 'storage' (Mark, 1993). Common definitions for spatial cognition tend to be broad in nature, not completely encompassing all the aspects of the two parts that comprise the construct itself. One such definition called spatial cognition "a specific type of mental processing involving objects that exist in space" (Rauscher & Zupan, 2000, p. 216). This definition was broad and did not provide a clear idea of how to derive spatial task performance from spatial cognition. Another definition which comprised of both 'spatial' and 'cognition' did provide a good abstraction of spatial cognition. "*[S]patial cognition* is the knowledge and internal or cognitive representation of the structure, entities, and relations of space; in other words, the internalized reflection and reconstruction of space in thought" (Hart & Moore, 1973, p. 248).

The mental processing, which comprises the theoretical definition of spatial cognition, has received further attention. A key issue is what is meant by processing and what actually is being processed (Witelson & Swallow, 1988). This has led to better operationalizations of spatial cognition being formed and justified. Witelson and Swallow (1988) explained that spatial cognition was formed based on its specific relationship to other concepts, specifically ones pertaining to tasks. This did not completely connect spatial cognition to spatial task performance though. Tasks in the meaning intended by Witelson and Swallow (1988) pertained specifically to spatial abilities.

Spatial cognition is said to be comprised of a conscious and a sub-conscious component (Mark, 1993). This reasoning suggests there are at least two concepts which relate to each. These concepts derive different pathways in disseminating spatial cognition to spatial task performance. The 'spatial' portion refers to tasks while, the other 'storage' refers to memory (Mark, 1993). Considering these rough groupings, the concepts could be separated allowing memory to be identified separately from tasks, see Fig. 10. For the purpose of defining spatial task performance, focusing on tasks made logical sense.

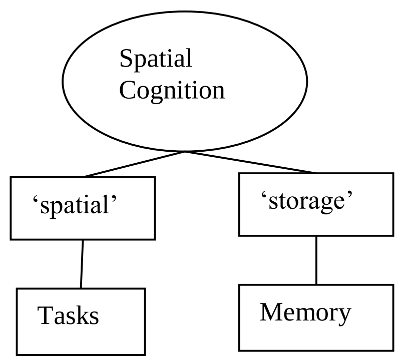

Figure 10: Conceptual break-down of spatial cognition.

Focusing specifically on the aspect of tasks should provide insight into the definition of spatial task performance. Within the literature on spatial task performance, two main concepts were found to pertain to the same idea of 'tasks' in spatial cognition: spatial abilities (Brosnan, 1998) and spatial navigation (Maguire, Burgess, & O'Keefe, 1999). To support this notion, another more specific definition of spatial cognition could be used: "the knowledge and beliefs about spatial properties of objects and events in the world as well as the way human beings deal with issues concerning relations in space, navigation and wayfinding" (Hajibabai, Delavar, Malek, & Frank, 2006, p. 2). Each of these two concepts are related yet defined differently. Aside from the similar abstraction found in spatial cognition, see Fig. 11, the two concepts are separate in terms of their definition and strategy for operationalization.

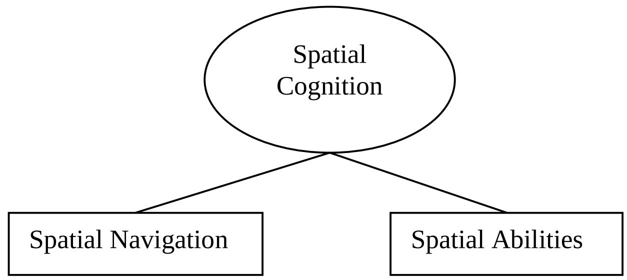

Figure 11: Conceptual break-down of spatial cognition.

Studies on spatial abilities contributed significantly to the literature on spatial task performance, particularly ones related to gender differences (Astur, Ortiz, & Sutherland, 1998). Witelson and Swallow (1988) explained the connection between spatial cognition and spatial abilities was based on the mental processes of perception and recognition. Spatial abilities have been identified as containing three different components: spatial perception, spatial visualization, and mental rotation (Brosnan, 1998), see Fig. 12. Each of the identified dimensions was found to be operationalized as spatial tasks focused on individual differences (Kyllonen, Lohman, & Snow, 1984). As this study is concerned with the impact of navigability through a virtual space, orientation and locomotion are more meaningful than abstract spatial abilities in spatial tasks, it was necessary to investigate spatial navigation more.

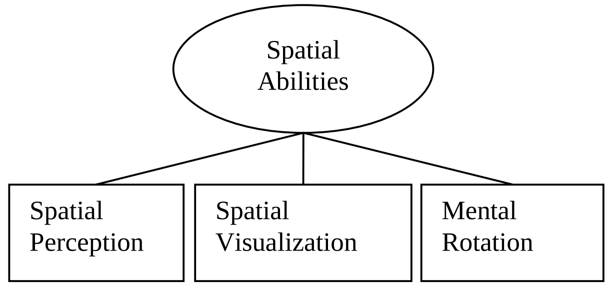

Figure 12: Conceptual break-down of spatial abilities.

Spatial navigation is the other component of spatial cognition and is based on the processing of three types of knowledge: survey, route, and landmark while moving through an environment (Werner, Krieg-Brückner, Mallot, Schweizer, & Freksa, 1997), see Fig. 13. Each of the knowledge types are based on how navigation occurs in terms of orientation and locomotion (Burigat & Chittaro, 2007). While spatial orientation and locomotion are sub-concepts of spatial navigation, they relate more as being types of spatial tasks related to wayfinding (Darken, Allard, & Achille, 1998). Landmark knowledge is the most basic and develops from the placement of prominent and distinctive features in an environment (Werner, et al., 1997). Route knowledge is specifically focused on processing information gathered while in motion within a space, forming paths by linking landmarks (Werner, et al., 1997). Survey knowledge is the most complex and consists of an understanding of the configuration of a space, usually presented in topographical form with proportionate measures and accurate layout (Labate, Pazzaglia, & Hegarty, 2014).

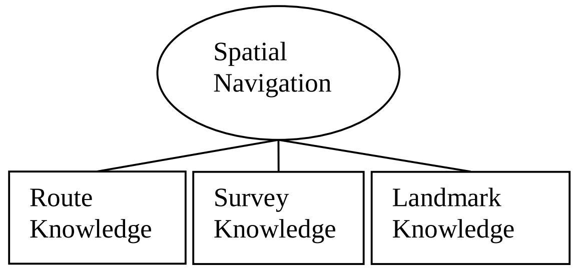

Figure 13: Conceptual break-down of spatial navigation.

Spatial navigation in the real world is based off spatial learning which moves from landmark to route and finally to the development of survey knowledge in what is called the Landmark-Route-Survey (LRS) model (Colle & Reid, 1998). In Colle and Reid (1998)'s study, the LRS model was applied to a virtual space with emphasis placed on the rapid development of survey knowledge. The study found that while important, landmark knowledge and route knowledge could be obtained and translated into basic survey knowledge when the right contextual clues were present. Labate et al. (2014) also noted that survey knowledge could be acquired through navigation. Spatial tasks could be assigned to operationalize each of the three types of knowledge. Spatial tasks allow for the measurement of each type of knowledge an individual may have used when processing information to navigate in an environment (Burigat & Chittaro, 2007). Spatial knowledge tasks occur either during navigation through an environment as in pointing tasks or after exposure to an environment as in sketch maps (Labate, et al., 2014).

This suggests that 'spatial tasks' are dependent on the context and focus of the concepts operationalizing it. To briefly note, spatial tasks are not to be confused with spatial skills. Spatial skills refer more to an individual's ability to perform spatial tasks (Dabbs Jr., Chang, Strong, & Milun, 1998) and therefore not the operationalizations of either spatial abilities or spatial navigation. To support this notion, Astur et al. (1998)

identified several tests of abilities (perceiving spatial illusions, map learning, route learning, pointing to places and judging water levels) which they indicated were often "clumped together" as spatial tasks (p. 185). The phrase 'spatial tasks' alludes more to what the definition of spatial task performance would encompass.

Looking closely at what was meant by 'tasks', the definition of spatial task performance becomes even clearer. Wood (1986) developed a theoretical model of tasks in terms of three main components which comprised all tasks: products, acts, and information cues. From these components, tasks could be formed. Products are what the tasks were set to produce whereas acts are the guidelines to create the products and information cues represent the auxiliary information necessary to complete the guidelines specified. The term 'spatial' relates back to the idea derived from spatial cognition and its subsequent conceptual dimensions of spatial abilities and spatial navigation. Therefore, the definition of spatial tasks became actions for goals based on specific mental processing of information cues. This basic working definition did not identify whether spatial abilities or spatial navigation was the main focus. Since the focus of this study is on spatial navigation, it was logical to rework the theoretical definition to focus on spatial navigation. Thus, the theoretical definition for spatial tasks became actions for locomotion-focused goals based on specific mental processing of information cues.

From this stand point, spatial task performance could then be defined. Performance is generally understood as an achievement or execution of an act. Based on this addition, the theoretical definition of spatial task performance could now be given. Spatial task performance is the achievement or execution of actions for locomotion-focused tasks based on specific mental processing of information cues.

From this theoretical definition, an operational definition can be developed. The theoretical definition of spatial task performance provides insight into how the concept could be operationalized. The 'achievement or execution of actions' indicated a need to measure completion whereas 'specific mental processing of information cues' indicated a need to measure the use of information cues. Based on these two understandings, spatial task performance comprised of two operationalizations: speed and accuracy. In addition to being measurable dimensions of spatial task performance, the use of both speed and accuracy were highly supported in the literature on spatial task performance (Henry & Polys, 2010). One last set of dimensions to establish was how speed and accuracy are operationalized. In many cases speed was straight forward, time to completion of a task. Accuracy was less straight forward. Accuracy could mean one of two things, number of correct steps taken to complete a task or the number of errors to complete a task. Commonly, the number of errors made is used as the metric for accuracy (Ragan, et al., 2010). Last, the entire explication of spatial task performance can illustrated graphically as shown in Fig. 14.

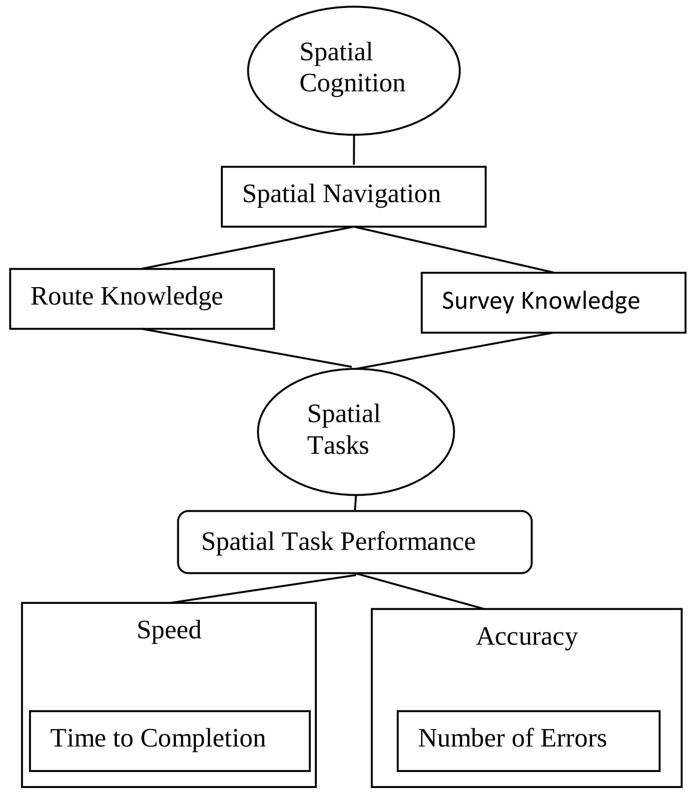

Figure 14: Explication of spatial task performance.

2.5.2 Spatial Recall

Spatial memory deals with the 'storage' portion of spatial cognition and pertains to information remembered from an experience (Mark, 1993). Recalling spatial information is important for individual processing of a space to occur (Riecke & von der Heyde, 2002). The way information is recalled is based on an individual's ability to process spatial experiences. There is also a need to decipher spatial information from other activities that may have occurred when experiencing the space (Wen, Ishikawa, & Sato, 2013). Spatial recall had been studied from two perspectives: an object focused and a spatially focused. Object focused spatial recall deals with objects in a space or memory of prominent landmarks (Bennett, Coxon, & Mania, 2010; Coxon & Mania, 2014) . Spatial recall pertains more to orientation and route memory (Stülpnagel & Steffens, 2013). Spatial recall was typically measured directly after an individual experiences an environment regardless if the perspective was object or spatially focused. Recall was commonly measured as accuracy and at times speed (Ragan, et al., 2010).

2.6 Hypotheses

Four main variables were proposed for this study: two independent variables, immersion and interactivity, along with two dependent variables, spatial experience and spatial understanding. To connect the proposed independent variables to the dependent variables at the theoretical level, it was important to consider the potential causal relationships between the independent variables and dependent variables. Several connections existed between immersion and interactivity with the dependent variables (e.g. spatial experience and spatial understanding). These connections were due to various mediating variables identified in previous research.

To better understand the overall model and the relationships of the independent variables on the dependent variables, it was necessary to examine each of the technology manipulations directly with the dependent variable dimensions. Immersion was explicated as visual immersiveness which consisted of two technology manipulations, stereoscopy and field of view. Interactivity was explicated as the technology affordance of navigability, degrees of freedom. This sets up the model to have three independent variables, see Fig. 15.

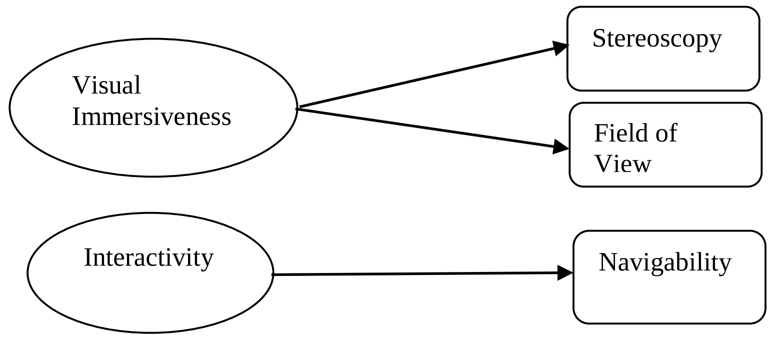

Figure 15: Explication of main independent variable concepts.

With the three independent variables established the relative connections to dependent variable dimensions could be made. Spatial experience comprised primarily of spatial presence, vection, and reality judgment. Spatial understanding consisted of two dimensions: spatial task performance and spatial recall.

Immersion as a construct can be considered related to spatial presence through attention. The concept of attention or as Wirth et al. (2007) explained, attention allocation, was a known cause for spatial presence. This in one sense left immersion out but, further decoding of how attention caused spatial presence allowed for immersion to assume an influencing role on attention. Considering Slater (1999)'s definition of immersion being technology-based leading to presence, technology induced immersion causes presence to increase by capturing a user's attention. Wirth et al. (2007) explained this connection of attention to be a concern of media factors encompassing a user's perceptual range through sensory modalities which, increases ones short-term orienting response. It was from the increase in short-term orienting responses that a user involuntarily focused his/her attention on the presented information. In this sense, the specific technology generating sensory immersion could increase a user's involuntary attention which therefore increased the sense of being in a space or spatial presence.

Considering attention as a main condition for immersion to influence spatial presence, it was necessary to look at the specific role of visual immersiveness. Under Biocca and Delaney (1995)'s definition of perceptual immersion in Rey, Alcañiz, Tembl, and Parkhutik (2008) "the degree to which a virtual environment submerges the perceptual system of the user" suggested the relationship between visual immersiveness and spatial presence could be a positive one (p. 210). Adapting Wirth et al. (2007)'s explanation, by submerging a user's visual system, a user's involuntary attention levels should increase, inducing a greater focus on the virtual environment as opposed to the real world. This helped force the user to attend to the content of the virtual environment by shutting out the information received from the real world. This process could eventually lead to an increased sense of spatial presence. Based on this basic process, Wirth et al. (2007) also suggested that highly immersive technologies may cause human users to "respond with feelings of spatial presence" (p. 496). Based on this understanding of visual immersiveness inducing greater attention towards the virtual environment causing a greater sense of spatial presence, it was predicted that:

H1: Greater levels of visual immersiveness will increase spatial presence.

Since visual immersiveness consisted of two technology manipulations, it was necessary to look at individual contributions of stereoscopy to spatial presence to explore H1. IJsselsteijn et al. (2001) conducted a study examining the effects of stereoscopy on various dimensions of presence including both subjective and a more objective approaches. Stereoscopy was found to have a significant positive effect on presence; especially when the displayed information was in motion when compared to a monoscopic (non-stereoscopic) condition. Similarly, Hendrix and Barfield (1995) conducted a study and found stereoscopy to influence presence when compared to monoscopic displays. In their study from 1995, Hendrix and Barfield established a relationship between stereoscopy and presence, determining the added illusion of depth increases participants sense of presence though not necessarily their sense of realism. From the notion that motion and depth cues can both help explain why sterescopy may relate to spatial presence, it was predicted that:

H1.A: Stereoscopic virtual environment will result in greater spatial presence than non-stereoscopic virtual environment.

Again visual immersiveness consisted of two technology manipulations, so it was necessary to also look at the individual contributions of field of view on spatial presence to support H1. The Hendrix and Barfield (1995) study also looked at the influence of geometric field of view (10°, 50°, and 90° specifically) on presence. Geometric field of view is the view from the virtual camera. The study found that geometric field of view did increase the sense of presence as the field of view increased. So the narrowest level of field of view, 10°, showed the least increase in participant's subjective presence ratings than the widest level of field of view, 90°. It was interesting the authors mentioned both the 50° and 90° manipulation together in comparison with the 10° manipulation. This could have been due to the small variation in findings between the 50° and 90° results. This provided some insight into using only a wide-narrow manipulation of field of view as opposed to a series of varying manipulations. As the previous studies indicated a wider field of view was able to capture user's attention more increasing the sense of presence, it was predicted that:

H1.B: Wider field of view will result in greater spatial presence than narrow field of view.

Immersion was also linked with spatial task performance through attention. Agarwal and Karahanna (2000) explained "focused immersion suggests that all of the attentional resources of an individual are focused on the particular task, thereby reducing the level of cognitive burden associated with task performance" (p. 675). The specific connection though lies in how immersion captures a user's attention. Through the display technology itself, a user's attention could be drawn to a virtual environment and subsequently the task (Wirth, et al., 2007). Attention alone does not completely explain the link between immersion and spatial task performance. In some cases, immersion was found to be completely unrelated to task performance (McMahan, et al., 2006). One possible explanation could be dependent on the type and complexity of the task (Raja, Bowman, Lucas, & North, 2004). Raja et al. (2004) also suggested that immersion was "shown to be beneficial to applications where spatial knowledge of an environment is useful" (p. 1). Therefore, the task itself played a role in linking immersion to spatial task performance.

The goal of visual immersiveness in the context of virtual environments is to engulf a user's visual system in order to block out the real world. This leads to a greater influence in attention and focus on the content of the virtual environment. With an increased focus on the content, a user is more likely to perform better at spatial tasks as the perception of the virtual environment temporarily replaces that of the real world reducing the cognitive burden of identifying two different environments at one time (Agarwal & Karahanna, 2000). Considering both attention and task type and complexity as factors for how visual immersiveness links to spatial task performance, this study predicted that:

H2: Greater levels of visual immersiveness will improve spatial task performance.

To better address H2, the individual technology manipulation of stereoscopy was examined for contributions to spatial task performance. Stereoscopy was also found to improve task performance measures but, only when grouped with other technology components. Schuchardt and Bowman (2007) found in their study that stereoscopy as a part of a grouped 'high level' immersion condition helped increase user accuracy and speed in navigation tasks. In their study, the 'high' level combined several components (stereoscopy (on), head-based rendering (on), and field of regard (270° horizontal)). For the other condition, the 'low' level of immersion utilized the components in an opposite manner (stereoscopy (off), head-based rendering (off), and field of regard (90° horizontal)). This suggests that stereoscopy's influence on spatial task performance may be split with other technology components but, still could play a role. Based on the above finding, this study predicted that:

H2.A: Stereoscopic virtual environment will result in improved spatial task performance than non-stereoscopic virtual environment.

Again, to better address H2, the other technology manipulation of visual immersiveness, field of view, was examined for influences on spatial task performance. Wider field of view had been found to increase spatial task performance. Tan, Czerwinski and Robertson (2006) investigated the use of field of view on spatial abilities and navigation through navigation tasks with a focus on gender performance. The manipulations of field of view were based on varying degrees of both display field of view and geometric field of view. The performance of both male and female participants was found to increase when display field of view increased, with a notably larger increase in female performance for larger display field of view manipulations. Similarly, Ni, Bowman and Chen (2006) conducted their study on navigation in a 3D space using wayfinding tasks under different manipulations of display size (e.g. FOV) with resolution. The study found that display size, specifically the large display improved task performance in all manipulations, including those where resolution was low, when compared to the small display. These findings suggest that gender and task type can explain the link between field of view and spatial task performance. With this understanding it was predicted that:

H2.B: Wider field of view will result in improved spatial task performance than narrow field of view.

Immersive experiences provide necessary spatial cues and a high level of engagement which increase the potential for users to recall material presented (Winn, Windschitl, Fruland, & Lee, 2002; Ragan, et al., 2010). Spatial recall could be considered dependent on a user's ability to focus and associate information with spatial locations

(Ragan, et al., 2010). This focus comes from spatial cues which have often been associated with immersion (Sowndararajan, Wang, & Bowman, 2008). Immersion in this sense refers to the display characteristics of the system (i.e. stereoscopy, field of view, etc.). The rationale behind spatial cues aiding memory is not a new idea (Yates, 1966; Hess, Detweiler, & Ellis, 1999). In particular, the loci method, a known mnemonic, has been cited for its link to the use of memorized locations in the memorization of new ordered information (i.e. speeches, lists, etc.) (Yates, 1966; Hess, et al., 1999; Sowndararajan, et al., 2008). Spatial cues link to memory as aids for generating mental maps or representations of spaces (Sowndararajan, et al., 2008). The logic is the more complete or accurate one's mental map became the more likely the recall of that representation would be accurate. So, when spatial cues were enhanced as in highly immersive virtual environments, the likelihood of accurate spatial recall should be higher.

Spatial cues were not the only connection between immersion and spatial recall. Highly immersive experiences allow for greater levels of engagement (Winn, et al., 2002). Perceptual immersion in particular engages the senses of the user. This could increase both attention and intrinsic motivation to perform in the virtual environment. Learning is highly connected to performance but, for virtual environments, without the incentive to participate, learning is less likely to be successful (Roussou, 2004). Therefore, higher levels of engagement of the senses as found in highly immersive systems should induce an incentive to perform in the virtual space which, presented a greater ability to learn and thus recall information learned.

Considering immersion in terms of visual immersiveness, spatial cues become more prominent to a user's visual attention. This could allow for the user to better establish a mental representation of the virtual environment. The stronger the mental representation of the space, the more likely the user would be able to recall information about the space, thus increasing spatial recall. This rationale of spatial cues and motivation and attention supports the idea that a positive relationship exists between visual immersiveness and spatial recall. Therefore, this study predicted that:

H3: Greater levels of visual immersiveness will improve spatial recall.

Stereoscopy was found to increase accuracy of memory. Bennett et al. (2010) in their study aimed to see if stereoscopy had an impact on memory of objects in a space when objects were displayed with contextual consistency or as primative shapes. Their study did find a positive influence of stereoscopy on memory of objects in a space, but they cautioned it was only when the objects were contextually consistent with the space. The other findings of influences of stereoscopy in the study were found to be insignificant. This finding suggests that again, stereoscopy is able to influence the dependent variables significantly when grouped with other components. But the finding should also take into consideration that few studies have actually investigated the influence of stereoscopy on spatial memory but, failed to detect any significant influence. Study by Baştanlar, Cantürk, & Karacan (2007) failed to detect any significant influence of stereoscopy on memory. The findings of this study though should take into considertation the size of the small sample size and form of analysis. Another study that looked at stereoscopy when combined with head-tracking on object recall found the condition with stereoscopy was not significant (Mania, Troscianko, Hawkes, & Chalmers, 2003). Instead, studies on the influences of virtual reality technology on memory have stated that stereoscopy would improve the results of memory due to the enhanced spatial cues (Sowndararajan, et al., 2008). As stereoscopy was found to positively influence the memory of objects in space when contextually consistent, it was predicted that:

H3.A: Stereoscopic virtual environment will result in improved spatial recall than non-stereoscopic virtual environment.

Field of view (FOV) was found to increase accuracy of memory. Ragan et al. (2010) found that their operationalization of wide FOV did significantly improve recall accuracy when dealing with procedural memorization. Procedural memorization pertains to the memory of steps in a procedure. The rationale of the study dealt with mapping the memorization of a multi-step procedure to spatial cues, suggesting that through spatial memory, non-spatial memory tasks could be more easily remembered. The manipulation of FOV was 60° for narrow and 180° for wide. In addition to the FOV, the study also included software field of view (another aspect of FOV) in two manipulations, matched (to the wide and narrow FOV) and unmatched. To clarify their definition of FOV, Ragan et al. (2010) explained that a wider FOV allowed a "user to see more of the environment at one time" (p. 530). All three components tested were found to have significant influences on the accuracy of procedural memorization. The authors did note they were surprised to find their hypothesis about wide FOV reducing recall time not being significant. This finding suggests that wide FOV can increase accuracy but possibly not speed of memory recall. As the manipulation of FOV was found to be significant for procedural memorization it was predicted that:

H3.B: Wider of field of view will result in improved spatial recall than narrower field of view.

Interactivity and navigability determines a user's ability to participate in a virtual space. Specifically, interactivity provides a user with a certain amount of control over actions taken to participate. This activity involves users in the virtual space and its plotline which, has been shown to increase a sense of spatial presence (Gorini, et al., 2011). By exercising control over decisions and locomotion, a user should feel more present in the virtual space. Thus, increasing the amount of control in the virtual space could potentially increase spatial presence. Likewise, if a user is not skilled in how to participate in the scene the lack of skill could interfere with feeling in the space. Poor skill level combined with a high level of challenge presented by the activities of a virtual environment could lead to lower levels of involvement which, is known to decrease the sense of spatial presence (Sherman & Craig, 2003).

Sheridan (1992) indicated the relationship between navigability and presence is based on the ability to manipulate viewpoints. Following Balakrishnan and Sundar (2011), navigability was operationalized in this study earlier as comprising of travel or locomotion and wayfinding. Travel in a virtual environment is defined by Bowman, Koller, and Hodges (1997) as the "control of user viewpoint motion through a VE" (p. 45). Based on that description, one could look further to the relationship as Witmer and Singer (1998) made the association that increasing one's ability to manipulate a viewpoint would positively influence the sense of spatial presence. By allowing for increased control over viewport motion, users become more active participants in the virtual environment. Increased participation could lead to greater involvement which, could potentially lead to increased spatial presence. With this understanding, this study predicted that:

H4: Greater navigability will increase spatial presence.

Similar to the relationship between navigability and spatial presence, spatial task performance was also derives from a measure of control and skill level (Mestre & Fuchs, 2006; Sayers, 2004). If a user is adequately skilled and given enough control over their participation, spatial task performance should increase as the user became more involved in the task. The relationship between interactivity and task performance could be understood to be based on a balance of amount of control and user skill level. With this understanding that skill level and amount of control connect to spatial task performance and navigability, it was predicted that:

H5: Greater navigability will improve spatial task performance.

The relationship between interactivity and spatial recall is not a clear one. Shelton and McNamara (1997) pointed out that spatial memory was either view-dependent or view-independent. As interactivity deals with the manipulation of viewpoints (Sheridan, 1992), the link between interactivity and spatial memory could be understood more clearly. A system must interpret a user's behavior in the 3D space and provide timely feedback of actions, particularly viewpoint manipulations. The key causal relationship between interactivity and spatial recall is dependent on feedback of user actions. Based on feedback, users are able to decide the next move and have more information to build mental maps of the space. In addition, feedback is necessary for both spatial presence and spatial recall (Moreno & Mayer, 2002). Interactivity leads to greater feedback in the form of increased spatial cues which, can improve spatial recall (Beall & Loomis, 1996). Spatial cues could be related to the two types of information stored from visual image maps: feature and structural (Kulhavy & Stock, 1996). Spatial memory from cognitive maps is based on visual stimuli was dependent on both types of information (Kulhavy & Stock, 1996) which, could be obtained through spatial cues in a virtual environment. Therefore, better feedback of spatial cues based on user actions would influence the building and rebuilding of a user's mental map which, could potentially increase a user's recall of the space.

Allowing a user to have more control over steering (i.e. the added functions for locomotion in an input device) would enable the user to obtain more feedback on spatial cues in the space. Based on the notion that mental maps are linked to spatial memory (Kulhavy & Stock, 1996), this newer information would be added into the user's mental representation which, could potentially increase the user's recall of the space. Also, the added control over steering would increase the amount of viewpoint perspectives a user gains of that space. This followed along the logic that, "large (i.e. navigable) spaces… are generally learned by exploration and from many different perspectives" (Shelton & McNamara, 1997, p. 103). From this explanation, this study predicted that:

H6: Greater navigability will improve spatial recall.

In addition to the above hypotheses, this study also posed following research question and sub-questions.

2.6.1 Research Question: What is the influence of the immersive experience on spatial experience and understanding in a virtual environment?

2.6.2 Sub-Questions:

- What is the influence of interactivity on spatial experience measures?
- What is the influence of visual immersiveness on spatial experience measures?
- What is the influence of interactivity on spatial performance measures?
- What is the influence of visual immersiveness on spatial performance measures?

Fig. 16 and Fig. 17 provide an overview of the hypotheses mapping indicating the relationship between the independent and dependent variables.

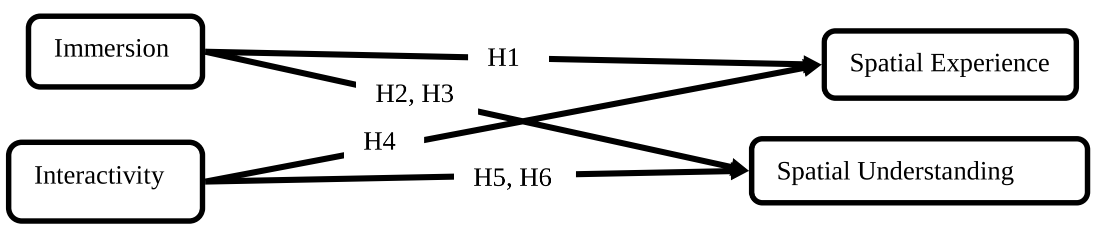

Figure 16: Main hypotheses.

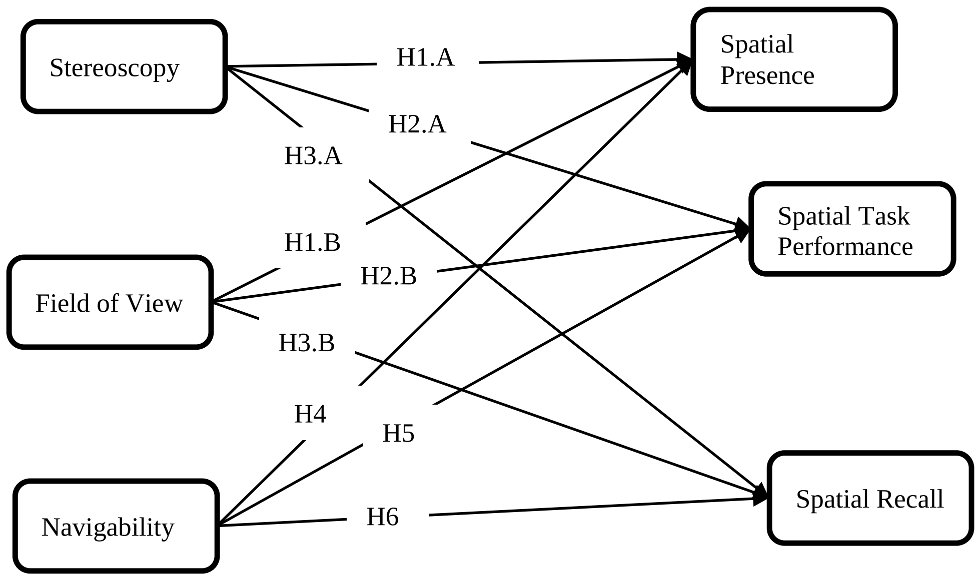

Figure 17: Mapped secondary hypotheses.

CHAPTER 3: METHODS

This chapter discusses the design of the controlled experiment to address the overall research question. First, the design of the experiment, experimental setup and stimulus details are discussed. The manipulations of visual immersiveness and navigability are then discussed followed by a description of the variables for spatial experience and understanding and their measures. Details of research participants and the procedure used in the experiment are described next. Lastly, the plan for analyzing the data is summarized.

In order to address the main research question and hypotheses, it was important to consider the factors involved in the immersive experience first and, then those in spatial experience and understanding. Previous research conducted on virtual reality system technology has typically used experimental design in order to systematically look at different technological contributions on a dependent variable (Bowman, Koller, & Hodges, 1997). This study utilized a controlled experiment in order to capture the relative contributions of visual immersiveness and navigability affordances on spatial experience and understanding. Using a combination of the variable-centered approach (Nass & Mason, 1990) with the mixed reality simulation approach (Laha, et al., 2013); visual immersiveness and navigability were broken down into affordances of specific technology. The independent variables here were treated as specific affordances of virtual reality technology that could be systematically manipulated. These affordance manipulations produce distinguishable, but often small effect sizes in terms of their impact on user perceptions. A controlled experiment offers more precision than other research designs to help identify contributions of technology attributes on user perceptions.

3.1 Design of Experiment

A controlled experiment using a 2 (stereo vs. non-stereo) x 2 (wide vs. narrow field of view) x 2 (high vs. low navigability) between-subjects design was used in this study. This design randomly assigned participants into different conditions for the three independent variables (IVs) on the six dependent variables (DVs), see Table 1.

Table 1: Variables of study.

Independent Variables	Dependent Variables
• Stereoscopy • Field of View • Navigability	• Spatial Presence • Vection (Self-Motion) • Reality Judgment • Spatial Task Performance • Spatial Recall

Each independent variable was implemented at two categorical levels. The resulting design incorporated eight different conditions combining the categorical levels of the three independent variables, see Table 2.

Table 2: 8 Experimental conditions.

		Navigability			
		Low Navigability		High Navigability	
		Stereoscopy	No Stereoscopy	Stereoscopy	No Stereoscopy
Field of View (FOV)	Large FOV	1	2	3	4
	Small FOV	5	6	7	8

3.1.1 Experimental Setting

The study was conducted in the Immersive Visualization Lab (iLab) in the department of Architectural Studies at the University of Missouri. The iLab display consists of a large, three-panel screen display (18'x6') and uses a single Dell Precision T7500 graphics workstation with dual NVIDIA Quadro FX5800 graphics cards to power the three active-stereo DepthQ 3D projectors. The projectors are synchronized with active shutter glasses using an infrared emitter to give the user a 3D viewing experience.

3.1.2 Stimulus Details

A 3D model of an office suite, as shown in Fig. 18, was developed using 3D Studio Max, based on an existing office environment unfamiliar to participants. The office space was built to contain seven distinct spaces in which participants could move freely, as shown in Fig. 19. The model was pre-tested for complexity and feasibility to engage the participant in a navigational task. The 3D model represented a single office suite acting as part of a multi-story building. The building model was unfamiliar to the participants as this helped to assess the task on spatial recall better since all participants had the same amount of knowledge about the building at the start of the study. The virtual environment incorporated constraints normally found in real life such as gravity, and barriers like walls and closed and locked doors. These constraints and navigability manipulations were implemented using EON Studio, an advanced virtual reality content authoring software.

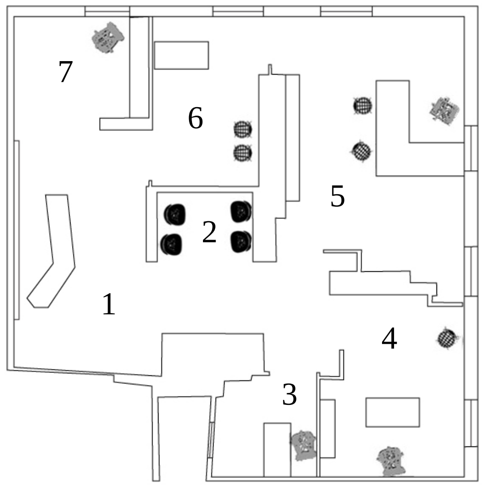

Figure 18: Plan of the office environment.

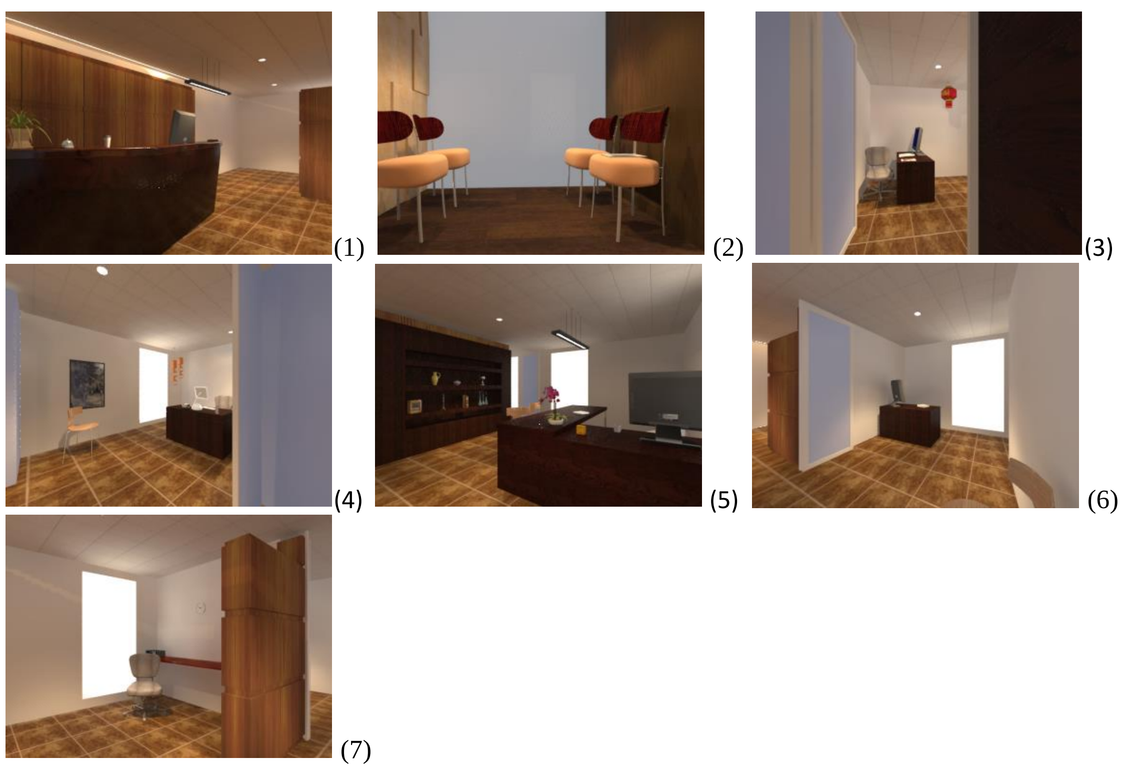

Figure 19: Perspectives of 7 office rooms.

3.2 Independent Variable Operationalizations and Implementation

The use of the variable-centered approach with the mixed reality simulation approach allowed for visual immersiveness to be examined from two technology components derived from Bowman and McMahan (2007)'s taxonomy: stereoscopy and field of view. The affordances of these operationalizations of visual immersiveness were then manipulated and grouped into 'levels' of high-low conditions allowing for the relative impacts of each to be measured (Ragan, et al., 2010).

3.2.1 Field of View

Field of view, from a virtual reality/computer-graphics perspective, generally refers to the physical field in which a user can see a simulated space. In other words, the screen or monitor and how much of a user's direct and peripheral vision is filled. In other words, humans generally have a specified field of view of 200 degrees horizontally and 135 degrees vertically (Arthur, 2000), see Fig. 20.

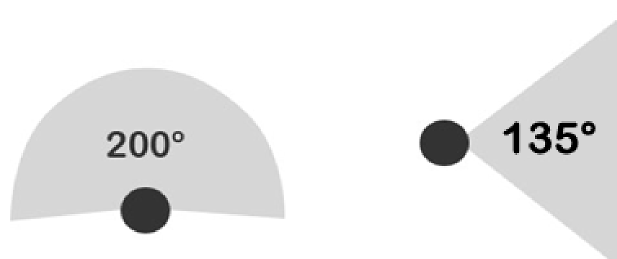

Figure 20: Horizontal FOV 200°, vertical FOV 135°.

Based on the normal field of view for an average human, a virtual reality system should try to match those values using technology. There are two challenges for simulating a virtual environment from a normal field of view. First, the technology itself must lend itself to filling as much of the normal human field of view as possible. Second, generally virtual environments are seen through the lens of viewpoints which, are based on camera angles. Because of this, field of view becomes slightly harder to realistically simulate. To successfully simulate field of view in a virtual environment, two complimentary aspects of field of view must be considered: display (DFOV) and geometric (GFOV) (Banton, Thompson, & Quinlan, 2001). The differences in the two aspects depend on what the focus was on. For DFOV, the focus was on the hardware (i.e. the display screen) enabling a virtual environment to encompass a certain portion of a user's field of vision whereas, a GFOV represented the software aspect (i.e. the camera view) which allowed the user to see inside the virtual environment. Both aspects of field of view are important to maintain a viewpoint that encompasses as much of a user's field of vision without any distortion. Generally, DFOV and GFOV should be equal to generate the least amount of distortion forming what was known as the DFOV/GFOV ratio or 'image scale' (Draper, Viirre, Furness, & Gawron, 2001). Both types of field of view could be increased both vertically and horizontally to accommodate specific needs. Increasing field of view, either DFOV or GFOV, would also require more display space, horizontally and vertically.

For this study, the DFOV was considered as the percentage showing across the number of screens. This consideration follows the manipulations of Zikic (2007)'s study that utilized the number of screens as DFOV in order to increase the field of view. The display in Zikic (2007) consisted of three 6'x8' Stewart Film Screen projector screens side-by-side. For this study, a larger DFOV was based on three screens showing 100% for the wide setting and a reduced projection of 25% decrease on all sides across the same three screens for the narrow setting.

To do this, a software manipulation within EON Studio allowed for direct manipulation of what the projectors showed. The wide field of view utilized the full screen setting capabilities of the projectors. The narrow field of view setting shrank the projected image by 25% on each side and centered it between the three projection screens. These two settings became the operationalization of wide and narrow field of view. The operationalization into these two specific size differences on the same three screens was previously tested and found to be viable for testing field of view (Balakrishnan, Oprean, Martin, & Smith, 2012). In addition to the DFOV, the GFOV remained consistent with the size of the projection in order to reduce the distortion effect. In other words, the camera field of view was set with a wide screen setting to accommodate the size DFOV being used (i.e. either wide or narrow). The specific setting for the camera field of view was determined through pre-testing of comfort level of users for the distortion effect and to better maintain the image scale. The rationale behind manipulating only DFOV was to help determine the influence of display technology size, whether it is through a large display screen or a monitor.

3.2.2 Stereoscopy

Much of the newer 3D technology appearing in today's market incorporate stereoscopy. This was one reason to include stereoscopy as a variable. Stereoscopy is defined as "a technique for creating the illusion of depth and 3D imaging while presenting a different image to each eye" (Baños, et al., 2008). Stereoscopy is a binary variable that is either on or off (Schuchardt & Bowman, 2007). This study also treats stereoscopy as either on (or enabled) or off (or disabled). Stereoscopy is commonly presented in two forms, active or passive. For this study, active stereoscopy was used by combining three 3D DepthQ projectors with the active shutter glasses worn by the subject. The projector images and the active shutter glasses were synchronized by an infrared emitter.

3.2.3 Navigability

In this study, navigability was the key interactive affordance under consideration. Navigability was operationalized in terms of degrees of freedom for steering control similar to Balakrishnan & Sundar (2011)'s study. Degrees of freedom were implemented by a manipulation of joystick functionality. Using a joystick, two different manipulations of degrees of freedom were implemented while, keeping the input device the same. This helped to control other confounding variables that might arise from using two different input devices with different degrees of freedom. The low navigability condition was implemented using just two degrees of freedom. The manipulation consisted of only basic movements (forward/backward movement and rotation left/right around the z-axis). The high navigability manipulation added one more degree of freedom. High navigability used the same capabilities as the low navigability condition plus the added capability for tilting the view point up and down, see Fig. 21.

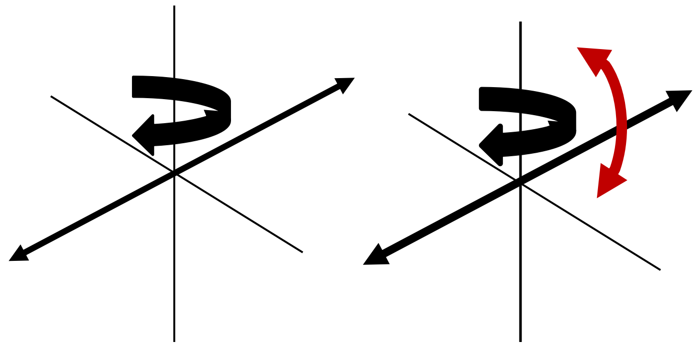

Figure 21: Joystick motion (low navigability on left) with added manipulation (high navigability on right).

3.3 Dependent Variables and Control Measures

In addition to the dependent variables of spatial experience and understanding, several demographic variables were gathered through self-report methods as potential control and confounding variables. All scaled measures were in a 1-9 Likert-type format with strongly agree or strongly disagree or similar adjectives as polar opposite ends.

3.3.1 Dependent Variables

Data for the dependent variables was collected through self-report and post-test performance measures. These correspond with the six intended dependent variables: spatial presence, vection, reality judgment, spatial task performance, and spatial recall. With virtual reality research, self-report has been a common method for collecting data about user experiences. Several well-established instruments were adapted for each variable as described below.

3.3.1.1 Spatial Experience

Spatial presence was measured by adopting items from the Spatial Presence Questionnaire developed by Vorderer et al. (2004) called the Measurement, Effects, Conditions – Spatial Presence Questionnaire (MEC-SPQ) for the sections of attention, self-location and possibilities for action. For *attention* measures, four items on a 9-point Likert-type scale were adapted which captured perceived attentional allocation in relation to spatial presence (e.g. I concentrated on the office suite I just viewed). Four items on a 9-point Likert-type scale were adapted from the MEC-SPQ for *spatial self-location* (e.g. It was though my true location had shifted into the environment in the office suite I just viewed). Lastly, *possibilities for action* used seven items adopted from the MEC-SPQ on a 9-point Likert-type scale (e.g. I felt I could have some influence on the environment of the office suite).

In addition to the spatial presence measures, vection and reality judgment were used and indirect measures for sense of presence. *Vection*, the illusion of self-motion, used four items on a 9-point Likert-type scale adopted from Riecke and Schulte-Pelkum (2006) (e.g. My sense of movement inside the office environment was very compelling). For the last measures, *reality judgment*, eight items on a 9-point Likert-type scale were adopted from Baños et al. (2000) (e.g. To what extent did you feel you "were" physically in the virtual world?).

3.3.1.2 Spatial Understanding

In addition to the self-report questionnaires, there were two post-test tasks. The first was for spatial task performance and the other for spatial recall. Spatial task performance consisted of measures of accuracy on placement of objects with specific spaces as well as knowledge of the office space's configuration. Placement of the objects consisted of matching the objects correctly to screenshots of each of the spaces. There were a total of 15 items with three of the items repeated across different rooms that participants were asked to find. Scoring was based on the number of errors made in matching objects to the rooms.

Participants were given an outline of the office suite following their exploration. Instructions were given to draw the boundaries between the spaces, and then to map their navigation by drawing the route taken to visit each space, see Fig. 22.

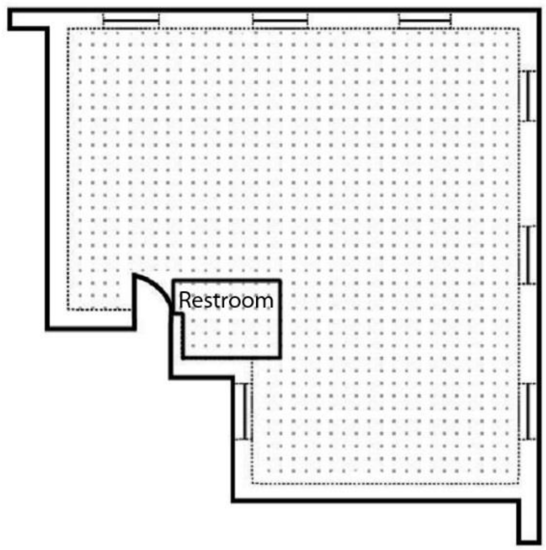

Figure 22: Plan outline task given to participants.

Accuracy of the cognitive maps was determined by comparison with the actual floor plan through three measures: 1) length and width estimations, 2) placement of rooms, and 3) configurational relationships between spaces (Kim & Penn, 2004).

3.3.1.3 Configurational Knowledge from Proportion Measures

The overall score for length and width was the absolute error score when compared with the actual layout. In addition to the length and width total scores, each was evaluated further as a ratio of length and width to provide information into over or under estimation of room sizes to test the accuracy of spatial perception (Interrante, Ries, Lindquist, Kaeding, & Anderson, 2008). The room placement score was scaled 1-8 with eight being the most accurate. Accurate placement was determined by splitting the original space into four quadrants and using corner and window references to determine if placement of rooms was accurate. The final eighth point was given if the cognitive map had correct orientation. This placement scale allowed for indication of how good the cognitive map was when compared with the actual floor plan (Zanbaka, Lok, Babu, Ulinkski, & Hodges, 2005).

3.3.1.4 Configurational Knowledge from J-Graphs

The last measure for the cognitive maps was the development of a convex mapping-justified graph using AGRAPH software. Justified graphs are commonly used for determining spatial relationships and configurations of designed spaces (Bafna, 2003). As the original cognitive maps were drawn without the specific requirement of doorways to be placed, the common quantifying analysis method of axial mapping could not be used (Stanney, et al., 2013). In this study, the justified graph was used to analyze and quantify how well participants developed configurational knowledge of the office space. To assess the cognitive maps for configurational knowledge, two coders were asked to independently score the maps. Using the AGRAPH software, each coder linked the convex boxes together, including corridors. Two scores were used to determine each room's score: 1) the mean depth and 2) the integration value. These scores would allow for statistical comparisons to be made between the actual floor plan and the cognitive maps (Kim & Penn, 2004). The final scores were then compared to the actual floor plan's justified graph and the absolute value of the error was summed across all seven spaces as the final measure for analysis.

To score the cognitive maps for accuracy, several rules (see Appendix E) were developed and two independent raters were asked to independently score each of the maps after receiving training (Picucci, Gyselinck, Piolino, Nicolas, & Bosco, 2013). Inter-rater reliability was tested across all three measures using correlations across the first 15 cases (see Table 3) on each individual measure. Each rater was asked to score the first 15 cases for all measures first using the guidelines provided to them. Following the scoring, the 15 cases were correlated. Correlations were calculated per individual measure between the two raters. This helped to establish accuracy in interpreting the line placements on the grid for the dimensions and the treatment of corridor spaces.

The initial differences were discussed and the guidelines for scoring the cognitive maps were revised. The raters were then asked to independently redo all 15 cases again using the revised guidelines. The correlations with the revised guidelines were significantly higher and in the acceptable range so the remainder of cases was split between the two coders independently.

Table 3: Inter-rater reliability correlations across two coders for the 7 rooms.

	Length	Width	Mean Depth	Integration Value
Lobby	0.96	0.88	0.62	0.67
Empty Office	0.62	0.91	0.95	0.92
Partition Office	0.95	0.98	0.87	0.92
Narrow Office	0.92	0.87	0.97	0.97
Main Office	0.97	0.87	0.66	0.59
Sitting Area	0.90	0.98	0.91	0.92
Burned Office	0.98	0.99	0.95	0.92

The maps were scored for several measures including length and width estimation of the seven rooms in the office space, placement of each room, and to use space syntax justified graphs (J-Graphs) as shown in Fig. 23 to score configurational understanding. Before scoring could be completed, each coder had to redraw each map as convex boxes representing each space and corridor originally drawn.

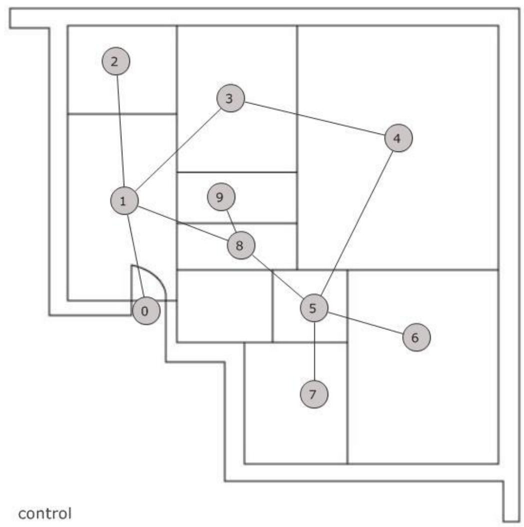

Figure 23: Convex-mapped J-graph of actual floor plan.

The convex drawings were done using Adobe Illustrator. Using the convex boxes the length and width were determined for each of the spaces with the grid originally provided as seen in Fig. 24.

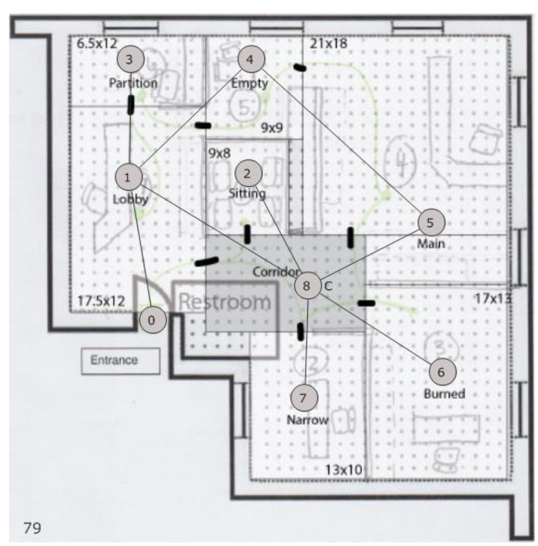

Figure 24: Participant cognitive map with dimension and J-graph nodes.

3.3.1.5 Spatial Recall

Spatial recall measures included specific measures of the memory of the participant's path through the simulation, i.e. their route knowledge. The recall activity incorporated two parts with the first being free recall where participants were asked to recall the path taken through the office space by numbering the rooms drawn on their cognitive maps in the order they visited them. The second part of the recall activity was a cued recall which provided screenshots of each room and asked the participant to again number the order visited from 1- 7.

3.3.2 Control for Confounding Variables

Utilizing an experimental design with random assignment of subjects helped reduce many of the confounding variables but, some were also controlled statistically, by treating them as covariates. One such variable that was controlled was immersive tendency. Immersive tendency is a measure of how inclined someone is to experience psychological immersion. Immersive tendency also collected information pertaining to user attention. To control for this variable, a questionnaire developed by Witmer and Singer (1998), the Immersive Tendencies Questionnaire (ITQ) was adapted. Eleven items were adapted on a 9-point Likert-type scale from the Witmer and Singer (1998)'s ITQ (e.g. How good are you at blocking out external distractions when you are involved in something?).

Enjoyment is a subjective, positive affective state that users experience as an outcome of being psychologically immersed in a medium (Green, et al., 2004). The concept of enjoyment has been positively linked to several other concepts: attention (Ji, Tanca, & Janicke, 2013), presence and simulator sickness (Nichols, Haldane, & Wilson, 2000), technology acceptance (Davis, Bagozzi, & Warshaw, 1992) and, pleasure (Lin, Duh, Parker, Abi-Rached, & Furness, 2002). Operationally, enjoyment is typically considered as items related to positive experiences measured using self-report (Ji, et al., 2013; Lin, et al., 2002). Therefore, to control for enjoyment, three 9-point Likert-type scale items were adapted from Davis et al. (1992) (e.g. Viewing the office suite was pleasant).

Gorini et al. (2011) suggested the use of narrative as the method of providing the context would increase the level of attention and motivation thus increasing the level of a user's engagement. This went along the same lines as Witmer and Singer's (1998) idea to incorporate a plot to better engage users. Therefore, the same narrative plot line was used for all conditions. Building on the narrative, basic audio was included for delivery of the narrative in the same manner for all conditions. To address the issues of attention and motivation, the study context needed to be carefully chosen. The user was actively involved, meaning he/she was able to control decisions in the context which, was used to address the issue of attention. By using specific tasks that go with the context, intrinsic motivation at a basic level should also occur. The study context is described in detail later on in this chapter.

Participant skill levels varied and were controlled best through a training session prior to data collection. In addition, previous experience with VR systems, video games/ computer games, and technology in general were assessed using a self-report component within the demographics portion of the questionnaire. Familiarity with 3D devices and video games consisted for six items developed for this study on a 9-point Likert-type format (e.g. How familiar are you with participating in 3D online virtual worlds?). In addition to familiarity, eight items pertaining to participant confidence level with different software packages on a scale of 1-9 was adapted from Balakrishnan et al. (2012). Participants were also asked to give an estimate of the number of months or years in experience they had with 3D modeling software packages.

Another measure was developed to control for individual spatial abilities, a three item sense of direction scale on a 9-point Likert-type format (e.g. I am good at remembering routes I use to travel).

One last measure was adapted from a previous study to capture participant's exposure to the iLab facility (Balakrishnan, et al., 2012). The question asked participants about ever attending presentations or events in the iLab prior to participating in the study. If the participant indicated yes, three items were provided for a rating of their experience.

3.4 Sample

Students in enrolled in architectural studies and textile apparel management courses from a mid-western university were asked to volunteer to participate in the study for one hour without compensation. Students were randomly assigned to a single condition. The sample (N =121) consisted of 88 students were architectural studies majors and minors while 33 were non-majors. The average amount of semesters spent in the architectural studies program was (M=2.59, SE = .26, SD = 2.82). The class standing of the students consisted of 27 freshmen, 22 sophomores, 24 juniors, 42 seniors and five graduate students.

3.5 Experimental Manipulations

The manipulations for each of the independent variables were implemented using EON Studio software. Stereoscopic view was turned on or off manually depending on the condition being presented. Participants in the non-stereoscopic condition did not wear the active shutter glasses. Field of view was manipulated following the dimensions from a preliminary study (Balakrishnan, et al., 2012). To manipulate field of view, EON Studio allowed direct manipulation of both the software field of view as well as the physical window sizing. For the wide field of view conditions, field of view within EON Studio was set to 152 units and the display was left to full-screen mode. For the narrow field of view conditions, field of view was also set to 152 units but the display size was reduced by 25% on all sides and centered. This reduction caused the active window created blank black space where the participant was able to focus on the center of the screen, as shown in Fig. 25.

Figure 25: Narrow field of view (Left), wide field of view (Right).

The navigability manipulations of the joystick were also handled using EON Studio. For the low navigability conditions, the joystick controls in EON Studio were set to only use basic translational movements and rotation. For the high conditions, the settings included basic translational movements and rotation in addition to head tilting, see Fig. 22. EON Studio allowed for specific buttons on the Logitech Freedom 2.4 GHz Cordless Joystick. For all navigability manipulations, the main trigger button had to be held down to move. In the high conditions, an extra button was programmed to allow for the head-tilting motion.

3.6 Pre-Testing

A significant effort and amount of time was taken to pre-test manipulations as well as measures in order to refine them multiple times before the final study was conducted. As the study covered a number of different types of manipulations, it was necessary to test if each manipulation was effective. Pre-testing also provided insights for refining the questionnaire as well as spatial tasks, specifically for spatial understanding. Prior research projects conducted in the iLab, notably Balakrishnan et al. (2012)'s study also helped to improve the protocol and operationalizations for this study by acting as a pilot study. The pilot study provided information into how far from the screen the participant should sit. It also addressed how to operationalize field of view specifically as a portrayal of actual image size projected on the screens as opposed to the virtual camera's field of view setting.

In addition to the pilot test, pre-testing was conducted with five architectural studies graduate students and three undergraduate students from computer science. Using these two diverse groups provided insight into how people from different disciplines would react to each component of the study so that refinements could be made. Subsequent revisions were made between every other pre-testing in order to gauge if the change was necessary.

The results of the pre-test helped make improvements to the stimulus (e.g. widening corridors and doorways for easier navigation), to help find a comfortable geometric field of view based on the display size, a time frame for the task to be completed (e.g. 10 minutes was the amount of time to complete the task on average), and to improve the measures for spatial understanding (e.g. the orientation of the cognitive map outline, image matching of objects to be found, and better worded instructions). Lastly, pre-testing helped to improve the narrative for the task scenario.

Pre-testing showed that participants, particularly ones not familiar with how to use a joystick had more difficulty with narrow corridors and doorways. When the corridors and doorways were widened, easier navigation allowed for better interaction with the virtual environment, subsequently compensation for the level of skill of the user with a joystick. Depending on whether the display size was for wide or narrow field of view, it was important to define a camera field of view or geometric field of view which best suited the manipulation. Pre-testing included asking users about their comfort and ease of navigating with two different camera field of view settings. To gauge the amount of time to interact with the virtual environment, each pre-test subject was asked to complete the task without a time limit. In timing each subject, the average time of 10 minutes was derived as enough time for accomplishing the search task.

Improving the measures for spatial understanding was one of the most involved portions of the pre-test subjects. Understanding of the written instructions was one of the first changes that occurred. In addition to the written instructions wording, the orientation of the cognitive sketch map provided pre-test subjects with a better sense of recording their own idea of the space. Lastly, pre-testing allowed for a change in free listing objects found in the rooms to more of a visual matching. This determination came when several of the pre-test subjects indicated that near the end of the questionnaire, fatigue was setting in making it harder to complete. Utilizing visual images to match objects found to the correct location negated some of the fatigue and enabled the pre-test subjects to complete the questionnaire.

3.7 Procedure

A detailed research protocol was developed (see Appendix A), complete with verbal scripts for instructions were developed to ensure consistency and avoid researcher bias. Following the scripted protocol, participants were greeted and briefed about the study. Once the participants indicated they understood what the study was about and what was expected from their participation, formal verbal consent was obtained in compliance with the Institutional Review Board specifications. The procedure included four main parts: filling out a demographics questionnaire (see Appendix C), training on the joystick, viewing the narrative for task instructions, performing the task, and filling out the post-test questionnaire (see Appendix D). The initial questionnaire captured all demographic data.

3.7.1 Joystick Training

Once the participant finished the first questionnaire, there was a short training session on how to use the joystick as well as to screen the participant for issues with simulator sickness. The training session lasted from five to ten minutes until the participant could confidently navigate with the joystick. A diagram was presented on how the joystick worked based on the specific condition. Along with the diagram explanation, the participant was actually shown how the joystick worked as well as how to handle any issues he/she may encounter when using the joystick.

Once the instruction for using the joystick was complete, the participant was asked to use the joystick to move around a virtual house freely. During the free exploration, more explanation and tips on use of the joystick were provided. In addition to the explanation and tips, the participant was prompted to make use of all the different movements the joystick condition provided.

The training environment was a simple residence with minimal furniture included to allow for optimal movement through spaces, see Fig. 26. The residence had several dead-ends as well as narrow spaces to help the participant become familiar with how to use the joystick to maneuver through different types of spaces.

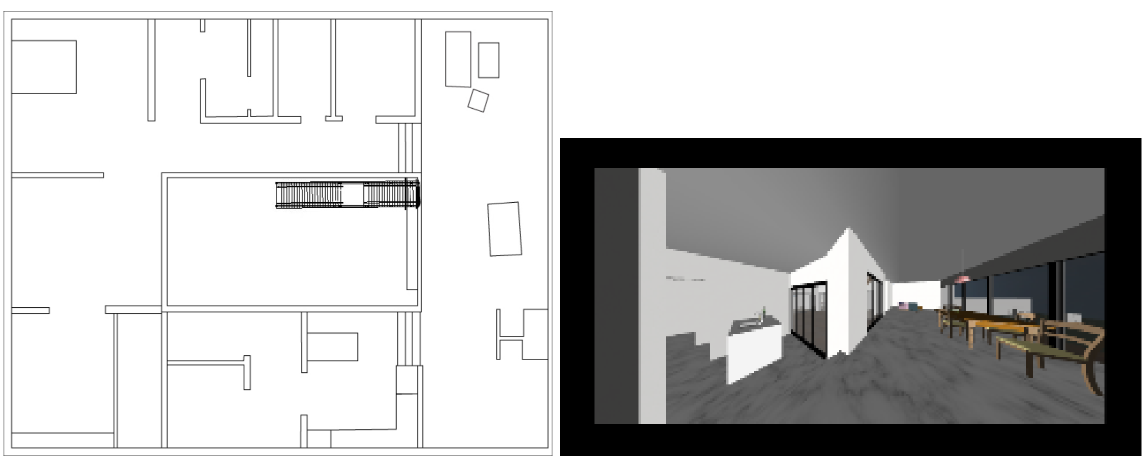

Figure 26: Training environment plan and perspective.

3.7.2 Study Task

Following the training, participants were asked if there were any further questions or concerns before moving on to the main task. Once the participant indicated there were no more questions or issues, the task procedure was explained. To aid with psychological immersion, it was important to help the participants maintain attention on the task. A scripted narrative was presented using a Power Point Slide show with voice over (see Appendix B) to provide details of the task to the participant. In addition to detailing the task, the narrative requested the participant imagine being a fire-fighter trainee going into a building to account for personal items left behind. This context was to narratively transport' the participant to the scenario and help keep participant motivation on the task (Green, et al., 2004). The refined narrative from initial pre-testing provided participants with the task details in both a verbal and written format. The narrative took the participants through each room of the office space while, listing objects that should be found.

To further help with maintaining attention, the verbal portion of the narrative was given through Bose™ noise-cancelling headphones. This allowed for participants to focus on the narrative instead of ambient noises which, might have occurred outside of the lab space. The participant was also asked to keep the headphones on during the task itself.

Following the narrative, the environment for the task was loaded and participants were told they could start the task. The instructions indicated there was a 10 minute time limit and that at the end of 10 minutes they would have two indicators that time was up:

1) the joystick would stop allowing any movement to occur, and 2) the fire chief would say through the headphones that time was up. The 10 minute time limit was used to help control for amount of time spent in the environment so it would remain consistent for all participants.

During the 10 minute task, the researcher noted the route taken, order rooms were visited, any use of the joystick manipulation, and any issues encountered. In addition to the observational notes, a video camera was set up behind the participant to capture only the screen while the task was being completed.

The task was made up of two parts where the first portion provided to participants was simple search task. A list of 15 objects, some being repeated objects, were spread across the seven room office suite. Participants were told of the room each object was located and asked to find each of the items using the joystick. The second portion of the task was to 'report' their findings by drawing a map of the space and indicating the location of the objects.

The task started out in the entrance of the office suite which was located on the upper level of a building. The fire chief narrated the task to the participants indicating there were seven rooms in the office suite along with specific items to find in each room. The fire chief also provided information about the task being two parts: 1) a ten minute search task and 2) a final report indicating how the search went.

3.7.3 Questionnaire

Once the search part of the task was completed, participants were able to start filling out the questionnaire and the second portion of the task. To keep responses independent from one another, participants were asked to not change any initial responses. Once the questionnaire and spatial understanding task were completed, the participants were thanked and any additional questions were answered.

3.7.4 Experimental Set-Up

Based on the pre-testing, the protocol for the experiment procedure (see Appendix A) was worked out. Only one participant was able to participate at any given time. The total time to complete the study from beginning to end was approximately one hour. The layout of the lab was set up to aid with making sure all participants experienced the study in the same manner and reduced the need for standing, see Fig. 27. Participants were seated in a rotatable chair that was positioned four feet from the center of the screen. A table was placed behind the chair so participants could simply rotate around to fill out the questionnaire after the task. On the other side of the table, the researcher sat to provide details of the study to participants at the beginning of the study. A video camera was positioned behind the researcher to capture the screen during the task. Off to the side of the screen another table was used as an observation station so, it would not interfere with the camera recording the screen. The researcher would move to the observation station once the task was started and remain there until the participant finished.

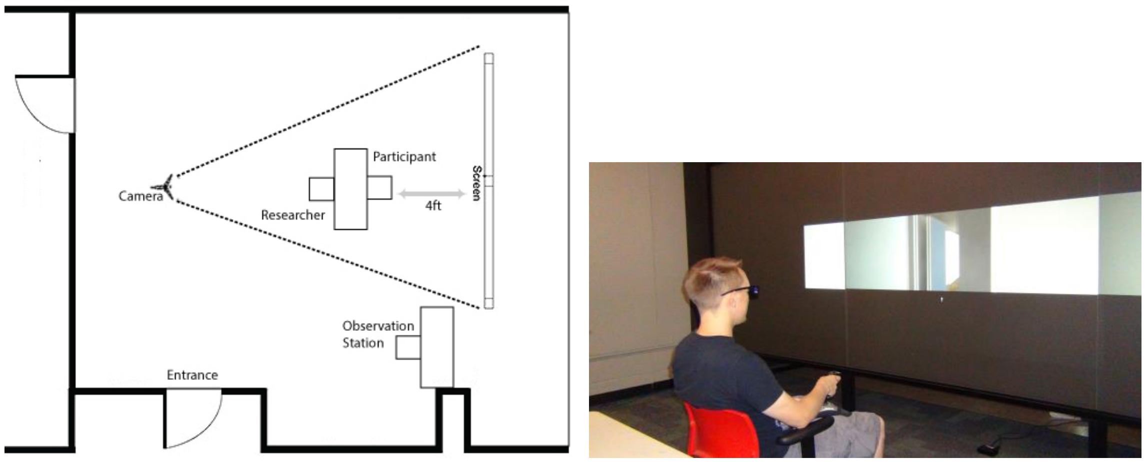

Figure 27: Experiment set-up.

3.8 Data Analysis Plan

In order to address the overall research question several statistical tests were used to conduct the analysis. As the research question looks at the relative impact of both visual immersiveness and navigability on spatial experience measures, it was important to examine that relationship first using a multiple analysis of covariance (MANCOVA). This provided insight into the overall contributions among the independent variables on the spatial experience responses. Follow-up to the main analysis was conducted through a series of analysis of covariance (ANCOVA) as necessary to see individual impacts on each spatial experience dimension. To analyze the results of the technology manipulations on spatial understanding, individual ANCOVAs were conducted to see if group differences existed in each dependent variable.

CHAPTER 4: ANALYSIS & RESULTS

This chapter reports the results of data analysis from the experiment. The first section will discuss data screening and assumptions. The next sections will detail out results of statistical tests to address the research question and hypotheses. Specifically, this study looked to investigate the influence of visual immersiveness and navigability on spatial experience and understanding in a virtual environment. The analysis was conducted using SPSS and JMP statistical analysis software. To address the overall research question and hypotheses, several statistical tests were conducted on each of the dependent measures. The initial analysis consisted of a multivariate analysis of covariance (MANCOVA) to address how the technology affordance manipulations impacted perceptions of spatial experience. Subsequent analysis to address each of the dependent measures individually utilized analysis of covariance (ANCOVA).

4.1 Sample Characteristics and Demographics

Participants ($N = 110$) volunteered from a mid-western university from architectural studies and textile apparel management courses. The average age was $M = 20.95$ with 42 males and 79 females. Academic standing consisted of 27 freshman, 22 sophomores, 24 juniors, 42 senior, and 5 graduate students. A total of 77 students were architectural studies majors with 33 non-majors. There were 79 students in the architectural studies program either as major or minor with 31 students not affiliated with the program outside of the courses they were taking. Of the students in the architectural studies program, the total number of semesters in the program ranges from 0 to 12, ($M = 2.66$, $S.E. = 0.27$).

Participants ranges from 0 to 66 months experience with 3D software (M = 14.28. S.E. = 1.66). When asked about familiarity with 3D devices, video games, and virtual environments, students reported an average of (M = 5.15, S.E. = 0.15). Similarly, when asked about confidence with different types of software packages including 2D programs (e.g. Photoshop, etc.) and 3D programs (e.g. 3D Studio Max, etc.), participants reported on average (M = 3.87, S.E. = 0.19). Following along the lines of participants experience with 3D technology, a total of 46 students had visited the iLab prior to the experiment leaving 64 who had never been in the facility. Lastly, participants were asked to rate their tendency to become immersed (M = 5.88, S.E. = 0.11) as well as their sense of direction (M = 6.24, S.E. = 0.18).

4.2 Data Screening

Before testing hypotheses, the data was first screened for missing data and outliers, both univariate and multivariate. A total of 23 missing data points were found across the dependent variables and covariates. Missing data was handled in two ways: 1) if a particular case had multiple missing data points it was treated as an outlier and removed and, 2) missing values were double checked for data entry issues first. If the missing values were not due to data entry issues, they were left as missing values.

Univariate outliers were detected in three ways: 1) Z-Scores were calculated and values above ±3.29 were marked as outliers, 2) histograms with normal curves were generated for visual confirmation of outliers, and 3) skewness and kurtosis were evaluated for ±2.0. Most cases fell within the normal range and were not detected as outliers. In some instances, the data showed outliers where the participant's responses or demographics were treated as special cases. Age showed three participants as outliers, it was decided to leave these participants in the data set as extreme cases. Outliers were found to differ across the two dependent variables and so outliers were excluded based on each. Multivariate outliers were detected through testing the Mahalonobis Distance through a chi-square distribution. Only one case was found to be a multivariate outlier. A total of eight outliers and participants with missing values were excluded from the entire analysis overall. Five of the cases were removed for analysis on the spatial experience measures and six different cases were removed for the spatial understanding measures.

The data was tested for the assumptions of independence of observations, normality and multivariate normality, homogeneity of variance-covariance matrices, measurement error of covariates, linear relationships between covariate and dependent variables, and homogeneity of regression. To test normality, outliers and missing data were handled and histograms with normal curves were used. Skewness and kurtosis were also examined. Reliability of the covariates and dependent variables was examined through Cronbach's α. Scatter plots were used to assess linearity of the covariates and dependent variables. Homogeneity of variance-covariance matrices was evaluated using Levene's test and Box's M test. Homogeneity of regression was checked to see if any interaction existed between the independent variables and covariates. In almost all instances the relationships between the independent variables and covariates were found to have no significant interaction.

The design of the experiment accounted for having balanced cell sizes, after dealing with the missing data and outliers the cells were still well balanced, see Table. 4.

Table 4: Number of cases per manipulation.

	Number of Cases
Stereo	54
Non-Stereo	56
Wide FOV	56
Narrow FOV	54
High Nav	53
Low Nav	57

4.3 Reliability Analysis for Dependent Variables and Covariates

Each of the scaled questionnaire items for the dependent variables and covariates were tested for reliability using Cronbach's α and were found to have good reliability, see Table 5.

Table 5: Reliability for dependent variables and covariates.

	Cronbach's α	Mean	StD
Possibilities for Action	0.93	6.29	1.73
Self-Location	0.92	7.02	1.48
Vection	0.85	6.29	1.49
Reality Judgment	0.94	5.95	1.52
Attention	0.84	8.22	0.84
Immersive Tendency	0.82	5.81	1.25
Enjoyment	0.97	7.66	1.47
Familiarity with 3D	0.73	5.05	1.59
Software Confidence	0.88	3.85	1.95
Sense of Direction	0.89	6.21	1.94

4.4 Relationship among Variables

To conduct the analysis with covariates, it was important to examine the relationship between the dependent variables and covariates. Several bivariate correlations were conducted to examine the strength of the relationship between the variables, see Table 6. These correlations were used to help inform the use of covariates for the analysis.

Table 6: Correlations between dependent variables and covariates.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Possibility for Action	-																			
Self-Location	.71**	-																		
Vection	.67**	.53**	-																	
Reality Judgment	.68**	.74**	.64**	-																
Object Error	.02	-.04	-.01	.04	-															
Room Correct	.04	.01	-.00	.13	-.25**	-														
Layout Score	-.11	-.04	-.02	-.16	-.44**	.15	-													
Area Error	.11	.03	.04	.14	.41**	-.20*	-.79**	-												
J-Graph MDn	.08	-.01	.08	.10	.35**	-.24**	-.70**	.60**	-											
Attention	.28**	.41**	.21*	.20*	-.16	.01	.05	-.07	-.12	-										
Enjoy	.52**	.55**	.61**	.58**	-.22*	.01	.04	-.05	.05	.32**	-									
3D Familiarity	.07	-.03	.10	-.10	-.25**	-.01	.15	-.19*	-.03	.10	.18	-								
Sense of Direction	-.03	.06	-.02	.00	-.18	.15	.22*	-.39**	-.27**	.11	.06	.16	-							
Class Standing	-.22*	-.18	-.10	-.08	-.05	.03	.15	-.10	-.09	-.04	.15	.14	.14	-						
3D Experience	.07	-.05	.12	.04	-.00	.02	.05	-.07	.01	-.10	.19*	.37**	.15	.46**	-					
Experience Object	.36**	.32**	.50**	.36**	-.17	-.03	-.00	-.01	.13	.31**	.60**	.16	.08	-.06	.03	-				
Object Difficulty	.15	.03	.17	.10	-.01	-.03	-.06	.04	-.06	.09	.03	-.09	.07	-.27**	.00	.25**	-			
Experience Joystick	.36**	.34**	.42**	.32**	.08	-.00	-.07	-.00	.13	.25**	.49**	.13	.07	-.01	.12	.58**	.23*	-		
Joystick Difficulty	.30**	.29**	.40**	.27**	-.03	.09	.03	-.06	.02	.19*	.34**	.13	.05	-.12	.07	.37**	.41**	.66**	-	
Area Ratio	-.09	-.01	.00	-.13	-.28**	-.01	.66**	-.41**	-.56**	.06	.19*	.16	.03	.25**	.10	-.09	-.06	-.11	.04	-

*significant at the p<0.05, **significant at the p<0.001.

4.5 Descriptives

Descriptive statistics of covariates and dependent variables after adjusting for missing values and outliers are listed below in Table 7.

Table 7: Descriptives of covariates and dependent variables.

	N	Mean	Standard Error	Standard Deviation	Skewness	Kurtosis
Age	110	20.82	0.20	2.05	1.06	1.78
Gender	110	0.65	0.05	0.48	-0.66	-1.60
Academic Standing	110	2.81	0.12	1.26	-0.19	-1.29
Major	110	0.70	0.04	0.46	-0.89	-1.24
Arch Student	110	0.72	0.04	0.45	-0.98	-1.05
Semesters	110	2.66	0.27	2.86	1.04	0.22
3D Experience	109	14.28	1.66	17.33	1.07	0.03
iLab	110	0.42	0.05	0.50	0.34	-1.92
Experience Object	110	7.29	0.12	1.76	-0.87	0.93
Object Difficulty	110	6.60	0.17	1.76	-0.92	0.51
Overall Locating	110	7.72	0.10	1.01	-1.11	1.81
Experience Joystick	110	7.16	0.14	1.43	-0.77	0.81
Joystick Difficulty	110	6.95	0.15	1.54	-0.44	-0.27
Overall Joystick	110	7.38	0.11	1.18	-0.55	-0.33
Familiarity with 3D and video games	110	5.15	0.15	1.58	0.03	-0.58
Software Confidence	110	3.87	0.19	1.95	0.11	-1.35
Immersive Tendency	110	5.88	0.11	1.20	-0.22	-0.15
Sense of Direction	110	6.24	0.18	1.91	-0.67	0.46
Attention	110	8.23	0.08	0.80	-1.27	1.07
Self-Location	110	7.08	0.13	1.36	-1.17	1.76
Possibility for Action	110	6.35	0.16	1.71	-0.66	-0.21
Enjoyment	110	7.70	0.14	1.43	-1.40	2.14
Vection	110	6.32	0.14	1.45	-0.50	-0.28
Reality Judgment	110	5.98	0.14	1.50	-0.47	-0.50
Proportion Error	110	415.58	15.83	166.05	0.24	-0.90
Width Estimation Error	110	21.55	0.99	10.41	0.81	-0.02
Length Estimation Error	110	27.27	1.23	12.94	0.30	-0.76
Width Ratio	110	1.01	0.01	0.15	-0.81	0.12
Length Ratio	110	0.94	0.02	0.17	-0.72	0.36
Layout Score	110	6.74	0.12	1.27	-0.76	-0.14
J-Graph INT	110	5.71	0.31	3.24	0.99	1.73
J-Graph MDn	110	3.29	0.21	2.16	0.88	0.76
Cued Route	110	3.95	0.23	2.43	-0.08	-1.38
Free Route	98	2.96	0.24	2.35	0.36	-1.07
Object Error	110	5.43	0.27	2.79	0.68	0.20

4.6 Hypothesis Testing

4.6.1 Spatial Presence Measures

Spatial presence measures included four dimensions: possibilities for action, self-location, vection, and reality judgment. All four dimensions were highly correlated suggesting a good fit for conducting a factorial multivariate analysis of covariance (MANCOVA). The MANCOVA was used to examine the impact of the each technology manipulation on all of the spatial presence measures including vection and reality judgment. The MANCOVA included two covariates: gender and attention. Attention was a scaled measure included in the spatial presence questionnaire to act as a control variable. In this analysis, attention was used as a covariate.

The MANCOVA analysis revealed a significant main effect for field of view (FOV), Wilks' $\lambda = 0.90$, $F(4, 103) = 2.81$, $p < 0.05$, partial $\eta^2 = 0.10$, see Fig. 28.

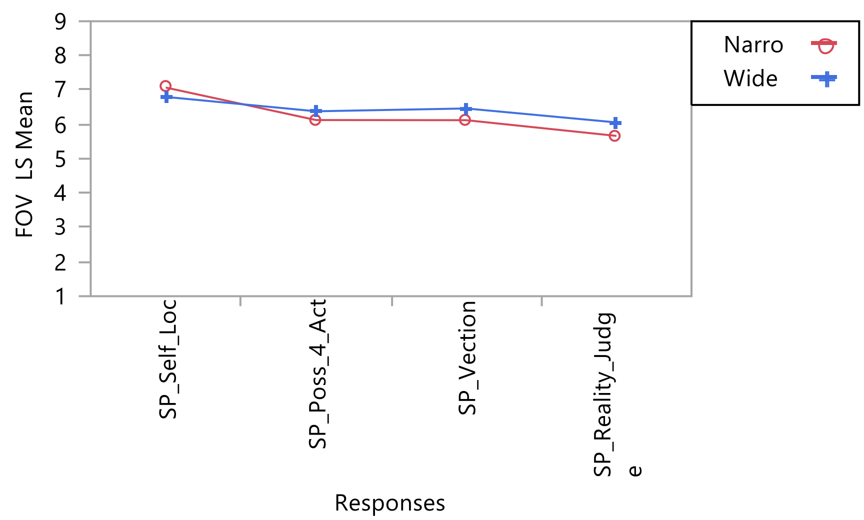

Figure 28: Significant main effect for FOV on spatial presence measures.

These results indicate that *field of view* significantly impacted all of the spatial presence measures with the exception of self-location. On all the other measures of spatial presence, a wider field of view increased the reported sense of presence. Further analysis, at the univariate level, showed that for self-location, stereoscopy was tending towards significance. The group with the *stereo* condition reported a higher perception of self-location (adj. M=7.23, SE = 0.17) than the *non-stereo* condition did (adj. M = 6.78, SE = 0.17), $F (1, 105) = 3.35$, $p = 0.07$, partial $\eta^2 = 0.03$.

These initial results help to support hypothesis H1 which predicted that greater levels of visual immersiveness would increase spatial presence. The support for the H1 comes from partial support for H1:B which, predicted that greater levels of field of view would increase spatial presence. In the case of all the spatial presence measures except self-location, a wider field of view indicated higher a reporting of spatial presence. Partial support of H1:A which, predicted that greater levels of stereoscopy would increase spatial presence. In the instance of self-location, the near significance of stereoscopy indicates partial support of the hypothesis. However, the H4 which predicted that greater levels of navigability would increase spatial presence was not supported by the MANCOVA. To better understand the influence of the independent manipulations on the individual measures of spatial presence, follow-up ANCOVAs were conducted.

4.6.1.1 Possibilities for Action

The first ANCOVA was conducted on *possibilities for action* using academic standing, months experience with 3D software and enjoyment as covariates. Possibilities for action are a dimension of spatial presence that examines how users feel they can take action within a simulated environment.

A significant interaction was found between stereoscopy and field of view $F (1, 103) = 4.14$, $p < 0.05$, partial $\eta^2 = 0.39$, see Fig. 29. For narrow field of view, there was hardly any difference between stereo (adj. M = 6.37, S.E. =0.27) and non-stereo (adj. M = 6.04, S.E. =0.26). However for the wide field of view condition there was a noticeable difference between stereo (adj. M = 6.07, S.E. = 0.27) and non-stereo (adj. M = 6.83, S.E. = 0.28). The results also indicated that *academic* and *enjoyment* both significantly covaried with *possibilities for action*, for academic $\beta = -0.49$, $t(103) = -3.99$, $p < 0.001$, for enjoyment $\beta = 0.59$, $t(103) = 6.18$, $p < 0.001$. The results indicate the combined effect of stereoscopy and field of view significantly influences possibilities for action. When the field of view is narrow, stereo helps increase the perception of possibilities for action. However, when the field of view is wide, stereo becomes less critical in increasing the perception of possibilities for action.

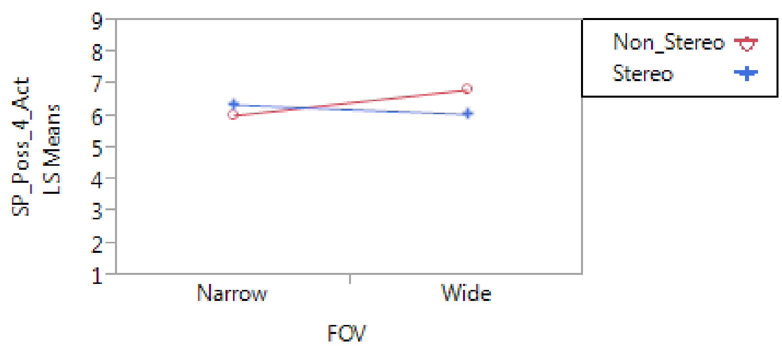

Figure 29: Significant interaction stereo*FOV on possibilities for action.

Non-stereo and wide field of view were the significant manipulations driving the interaction effect, see Table 8.

Table 8: Simple effects interaction contrast for possibilities for action.

	df	F	Partial η^2
Narrow FOV	1	0.783	0.08
Wide FOV	1	3.897*	0.036
Stereo	1	.596	0.006
Non-Stereo	1	4.370*	0.041
Error	103		

* significant at the $p < 0.05$.

4.6.1.2 Self-Location

The next ANCOVA was conducted on *self-location* with enjoyment, sense of direction, experience with joystick, and experience finding objects as covariates. Self-location is a dimension of spatial presence that deals with the feeling of transferring from the real world into the simulated one.

A significant interaction was found for field of view and navigability, F (1, 104) = 4.34 $p < 0.05$, partial $\eta^2 = 0.04$, see Fig. 30. For low navigability, there was hardly any difference between wide (adj. M = 7.317, S.E. = .236) and narrow (adj. M = 7.033, S.E. = .241) field of view. However for the high navigability condition there was a noticeable difference between wide (adj. M = 6.497, S.E. = .239) and narrow (adj. M = 7.213, S.E. = .239) field of view. The results also indicated that *enjoyment* significantly covaried with *self-location*, $\beta = 0.52$, $t(104) = 5.21$, $p < 0.001$. The results of this ANCOVA on self-location indicated a combined effect of field of view and navigability where a greater level of navigability reduces the need for a wide field of view when reporting a sense of self-location.

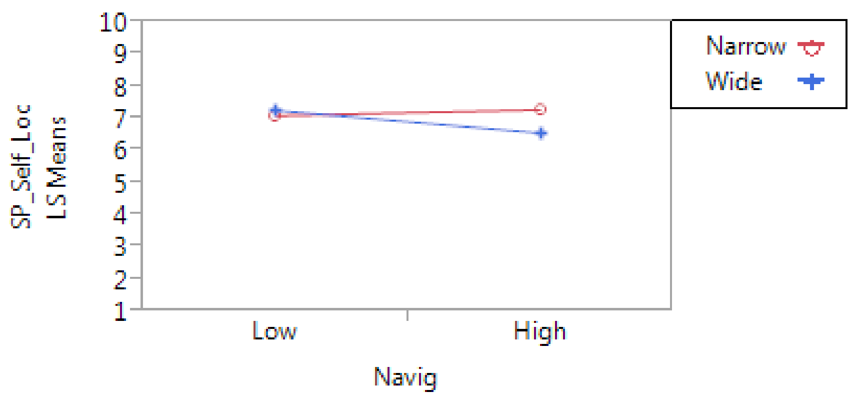

Figure 30: Significant interaction between FOV*navigability on self-location.

A wide field of view and high navigability were the significant manipulations driving the interaction effect, see Table 9.

Table 9: Simple effects interaction contrast for self-location.

	df	F	Partial η^2
Narrow FOV	1	0.272	0.003
Wide FOV	1	5.994*	0.054
Low Nav	1	0.696	0.007
High Nav	1	4.527*	0.042
Error	104		

*significant at $p < 0.05$.

4.6.1.3 Vection

The next ANCOVA was conducted on vection using enjoyment, experience with joystick, object difficulty, months of 3D experience and gender as covariates. Vection is a related dimension of spatial presence that deals with the illusion of self-motion.

A near significant interaction between field of view and navigability was found, $F(1, 102) = 3.70$ $p=0.06$, partial $\eta^2 =0.04$, see Fig. 31. For high navigability, there was hardly any difference between wide (adj. M = 6.20, S.E. = 0.22) and narrow (adj. M = 6.43, S.E. = 0.23) field of view. However for the low navigability condition there was a noticeable difference between wide (adj. M = 6.60, S.E. = 0.22) and narrow (adj. M = 5.98, S.E. = 0.21) field of view. The results also indicated that *enjoyment and experience with joystick* both significantly covaried with *vection*, for enjoyment $\beta = 0.55$, $t(102) = 6.39$, $p < 0.001$, for experience with joystick $\beta = 0.18$, $t(102) = 1.97$, $p < 0.05$. The results of this ANCOVA only showed a near significant interaction between field of view and navigability. Although only nearing significance, the direction of the influence can be noted. When navigability was low, a wider field of view helped in producing a sense of vection. However, when navigability was increased field of view became less critical for vection.

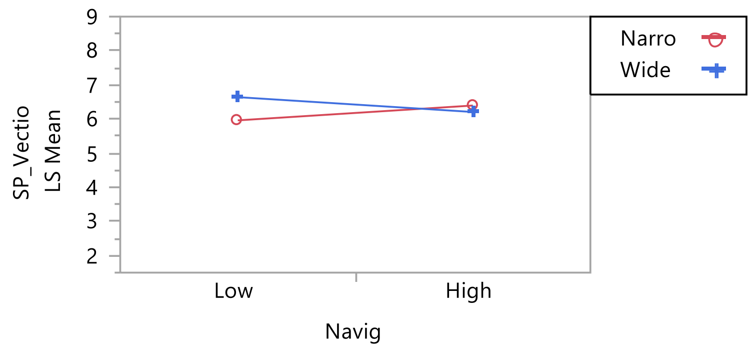

Figure 31: Near significant interaction between FOV*navigability.

Low navigability was the significant manipulation driving the interaction effect, see Table 10.

Table 10: Simple effects interaction contrast for vection.

	df	F	Partial η^2
Narrow FOV	1	2.045	0.020
Wide FOV	1	1.665	0.016
Low Nav	1	4.167*	0.039
High Nav	1	0.492	0.005
Error	102		

*significant at the $p < 0.05$.

4.6.1.4 Reality Judgment

The last ANCOVA for spatial presence dimensions was conducted on reality judgment while controlling for familiarity with 3D and enjoyment as covariates. Reality judgment is a related dimension of spatial presence where a user's perception of a simulated space becomes 'real'.

A significant interaction was found between Field of View and Navigability $F(1, 106) = 4.63$, $p<0.05$, partial $\eta^2 = 0.04$, see Fig. 32. For high navigability, there was hardly any difference between wide (adj. M = 5.77, S.E. = 0.23) and narrow (adj. M = 5.88, S.E. = 0.22) field of view. However for the low navigability condition there was a noticeable difference between wide (adj. M = 6.50, S.E. = 0.22) and narrow (adj. M = 5.65, S.E. = 0.22) field of view. The results also indicated that *familiarity with 3D* and *enjoyment* both significantly covaried with *reality judgment*, for familiarity with 3D $\beta = -0.20$, $t(106) = -2.67$, $p < 0.01$, for enjoyment $\beta = 0.67$, $t(106) = 8.27$, $p < 0.001$. The results of this last ANCOVA on spatial presence measures showed again a combined impact of field of view and navigability. When navigability was low a wider field of view helped in increasing reality judgment. However, when navigability was high, reality judgment was reported nearly the same for both narrow and wide field of view.

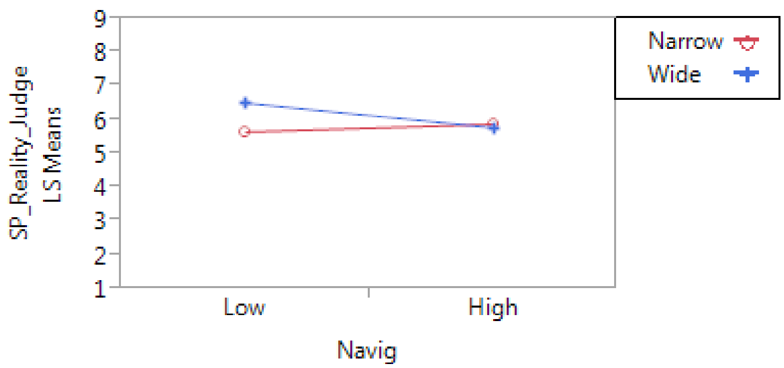

Figure 32: Significant interaction between FOV* navigability on reality judgment.

Low navigability and a wide field of view were the significant manipulations driving the interaction effect, see Table 11.

Table 11: Simple effects interaction contrast for reality judgment.

	df	F	Partial η^2
Narrow FOV	1	0.540	0.005
Wide FOV	1	5.249*	0.047
Low Nav	1	7.476*	0.066
High Nav	1	0.115	0.001
Error	106		

*significant at the $p < 0.05$.

4.6.1.5 Spatial Presence Summary

Spatial presence consisted of four dimensions: possibilities for action, self-location, vection, and reality judgment. Individual ANCOVAs, see Table 12, show significant interaction effects after controlling for covariates.

Table 12: ANCOVAs for all spatial presence dimensions.

Source	df	Possibilities for Action F	Self-Location F	Vection F	Reality Judgment F
Covariates					
Enjoyment	1	38.16**	27.14**	40.79**	68.31**
Familiarity with 3D	1	-	-	-	7.12*
Academic	1	15.93**	-	-	-
3D Experience	1	3.39	-	0.17	-
Sense of Direction	1	-	2.03	-	-
Experience with Joystick	1	-	2.05	3.86	-
Experience finding Objects	1	-	0.49	-	-
Gender	1	-	-	0.49	-
Object Difficulty	1	-	-	2.27	-
Main Effects					
Stereo	1	0.64	0.01	0.06	0.02
FOV	1	0.88	0.82	0.78	2.80
Navigability	1	0.52	1.75	0.01	1.27
Interaction Effects					
Stereo*FOV	1	4.14*	1.52	0.02	0.81
Stereo*Nav	1	0.10	0.94	0.19	0.13
FOV*Nav	1	2.12	4.34*	3.70(*)	4.63*
Stereo*FOV*Nav	1	0.14	0.11	0.06	0.76
Error	106	(205.70)	(164.23)	(137.63)	(152.27)

Note: Values enclosed in parentheses represent mean square errors. *significant at the $p<0.05$, **significant at the $p<0.001$, (*) near significant $p < 0.05$.

4.6.1.6 Hypotheses Set I: Spatial Experience

The results of each of the individual ANCOVAs should be considered together to address the study's hypotheses. Four hypotheses were posed to predict the influence of visual immersiveness and navigability on spatial presence:

- H1: **Greater levels of visual immersiveness will increase spatial presence**
    - H1:A: Stereoscopic virtual environment will result in greater spatial presence than non-stereoscopic virtual environment
    - H1:B: Wider field of view will result in greater spatial presence than narrow field of view
- H4: **Greater navigability will increase spatial presence**

Overall, the results provide partial support for H1 (greater levels of visual immersiveness will improve spatial presence). This finding is supported partially through the significance of field of view on all four dimensions of spatial presence as well as from the MANCOVA analysis. Looking closer at the individual hypotheses for H1, only H1:B (wider field of view will improve spatial presence) is partially supported due to each of the findings being interaction effects as opposed to main effects. Another distinction is the directionality of the H1:B hypothesis was not found to be exactly true on each individual dimension. For self-location, it was the narrow field of view that improved instead of the predicted wide field of view. The other individual hypothesis of H1 was found to not be supported, H1:A (stereoscopy will improve spatial presence) was only found to be significant on one dimension of presence and only within an interaction effect.

The results also indicated partial support for H4 (greater levels of navigability will improve spatial presence). Partial support comes from the interaction effects of navigability with field of view across nearly all the dimensions of spatial presence. Similar to field of view, the directionality of the influence of navigability on certain dimensions did not act as predicted. For reality judgment, high navigability was found not improve ratings.

For the four hypotheses, only three were partially supported. The hypothesis on stereoscopy, H1:A, was not supported by the results of the analysis.

4.6.2 Spatial Understanding Measures

Spatial understanding was examined from a series of measures that either dealt with spatial task performance or spatial recall. The measures were considered separate from each other so only individual ANCOVAs were conducted. The tasks associated with spatial task performance provided participants with a blank floor plan and asked them to sketch the layout of the office they had navigated proportionately. Spatial task performance consisted of several measures: 1) area proportion error and area ratio, 2) length and width ratios, 3) layout score and 4) J-Graph INT and MDn. The tasks associated with spatial recall asked participants to label the route they had taken to find the objects within the office as well as to match the room location to each of the objects. Spatial recall measures include a cued and a free route recall and object error.

Spatial task performance measures consisted of scores obtained from participant's cognitive maps of the office space. Area proportion score took the differences in calculated area from the cognitive maps and the actual dimensions and added them across the seven spaces. Area ratio is division of the participant's calculated area score over the actual area score to help determine over and under estimation. Similarly, length and width ratios were calculated by dividing each participant's score length and width by the actual dimensions. Layout score was a measure which examined the placement and orientation of the seven spaces on the participant's cognitive map. Lastly, both the J-Graph INT and MDn are measures of layout integration and mean depth of the spaces in relation to each other. Independent raters scored each cognitive map to determine these scores.

Spatial recall measures dealt more with route memory and the object reporting task. Cued and free route recall asked participants to label 1-7 the order of the rooms they visited. In the cued version, images of each room were provided. For the free recall, the participants were asked to label their cognitive maps. The last measure for the object reporting task asked participants to make photos of the objects to images of the rooms.

4.6.2.1 Area Proportion Error

An ANCOVA was conducted on area proportion error controlling for object error. Area proportion error is a measure of spatial task performance that was calculated from length and width estimates scored from participant's cognitive maps. The length and width differences from the actual dimensions of each of the seven rooms were multiplied and then added to obtain a total error score for area.

For area proportion error, a significant main effect for field of view was found when controlling for object error, $F(1, 104) = 5.45$ $p < 0.05$, partial $\eta^2 = 0.05$, see Fig. 33. The results also indicated that *object error* significantly covaried with *area proportion error*, $\beta = 26.61$, $t(106) = 5.19$, $p < 0.001$. As field of view had a significant main effect, it was necessary to look at the impact of each condition separately. Wide field of view (adj. $M = 433.86$, $SE = 20.16$) resulted in greater area proportion error when compared to narrow field of view (adj. $M = 402.91$, $SE = 20.35$). To gain a better understanding of the impact of field of view, it was necessary to look closer at the accuracy of individual width and length ratios for over and underestimation.

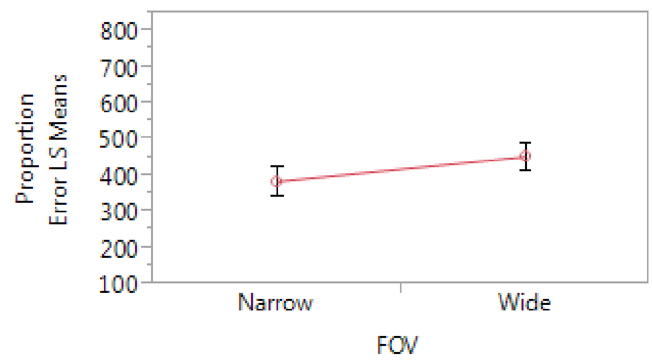

Figure 33: Significant main effect for field of view on area proportion error.

4.6.2.2 Area Ratio

Area ratio was calculated to better interpret the results of area proportion error, by providing a sense of over or under estimation for the scored area of the cognitive maps. The area ratio was calculated by taking the participant's calculated area scores and dividing them by the actual area dimensions. The resulting ratio was used as a measure of over or under estimation where < 1 is underestimation and > 1 is over estimation. An ANCOVA was conducted on area ratio controlling for object error as a covariate.

For area ratio, there was a near significant main effect of field of view when controlling for object error, F (1, 106) = 3.42 $p = 0.07$, partial $\eta^2 = 0.03$, see Fig. 34. The results also indicated that *object error* was significantly covaried with *area ratio*, $\beta = -0.03$, $t(106) = -3.50$, $p = 0.001$. While this finding only achieved near significance, it shows the overall area was slightly more accurate in wide field of view (adj. M = 1.01, S.E. = 0.03) condition when compared to narrow field of view (adj. M = 1.08, S.E. = 0.03).

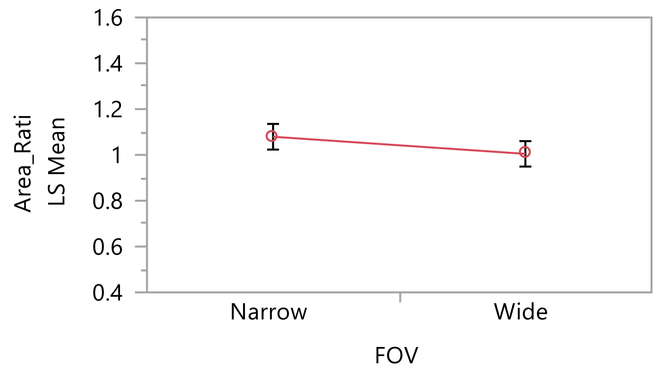

Figure 34: Near significant main effect for FOV on area ratio.4.6.2.3 Width Ratio

In order to better understand the error in area proportion error and area ratio, the ratio for width estimates was calculated by dividing the participant's width scores from the cognitive maps by the actual width. The resulting ratio was used as a measure of over or under estimation where < 1 is underestimation and > 1 is over estimation. Width ratio was tested using an ANCOVA while controlling for J-Graph mean depth.

For width ratio, there was a near significant interaction between field of view and navigability when controlling for J-Graph MDn, F (1, 106) = 3.81 p = 0.05, partial $\eta^2 = 0.04$, see Fig. 35 The results also indicated that *J-Graph mean depth* significantly covaried with *width ratio*, $\beta = -0.04$, $t(106) = -8.21$, $p < 0.001$. For high navigability, there were slight differences between wide (adj. M = 1.05, S.E. = 0.22) and narrow (adj. M = 1.01, S.E. = 0.22) field of view as both conditions overestimated. However for the low navigability condition there was a noticeable difference between wide (adj. M = 0.98, S.E. = 0.22) and narrow (adj. M = 1.02, S.E. = 0.22) field of view. For low navigability, wide field of view underestimated while narrow field of view overestimated. While this finding only achieved near significance, it shows that with a higher navigability, participants tend to overestimate the width of the spaces they are in.

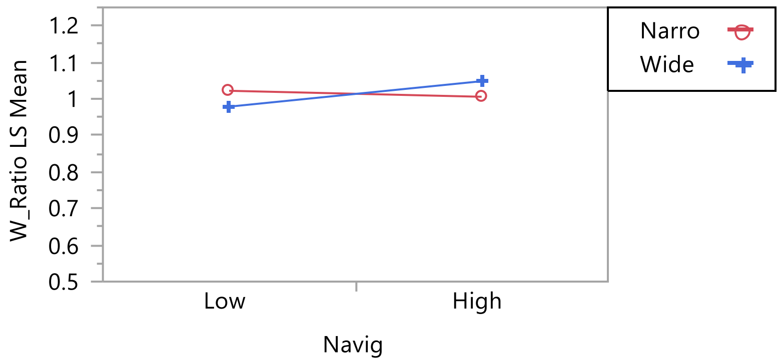

Figure 35: Near significant interaction between FOV*navigability on width ratio.

Wide field of view was the significant manipulation driving the interaction effect, see Table 13.

Table 13: Simple effects interaction contrast for width ratio.

	df	F	Partial η^2
Narrow FOV	1	0.272	0.003
Wide FOV	1	5.005*	0.045
Low Nav	1	1.955	0.018
High Nav	1	1.855	0.017
Error	106		

*significant at the p < 0.05.

4.6.2.4 Length Ratio

Again, in order to better understand the error in area proportion error, the ratio for length estimates was calculated by dividing the participants measured length score by the actual score. The resulting ratio became a measure of over or under estimation with anything < 1 being under estimation and anything > 1 being over estimation. Length ratio was tested using an ANCOVA while controlling for object error.

For length ratio, a significant main effect for field of view was found when controlling for object error, $F(1, 106) = 4.91$ $p < 0.05$, partial $\eta^2 = 0.04$, see Fig. 36. The results also indicated that *object error* significantly covaried with *length ratio*, $\beta = -0.03$, $t(106) = -4.84$, $p < 0.001$. Length estimation was slightly more accurate in narrow field of view (adj. M = 0.98, S.E. = 0.02) condition when compared to wide field of view (adj. M = 0.91, S.E. = 0.02).

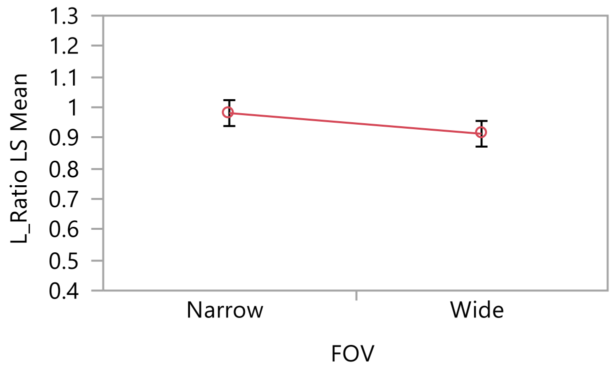

Figure 36: Significant main effect for FOV on length ratio.

4.6.2.5 Layout Score

An ANCOVA was conducted on layout score while controlling for object error and cued room error. Layout score was a measure of spatial task performance which looked at the cognitive maps drawn by participants to see if seven rooms were in the correct locations and orientation. The higher the score the more accurate the cognitive map layout when compared to the actual floor plan.

For layout score, a significant main effect for field of view when controlling for object error and cued room error was found, F (1, 105) = 7.19 $p < 0.01$, partial $\eta^2 = 0.06$, see Fig. 37. The results also indicated that *object error* significantly covaried with *layout score*, $\beta = -0.21$, $t(106) = -5.40$, $p < 0.001$. The findings indicate the narrow field of view (M = 7.04, S.E. = 0.15) produce better layout scores than the condition with the wider field of view (M = 6.45, S.E. = 0.15).

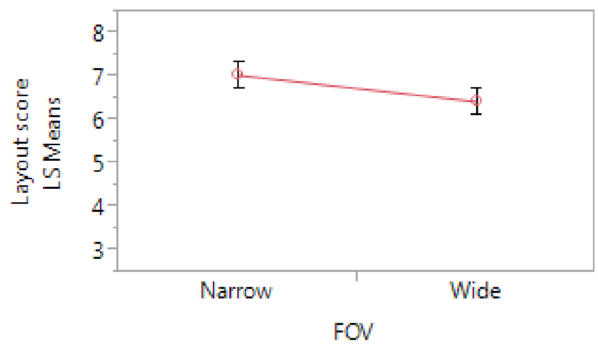

Figure 37: Significant main effect for FOV on layout score.

4.6.2.6 Object Memory

An ANCOVA was conducted on object memory controlling for familiarity with 3D devices and video games. Object memory was a measure of spatial recall where participants where participants were asked to match pictures of the objects to screenshots of the office rooms. The measure was defined as the number of errors made in matching the objects.

For object memory, a significant main effect for FOV when controlling for familiarity with 3D devices and video games was found, $F(1, 106) = 7.58$ $p < 0.01$, partial $\eta^2 = 0.07$, see Fig. 38. The results also indicated that *3D familiarity* significantly covaried with *object error*, $\beta = -0.49$, $t(106) = -2.97$, $p < 0.001$. The findings for the significant main effect for field of view indicate that fewer errors were made in the wide field of view condition (M = 4.79, S.E. = 0.36) compared to the narrow condition (M = 6.21, S.E. = 0.36).

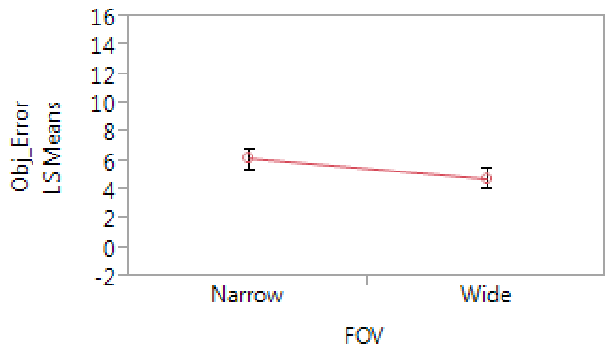

Figure 38: Significant main effect for FOV on object memory.

4.6.2.7 Cued Route Recall

An ANCOVA was conducted on cued route recall while controlling for area proportion error and object error. Cued route recall was a measure of spatial recall that used screenshots of the stimulus to cue participant's memory on the route taken through the office space. Two covariates were used in this ANCOVA, area proportion error as well as object error.

For cued route memory, a significant main effect for FOV was found when controlling for proportion error and object error, $F(1, 105) = 5.10$ $p < 0.05$, partial $\eta^2 = 0.05$, see Fig. 39. The results also indicated there were no significant covariates for *cued route recall*. The findings suggest that with a wider field of view (adj. M = 4.43, S.E. = 0.32), the more accurate the cued recall of the route was when compared to the narrow field of view (M = 3.39, S.E. = 0.32).

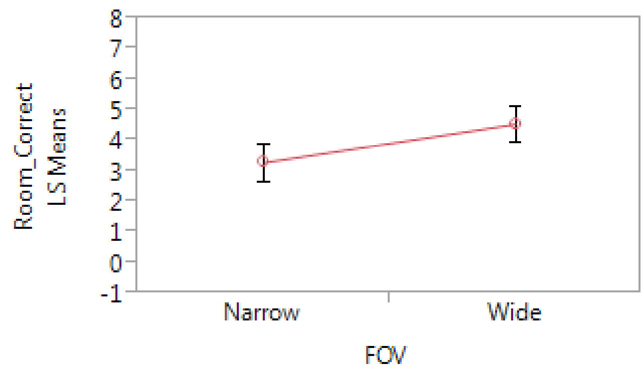

Figure 39: Significant main effect for FOV on cued route recall.

4.6.2.8 Spatial Understanding Summary

Several individual ANCOVAs were conducted on the seven measures of spatial understanding and covariates, see Table 14.

Table 14: ANCOVAs for spatial understanding measures and covariates.

Source	df	Area Proportion Error *F*	Area Ratio *F*	Length Ratio *F*	Width Ratio *F*	Layout Score *F*	Cued Room Recall *F*	Object Error *F*
Covariates								
Object Error	1	26.93**		23.45**	-	29.18**	1.56	-
J-Graph MDn	1	-		-	67.37**	-	-	-
3D Familiarity	1	-		-	-	-	-	8.79*
Proportion Error		-		-	-	-	2.53	-
Room Correct		-		-	-	1.43	-	-
Main Effects								
Stereo	1	0.464		0.11	0.28	1.00	1.99	0.01
FOV	1	5.45*		4.91*	0.00	7.19*	5.10*	7.58*
Navigability	1	2.26		0.64	1.44	0.01	0.56	0.31
Interactions								
Stereo*FOV	1	0.22		0.07	1.05	1.32	1.82	0.31
Stereo*Nav	1	1.33		1.75	1.00	0.23	0.58	0.85
FOV*Nav	1	0.01		0.51	3.81(*)	0.10	0.59	0.03
Stereo*FOV*Nav	1	1.90		0.01	0.26	0.97	0.01	1.30
Error	105	(2420031.60)		(2.67)	(1.477)	(133.05)	(570.11)	(801.82)

Note: Values enclosed in parentheses represent mean square errors. *significant at the $p<0.05$, **significant at the $p<0.001$, (*) near significant $p < 0.05$.

4.6.2.9 Hypotheses Set II: Spatial Understanding

The results of each of the individual ANCOVAs should be considered together to address the study's hypotheses. Eight hypotheses were posed to predict the influence of visual immersiveness and navigability on spatial task performance and spatial recall:

- H2: **Greater levels of visual immersiveness will improve spatial task performance**
    - H2:A: Stereoscopic virtual environment will result in improved spatial task performance than non-stereoscopic virtual environment
    - H2:B: Wider field of view will result in improved spatial task performance than narrow field of view
- H3: **Greater levels of visual immersiveness will improve spatial recall**
    - H3:A: Stereoscopic virtual environment will result in improved spatial recall than non-stereoscopic virtual environment
    - H3:B: Wider of field of view will result in improved spatial recall than narrower field of view
- H5: **Greater navigability will improve spatial task performance**
- H6: **Greater navigability will improve spatial recall**

Overall, the results do not support for H2 (greater levels of visual immersiveness will improve spatial task performance). These findings are in light of each measure of spatial task performance showing field of view to be significant but with narrow field of view improving spatial task performance. The fact that wide field of view did not improve spatial task performance does not support H2:B (wider field of view will improve spatial task performance). Lastly, H2:A (stereoscopy will improve spatial task performance) was not supported as stereo was not significant for any of the spatial task performance measures.

There was however partial support for H3 (greater levels of visual immersiveness will improve spatial recall). A wider field of view was found to improve spatial recall measures. This finding also supports H3:B (wider field of view will improve spatial recall). However, again stereo was not found to be significant on any of the spatial recall measures which does not support H3:A (stereoscopy will improve spatial recall).

Similar to the findings with stereoscopy, navigability was found to have no significance on either spatial task performance or spatial recall. There was no support for H5 (greater levels of navigability will improve spatial task performance) though one measure had a near significant interaction between navigability and field of view. This interaction effect though showed that greater navigability did not improve spatial task performance. Lastly, there was no support for H6 (greater levels of navigability will improve spatial recall). There were no significant findings of navigability on either spatial recall measure.

Overall, field of view influenced spatial understanding both dimensions. But the findings should be considered in light of how field of view influenced each measure. For spatial task performance, field of view did not always perform as predicted with narrow field of view showing more accuracy. For spatial recall however, field of view performed as predicted with a wider field of view improving both measures.

CHAPTER 5 – DISCUSSION

This chapter will first summarize the results of the analysis and then discuss interpretation and implications of findings from the analysis. Then theoretical and methodological contributions to virtual reality research and practical implications for architectural visualization and related disciplines will be discussed. The chapter will conclude with limitations of this study and future research directions.

5.1 Summary of Results

The analyses indicated that overall, the manipulation of field of view had a significant impact on various dimensions of spatial presence and spatial understanding. As predicted, a wider field of view did lead to a stronger sense of *spatial presence*. But the findings of field of view on *spatial presence* should be considered in light of the significant interactions that occurred between field of view and the other two manipulations, see Fig. 40. Individual analysis of each *spatial presence* dimension revealed that while field of view had a significant influence across the board, its impact often depended on stereoscopy or navigability. In all cases with the exception of *possibilities for action* dimension, a wider field of view accounted for higher feelings of *spatial presence* in each dimension. But the combined effect with navigability showed that a greater level of navigability actually reduced the need for a wide field of view. This finding partially supports the prediction that a greater level of navigability will increase spatial presence. For *possibilities for action*, the interaction of field of view and stereoscopy showed that a greater level of field of view generated higher feelings of presence. Stereoscopic display when compared to non-stereoscopic display increased spatial presence when field of view was narrow. This partially supports the prediction of greater levels of stereoscopy increasing spatial presence.

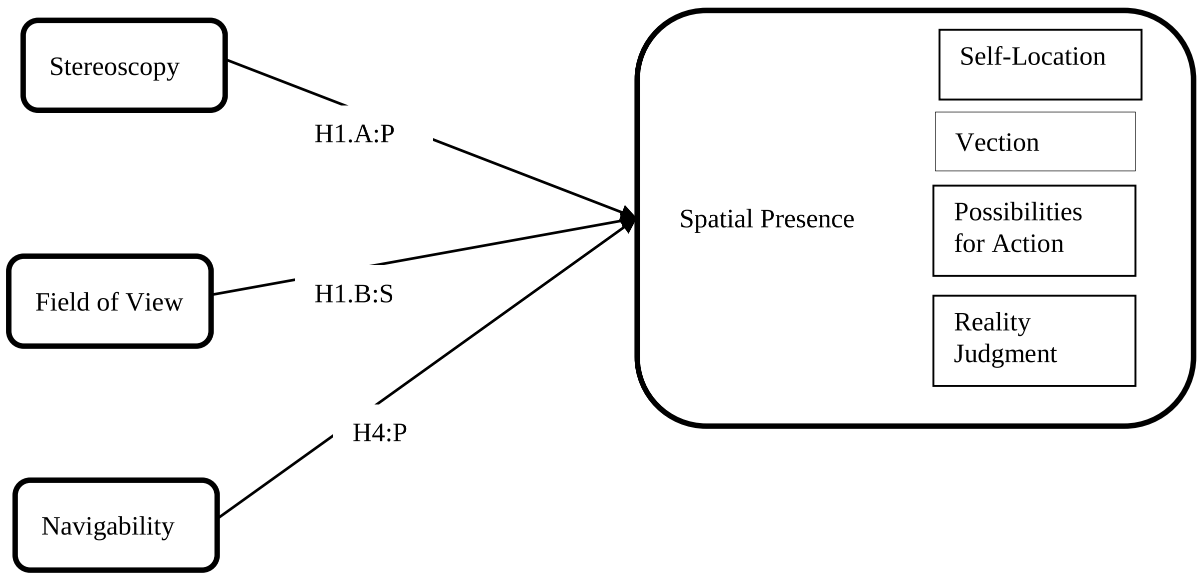

Figure 40: Hypotheses for spatial presence (P - partially significant, S - significant).

Looking at the *spatial understanding* dimensions, field of view again played a significant role but not always as predicted, see Fig. 41. In breaking down the results of spatial understanding, a wider field of view adversely impacted all aspects of *spatial task performance* compared to what was predicted. It is important to note that field of view impacted the two categories of spatial tasks in opposite ways. For the *spatial configuration task*, a wider field of view negatively influenced the results. With the *spatial recall tasks* (object matching and route knowledge), a wider field of view positively influenced the results. Stereoscopy was found to have no significant influence on spatial understanding measures contrary to the predictions in the hypotheses that stereoscopy would increase spatial understanding when compared to non-stereoscopic conditions. *Navigability* played a small role in influencing the spatial understanding dimensions, but not as predicted. Navigability had no significant influence on spatial recall contrary to the hypothesized prediction.

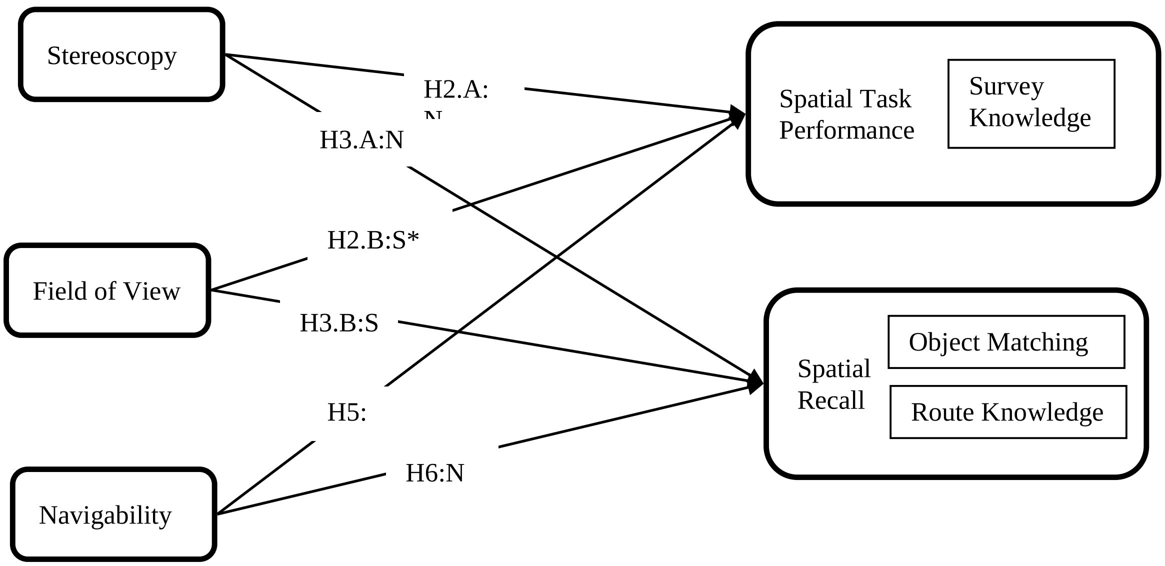

Figure 41: Hypotheses for spatial understanding (S - significant, S*-significant but opposite to predicted, P - partially significant, N - no significance).

5.2 Interpretation of Results

In light of the findings, insight can be gained from the interpretation of the significant and insignificant influences of each of the technology affordances (stereoscopy, field of view, and navigability) on each of the dependent variables (spatial presence, spatial task performance, and spatial recall). These insights can help to inform an understanding of the relative impact of each technology affordance on the outcome variables and how it ties back to previous studies. These interpretations also tie back into the overall relationship that exists between the constructs of immersion and interactivity with spatial experience and spatial understanding.

5.2.1 Impact of Visual Immersiveness on Spatial Experience

The findings from the analysis confirmed that visual immersiveness did significantly impact perceptions of spatial experience with the exception of one dimension, *self-location*. In the literature, it is speculated that manipulations of visual immersion alone would enrich but, not establish a sense of presence (Wirth, et al., 2007). This idea suggests that influences of interactivity should also exist as they relate to Dalgarno and Lee (2010)'s 'interactive capabilities'. The results from this study indicated that visual immersiveness alone was sufficient in influencing spatial experience when controlling for gender and attention. Looking closer at the manipulations of visual immersiveness, when field of view was wide, feelings for each *spatial presence* dimension increased except for self-location. Adversely, stereoscopy had little to no role in impacting *spatial presence*. This suggests the immersive experience is not dependent on a higher/lower level of each affordance.

Spatial presence is about establishing the experience that one feels present within a simulated space (Schubert, Friedmann, & Regenbrecht, 1999). Wirth et al. (2007) established this sensation occurs due to attention allocation and being able to block out the real-world. A wider field of view is able to occupy more of an individual's periphery vision, thus blocking out the immediate physical environment to keep focus on the virtual space. Stereoscopy only provides an added illusion of depth and therefore does not provide the same ability in maintaining user focus on the virtual space.

Of the measures of spatial experience, *self-location* was found to not be significantly influenced by either measure of visual immersiveness. Interestingly, there was a near significant influence from stereoscopy though the mean differences between the stereo and non-stereo groups were small. Stereoscopy provides visual depth cues to existing images (Crone, 1992). Self-location is the feeling of being located within a simulated space (Wirth, et al., 2007). It was speculated that from its shared characteristics with embodiment that *self-location* was dependent on the perception of sensory cues to develop an 'image schemata'. It is also important to note that stereoscopy is only one of many depth cues. In an interactive, highly navigable VR environment, an abundance of other depth cues are present reducing the necessity for stereoscopy, hence only the near significance of stereoscopy.

The connection between stereoscopy and *self-location* is dependent on the use of visual depth cues to enhance image schemata which, leads to a higher sense of *self-location*. Again with this finding it is also important to consider controlling for attention which, would have allowed the visual depth cues provided by stereoscopy to be more prominent. Overall, the findings of significance of field of view and near significance of stereoscopy support earlier findings of the influence of visual immersion on spatial presence (IJsselsteijn, et al., 2001). Each technology feature (field of view and stereoscopy) impacts spatial experience in a different way and these differences should be considered when attempting to achieve a certain type of spatial experience.

Possibilities for action, the dimension of spatial presence focused on users feeling as 'active participants' in a virtual environment, was speculated to have an interactive effect between manipulations of immersion and interactivity. This was due to the nature of the 'active participant' being connected to movement of the body (Glenberg, 1997). The findings of this study though found a significant interactive effect for field of view and stereoscopy when the main effects for each affordance was not significant. Subsequently, there were no significant influences from interactivity. This suggests that other factors may have played a role in raising user perceptions of *possibilities for action*. The significance occurred when controlling for class standing, experience with 3D software, and enjoyment.

Possibilities for action are reported as higher when there is suppression of the influence of the immediate real world on perceptions of the virtual environment and focus is placed on visual cues from the simulated space (Wirth, et al., 2007). This requires focused attention to the virtual environment but also mechanisms to aid in filtering out the real world. It is known that both field of view and stereoscopy are capable of helping user's focus attention on the simulated environment by filtering out the immediate physical environment (Hendrix & Barfield, 1995). In the case of the findings from this study, a wider field of view increased *possibilities for action*, meaning it was able to block out more of the real world supporting this notion. In doing so though, stereoscopy became less necessary. This result again supports the idea that technology affordances of visual immersiveness can work independently from one another.

Field of view is able to help suppress the outside world in two ways: 1) by providing more visual cues at any given time and 2) to fill more of the peripheral view reducing the amount of external visual distraction. Through the interactive effect the opposite effect occurred when field of view was narrow and stereoscopy compensated for increased user experiences for possibilities for action. This could be due to the visual depth cues described by Crone (1992). With a narrow field of view though visual depth cues may not be enough to keep a user's attention focused on being active in the virtual environment.

5.2.2 Impact of Visual Immersiveness and Interactivity on Spatial Presence

Exploration of the other dimensions of spatial presence revealed significant interactions between field of view and navigability. Specifically, the interaction effect was significant for self-location, vection and reality judgment.

5.2.2.1 Self-location

Results for *self-location* revealed a difference from the overall model which, indicated a near significant influence of stereoscopy. The results for *self-location* showed a significant interaction effect for field of view and navigability. Again self-location is the sensation of being located in a simulated space (Wirth, et al., 2007). Field of view influences self-location through the ability to increase the amount of visual cues by enlarging the scale of what can be seen in the virtual environment. Therefore, when navigability was low, a wider field of view produced slightly higher feelings of self-location. Navigability impacts spatial presence through the ability to control the manipulation of viewpoints (Sheridan, 1992). So when field of view was narrow, a higher navigability offered more control over the viewpoints which increased the feeling of self-location.

5.2.2.2 Vection

A near significant interaction between field of view and navigability was found for the ancillary dimension of *vection*. Vection is the illusion of self-motion (Schulte-Pelkum, et al., 2003). The connection between both field of view and navigability with vection can be speculated to be based on the perception of visual cues of motion. Where the visual cues come from a wider field of view and motion comes from navigability. In the case of this study, the findings indicated that a wide field of view elicited stronger feelings of vection when navigability was low. This suggests that a wider field of view results in an increased optic flow, creating the sensation of self-motion within the virtual environment as described Riecke (2011). This suggests that visual cues from just the basic motion of the low navigability condition provided a sense of self-motion. When navigability was high though, experiences for wide and narrow field of view were similar. This suggests that added control over motion in a virtual environment makes little distinction over the number of visual cues from the display size. Lastly, the non-significant finding for stereoscopy is consistent with earlier studies and can be speculated to be due to large number of spatial cues in a large-screen interactive virtual environment when compared to non-interactive, small-screen virtual environments (IJsselsteijn, et al., 2001).

5.2.2.3 Reality Judgment

Reality judgment was the last spatial presence dimension explored in this study. A significant interaction effect between field of view and navigability was found. Reality judgment is the acceptance of what is perceived as being real (Baños, et al., 1999). In order for simulated space to be perceived as ‘real’ certain cues need to be portrayed to a user. These cues need to enhance the congruency of the virtual space to the physical space it is attempting to portray. The virtual environment also needs to suppress any cues that would suggest the non-real nature of the virtual space. In this study field of view enabled the virtual environment to block out the real world as the field of view widened. This reduced the cues that from the immediate physical environment which were highly incongruent with the virtual environment.

Cues that enhanced congruency between the simulated and physical space were found in the navigability condition. The ability to tilt head up and down like in the real world and feelings of self-motion were able to increase the congruency of the virtual office space experience with a real office space. As a result, low navigability and a wide field of view resulted in improved reality judgment. As navigability increased though, there was less distinction between wide and narrow field of view. To better understand the connection between reality judgment and navigability, it is necessary to consider the link between navigability and spatial presence. Similar to vection, reality judgment could be influenced by the amount of control provided to the user by the navigability condition, but could also be adversely affected by the skill level of the user. This suggests that navigability and field of view could both increase reality judgment but through different means. Field of view blocked out incongruencies of the immediate physical environment while navigability included congruency between the virtual and physical space being portrayed. This study specifically showed that to increase reality judgment a combination of the two VR system variables was necessary.

5.2.3 Visual Immersiveness on Spatial Understanding

Visual immersiveness was found to significantly influence spatial understanding while interactivity had no significant influence. First, the insignificance of interactivity on spatial understanding could be attributed to how information is received and comprehended in the real world, which is mostly through visual and auditory means. While interaction itself may play a role in obtaining spatial information, visual and auditory processes can function at comprehending information without the need for movement as discovered in the study conducted by Balakrishnan et al. (2012).

Second, the significant impact of *visual immersiveness* was driven mainly by field of view. The stereoscopy manipulation had no significant impact on spatial understanding measures. Similar to the rationale for the role of visual immersiveness on spatial experiences, attention and the ability to block out the real-world could help negate the effects of stereoscopy on spatial understanding. Another reason why stereoscopy did not attain significance could be due to type of task utilized, an object search task. Added depth may not have aided locating objects in the space whereas a wider view could. Considering visual immersiveness as the outcome of independent technology factors as described in the spatial experience section, it is necessary to examine the relationship of spatial understanding measures with visual immersiveness closer.

5.2.3.1 Spatial Task Performance

Although not significant, interactivity could have impacted how visual immersiveness influenced *spatial task performance*. First, only field of view was found to significantly influence spatial task performance but, not as the hypotheses originally predicted. Spatial task performance included several measures focused on measuring configurational knowledge based on participant exploration. The measures of configurational knowledge found to be significantly influenced by field of view included area proportion error, area ratio, length and width ratios, and layout accuracy. On all measures of configurational knowledge, field of view adversely influenced accuracy meaning that a wider field of view produced more errors. These findings could be considered to show that survey knowledge was not completely developed during navigation of the space as predicted.

Looking closer at each measure, the mean differences were not large between the field of view conditions except for area proportion error. This could be due to the multiplying effect of length and width scores forming the overall area proportion score. Looking at the area ratio differences, a wider field of view actually showed better accuracy than a narrow field of view. Individually, the findings of width and length ratios (indicators of over or underestimation) better supported the idea that a wider field of view is known to cause scaling issues found in the area proportion error. Stanney et al. (2013) pointed out that optic flow motion cues can lead to overestimation of distances, suggesting that proprioceptive motion cues were better suited for better interpretation of spatial information.

The findings for space estimation also differ from previous research which, looked at the accuracy of dimensions from a single room and found a wider field of view to associate more with overestimation (Balakrishnan, et al., 2012). A possible explanation could be due to the incorporation of interactivity as part of the search task. In the low navigability condition, the participant was limited and the viewpoint perspective was always level. Even though the implementation of high navigability condition mimicked real-world head movements, an important point needs to be noted. In the real world our heads are able to move and the representation of space is not perceived as distorted in our brains. However, an interactive virtual environment attempting to mimic real world head motions can create a slight distortion depending on the viewpoint. This was the case in this study where participants found it challenging to re-align the viewpoint after using the head-tilt manipulation, possibly causing a distorted view of the space. Alternately, for length over and under estimation, a wider field of view was found to associate with underestimations of the spaces. The differences in the findings from this study and previous studies could be due to the nature in which individuals were able to gather spatial information. In the Zikic (2007) study, the simulation was paused and participants were asked to estimate the still space.

There are two key differences between these studies: 1) participants were asked to fill in estimations in individual spaces directly after experiencing them, and 2) movement was paused to allow for participants to estimate the spaces. This presents an important methodological challenge when including visual immersiveness and interactivity in the same study. When visually immersed, pulling a viewer away from the simulation to momentarily fill out a question could reduce the overall accuracy by pulling the user out of the experience of the space. The issue of interactivity however, may increase accuracy but, will not be seen as a realistic behavior within the space. An individual may stop to take in the details of a virtual space when conducting a task but, to be forced to stop may become less natural.

5.2.3.2 Spatial Recall

The findings of the influence of field of view on *spatial recall* confirmed the prediction that a wider field of view would improve recall accuracy. The findings should be considered in light of the measures that comprised spatial recall: object memory and route memory. Both measures were found to be positively influenced by a wider field of view but, only when controlling for different factors. In the case of object memory, familiarity with 3D and video games was a significant covariate. Removing the influence of an individual's familiarity with 3D and video games allowed for the findings of field of view to be more prominent. Considering the role of field of view, with a wider field of view, more of the space was visible to the viewer at one time allowing for better associations of the object to each space to be made.

For cued route memory, object memory was controlled as a significant covariate. As the participants were focused on the object locating task, attention and focus were placed on locating the objects. By accounting for the influence of attention to the object finding task, the individual influences of field of view on cued route memory became clearer. Similar to the findings with object memory, with cued route recall, a wider field of view allowed for more of the spaces to be seen at any given time providing more spatial cues to be presented to the participant. The more spatial cues presented could provide a base for participants to generate landmarks for remembering spaces. This allowed for easier processing of remembering of the route taken to visit each of the spaces.

In the literature, navigation tasks for gaining route knowledge were found to be successful with concurrent tasks. Wen et al. (2013) found there was no significant trade-off between concurrent task types based on whether it was visual, verbal, or spatial when developing route knowledge. This suggests that while searching for the objects, the participants were able to generate a mental map that better allowed for memory of the route taken to find the objects. In this study, there was no significance for the free recall of route. This could be attributed to the free recall of the route being dependent on the participant to successfully construct the configurational knowledge of the space in their cognitive maps.

5.3 Theoretical Implications

The immersive experience provided through technology components of a virtual reality system have been confirmed to have an impact on spatial experiences and how well people understand the virtual environment. The findings of the study provide a few theoretical contributions.

Research in spatial presence has built on the model developed by Wirth et al. (2007).The two-step process proposed by Wirth et al. (2007) suggests that spatial cues from various sources influence the development of a spatial situation model (SSM) which, then works to confirm the perceptual hypothesis, PERF hypothesis resulting in spatial presence. Balakrishnan and Sundar (2011) though found that with a high fidelity environment there is less need for SSM to generate a sense of spatial presence. Other means such as steering control can provide low-level sensory cues which affect spatial presence without the need for a SSM. This was speculated to be due to virtual environments offering direct spatial cues and dynamic feedback so, the SSM was no longer necessary. Though this study did not examine the development of the SSM, the findings indicate the role of field of view on the different dimensions of spatial presence. This follows along the lines that when user's expectation is high, there is less need for supporting information to confirm the PERF hypothesis and when the expectation is low the opposite is true (Gregory, 1980). With a wider field of view, more of the real-world is blocked out, keeping user attention focused on the simulated environment and providing more visual cues, and increasing the expectation of the user. A narrow field of view however, had lower expectations and was supplemented with navigability to help improve the PERF hypothesis. These findings were consistent with previous research on the development of spatial presence through a more bottom-up process.

This study sought to investigate the development of spatial understanding as a function of technology affordances that create the immersive experience. The results confirmed the development of route knowledge and object-focused task performance were positively impacted by technology affordances. The development of configurational knowledge, survey knowledge, though was not confirmed and indicated an opposite effect. Research on the development of spatial knowledge in virtual environments have stated that survey knowledge can form rapidly and accurately (Colle & Reid, 1998) and from navigation (Labate, et al., 2014). A key difference between the studies is how participants are primed. In many of the studies on the development of spatial knowledge in virtual environments, participants were informed they needed to be aware of the space as either route or survey knowledge tasks were primary. In this study however, survey and route knowledge development were presented as secondary tasks to finding objects. This suggests that attention to dual tasks is split across what is primary and what is secondary. This notion supports the findings of Labate et al. (2014). Specifically, it follows along the lines that spatial knowledge is dependent on attentional allocation and working memory capacity. The findings from this study on primary versus secondary tasks to obtain and retain information tie back into Lang (2000)'s limited capacity model of mediated message processing. The limited capacity model states that people process perceived stimuli but the mental resources for processing are limited. This findings of this study support this idea that mental resources for encoding, storing and retrieving information for a primary task will influence any secondary tasks.

5.4 Methodological Implications

This study combined two approaches to examining virtual reality system technology, the variable-centered approach (Nass & Mason, 1990) and the mixed reality simulation approach (Laha, et al., 2013). The mixed reality simulation approach introduced a taxonomy of technology to be systematically manipulated. The variable-centered approach was used to examine the technology by its affordances. The combination of the two approaches allowed for clearer mapping of concepts to technology features leading to more precise measurement of influences of individual affordances.

Specifically, operationalizing the concepts that comprise the immersive experience into manipulatable affordances of technology allowed for a much more precise way to measure the relative impact of each technology feature. While the findings of this study indicated the impact of each technology affordance was significant, the overall influence was small in terms of the size of the effect. In any given VR system there is a large number of parameters which, cause the effect of any one parameter to be relatively small but still contributing to the overall experience. As a result, the findings produced a much truer reflection of the influence of the technology features when taking other related factors into consideration. Kalawsky (1998) sought to develop a model to drive a tool for measure factors contributing to presence. This tool suggested several factors existed pertaining to demand and supply of attentional resources, understanding of situation, information and technological features. These listed groupings of factors can include context, content, and individual differences which, all play a significant role in making the immersive experience successful. Using the combination of the two approaches allowed for those factors to be parsed out, helping with not only conceptual clarity but, also a cleaner experimental design to test each technology feature.

While the purpose of this study was the look more at theoretical aspects of virtual reality components, the combined taxonomy and variable-centered approach can prove useful to other experimental designs such as fractional factorial designs (i.e. screening designs). Specifically, this approach helps to simultaneously consider a large number of factors related to virtual reality systems including technological and psychological factors together. This aids in identifying relative contributions of a large number of factors and establish which factors have more impact than others. The methodological approach based on the variable-centered and mixed-reality approaches hold great potential for virtual reality research as well as system design.

5.5 Practical Implications

Three main practical implications can be drawn from this study. It has implications for architectural visualization and education, virtual reality system development, and for training programs.

5.5.1 Implications for Architectural Visualization

This study has practical implications for architectural visualization and design education. Specifically, the significant influence of field of view on not only spatial presence but, also spatial understanding holds benefits in understanding how people interpret their experiences in virtual environments and translate that to real-world knowledge, particularly on the issue of scale. The true benefit of the findings comes from how they can be adapted to improve how virtual reality systems are used as tools to experience and evaluate architectural spaces under design.

Virtual reality in architectural design and visualization is not a new phenomenon (Campbell & Wells, 1994). The rationale for incorporating virtual reality into architectural design and visualization comes from the ability to experience simulated spaces without having to build large scale physical prototypes that cost time and money and are not easily modified. Many of the early explorations of virtual reality systems being incorporated as computing tools for architectural design and visualization were impeded by the technology itself (i.e. slow frame rates, narrow fields of view, etc.). In many cases, the technology was found to inadequately handle the situation necessary for design to occur (Campbell & Wells, 1994). Advances in technology have aided in making virtual reality technology more robust and therefore, better able to handle information specific to architectural design and visualization.

Despite the improvements made to technology for architectural visualization, there is still little understanding of the influences on architectural design. Though not specifically focused on architectural design and visualization, Wann and Mon-Williams (1996) explored questions of how virtual reality technology influences sense of space and spatial perception through specific linkages like depth cues. In terms of understanding space, this study found the added depth cues from stereoscopy did not have any significant impact. This suggests that stereoscopy may not be as beneficial to understanding designed spaces when compared to other technology features like field of view. But to also consider that stereoscopy may have more of an additive effect to significant features of a virtual reality system like field of view (Schuchardt & Bowman, 2007). The findings from this study with the interaction effects on spatial presence support this idea.

As both architectural design and visualization center on the communication of designed space, a better understanding of the influence of immersion on user experience and performance measures can provide insight on design computing tool development.

Campbell and Wells (1994) discussed that immersion worked well in terms of facilitating an understanding of spatial qualities of spaces designed during different stages of the design process. This indicated that immersion could play a role in the understanding of virtual spaces. The findings from this study supported this notion that visual immersiveness did improve the understanding of virtual spaces when users attended to the task given.

The findings from the empirical testing of the two components of immersion (e.g. stereoscopy and field of view) provided insight on the individual and combined contributions to overall understanding of spatial qualities and more specifically spatial experiences. As virtual reality technology tends to be grouped as sets of components (i.e. varying screen sizes, stereoscopic projectors, different input devices, different image resolutions, etc.), understanding the influence of components individually as well as collectively can help in improving virtual reality systems for architectural design and visualization. In the case of this study, field of view did not improve overall survey knowledge but, it aided in route knowledge development. Looking at spatial experience though, field of view combined with stereoscopy and navigability aided in generating better spatial experiences, supporting the findings of Balakrishnan et al. (2012). This insight into virtual reality technology allowed for assessment of not only individual components but, also group effects of having multiple components in one system, which is closer to how actual virtual reality systems tend to work.

5.5.2 Implications for Virtual Reality Technology Development

The findings of this study hold practical implications for the design and development of virtual reality technology, specifically ones that rely on wide field of view. Virtual reality systems are both complex and very diverse in the technology that comprise them. Lately, newer and more affordable technology has tended to focus on key aspects of virtual reality systems. One such technology would be the Oculus Rift, an affordable head-mounted display (HMD) which is highly dependent on the aspects of field of view and stereoscopy to immerse users in video game play. The Oculus Rift utilizes the wide field of view offered by HMDs coupled with stereoscopy but, has low fidelity graphics in terms of resolution. This trade-off presents an opportunity for the findings of this study to help with the improvement of such systems. Systems like the Oculus Rift can greatly benefit from a better understand of key features of a virtual reality system. For instance, gaming devices may require different features to help improve the overall experience of a gamer, while a training simulator may require features which improve task performance and memory. Understanding the role of key technology affordances could help to improve different needs.

Looking closer at the dependent measures from this study, the combination of the three manipulations provided insight into the tradeoffs of using each for both spatial experience and understanding. So, a virtual reality system such as the Oculus Rift could benefit more with the understanding of how each individual feature works not only independently but, also collectively on spatial experiences. For instance, field of view combined with stereoscopy in this study was found to improve one dimension of spatial presence. However, it was the combination of field of view and navigability in this study that accounted for the rest of the dimensions of presence. Considering these findings, it can be suggested that improvements to the Oculus Rift could use findings like the ones from this study to improve the overall user experience.

5.5.3 Implications for Training Programs

This study also has practical implications for training programs involving both spatial experiences and spatial activities. Training programs that use simulation systems can roughly be grouped into two main categories: 1) ones that provide a spatial context that is more realistic for trainees to develop specific skills and 2) ones that help to develop spatial skills. Training programs that focus on the development of specific skills provide very specific scenarios such as how to use machinery. In these cases, the spatial context of the machinery and location of the user in the virtual space needs to be as realistic as possible as the simulation is meant as a direct replication of the real-world. Training programs that help users develop spatial skills on the other hand are not as dependent on realism. In cases of developing spatial skills, there is not necessarily a direct translation of say a specific layout of a building that may be on fire. Developing skills for traversing spaces that are on fire is meant to relate to different situations. The contributions of this study for training programs can then be considered from the perspectives of spatial presence and spatial understanding.

For training programs that use spatial contexts to help trainees develop specific skills, there is an aspect of 'believability' that becomes important. These training programs are highly dependent on user experience in order to increase believability in the simulated environment. These types of training programs include manufacturing operations training (Dorozhkin, Vance, Rehn, & Lemessi, 2012), surgical training (Beyer-Berjot & Aggarwal, 2013), and so on. The key aspect of these training programs is the specific focus on learning a skill and the simulated environment aids in the believability in accomplishing the task (Dorozhkin, et al., 2012). The findings from this study suggest that key features of a virtual reality system such as field of view play a large role increasing the sense of presence but, that it does not act alone. These findings for improving spatial presence could be used to improve the current systems for training without necessarily spending money on a top of the line system that may have features that do not actually impact spatial presence.

The other category of training programs focus on the acquisition of spatial knowledge to develop spatial skills. For training, the acquisition of spatial knowledge is meant to transfer beyond the technology medium into the real-world (Stanney, et al., 2013). This is a key difference where the contributions of this study come in. These training programs can be thought of in two ways: 1) focused on recall of spaces and 2) developing route and survey knowledge. The findings of this study suggest that field of view plays a large role in the recall from search tasks and routes. This is particularly useful for training programs such as fire fighter training where burn building simulations require not only quick development of route knowledge but to also search for people trapped inside. Building on the development of route knowledge, other training programs such as flight and ship simulators can benefit from how field of view could adversely influence precision of spatial knowledge development.

Overall, the findings of this study indicated that a wider field of view was necessary in the acquisition of route knowledge but had adverse effects on survey knowledge development. This key difference was speculated to have occurred due to the task type and the focus of the users. The main contribution for training programs is that visual immersiveness will increase spatial knowledge acquisition but within the context and nature of the task given to obtain that knowledge.

5.6 Potential Threats to Validity and Limitations of the Study

Several steps were taken in this study to help mitigate potential threats to validity and limitations. As with any research that takes place in a lab setting, there will be many limitations that apply to the design of the experiment and method of analysis. Research in human behavior simulation with virtual reality is no exception. Thinking about human behavior simulation, there are limitations which relate to different aspects: development, measurement, and equipment. Virtual reality, in general, tends to have some commonly listed limitations in the literature. These limitations have, for the most part, existed since virtual reality research first started (Psotka, 1995). Despite great progress made over the years with improvements to technology and practices, some limitations cannot always be easily overcome. The potential and critical limitations currently and in the foreseeable future include fatigue, simulator sickness, novelty, believability, and inferring generalizations from measurement.

Pretesting was performed on each of the different conditions for duration times in order to gauge an average time for fatigue. This helped establish more optimal durations for each step of the procedure (questionnaires, training session, etc.) including the experimental tasks. Determining optimal times to complete all steps of the procedure helped to potentially alleviate some frustration participants may have experienced.

Addressing simulator sickness is an aspect all studies utilizing virtual reality face (Draper, et al., 2001). There is no real way to overcome this threat aside from limiting the amount of exposure time and possibly identifying subjects who are susceptible to motion sickness before beginning the experiment. To help with this issue, participants were screened before and during the joystick training session for signs of simulator sickness.

To aid with the issue of novelty in being exposed to 3D technology, a short set of items were added to the demographics questionnaire to control for previous experience with the iLab technology in any capacity. Additionally, if users had been exposed to the iLab technology there were an additional set of three items to rate their experience by the frequency of their exposure to the technology.

One of the more critical limitations for human behavior simulation specifically is that of believability. Research in the area of human behavior simulation is concerned with replicating human reactions to specific events, activities or situations (Orr, Mallet, & Margolis, 2009). Even with high fidelity virtual environments, creating a believable experience is a challenge. As Psotka (1995) explained, users will always possess the knowledge that the illusion of the simulation is virtual (p. 409). This knowledge can therefore disrupt potential findings. Specifically, users may not behave as they normally would in the same event in the real-world. For instance, the use of the office setting without lots of smoke damage or a simulated ‘haze’ could have impacted the user’s belief the simulation was about visiting a space that was recently in a fire. Another way to perceive the office setting believability was by the brightness of the office space depicted by the projectors. The bright light of the projectors could also have negated the belief the office space had been in a fire. Another related aspect to this limitation is that measurement equipment could further disrupt the illusion of the simulation.

One last potential limitation could relate to lack of sufficient tools to capture and measure human behavior. This could lead to issues in inferring findings as generalizable results. Human behavior is linked to so many processes that researchers have no way of capturing to measure. For instance, presence is a measure that is highly studied in virtual reality research. Despite its intensive measurement over the years, some believe it is not entirely possible to measure (Slater, 2009). As a result, a lot of trust is put in the participant to accurately fill out questionnaires about his/her experience once it has happened. To overcome this limitation founded in self-report methods of measurement, some researchers look to more objective measures like brain waves, heart rate, and postural response (IJsselsteijn, et al., 2000). While more objective measures reduce the need to rely on user's to remember their experiences, there is another limitation. Objective measures only capture the behavior, not the mental processes that led to the behaviors. Again this leads to limitations in inferring that behaviors occur due to parts of the simulation. Brain waves (EEG) research and other areas in neuroscience are currently working towards developing objective measures which, could potentially reduce the limitation of objective measures but, the measurement tools are still not reliable enough at this point (Bohil, Alicea, & Biocca, 2011).

Looking at potential threats to the validity of this study, there was one threat to external validity in the form of statistical conclusion validity. The choice of analysis included an ANCOVA and MANCOVA. The statistical power of these tests may not have been enough as the effect sizes could be small based on the data provided by the sample size. This could have caused issues when trying to generalize findings (either significant or non-significant). It could also have caused issues when making inferences about the experimental condition's influence on the participant's overall experience. To help mitigate this, the design of the experiment sought at least 120 participants and generated experimental runs to randomly assign conditions. This helped with balancing the cell sizes of each condition which, helped to improve the statistical power of the two tests used for the analysis.

Lastly, there was a potential threat to construct validity is mono-method bias towards spatial presence. Spatial presence was measured using only a self-report questionnaire. As Slater (2009) indicated in his study, presence is typically not a directly measurable variable. This indicates that multiple measures may be better suited to identifying the experience of spatial presence. Using a pre-existing questionnaire that has been highly cited was one way of mitigating the issue of mono-method bias. Although multiple measures of spatial presence would produce more robust results, previous studies have utilized single self-report measures for spatial presence and have proven to valid (Balakrishnan & Sundar, 2011).

5.7 Conclusion & Future Directions

This study sought to investigate the influence of the immersiveness on spatial experience and spatial understanding. Specifically, the study looked at the constructs that made up the immersive experience: immersion and interactivity. From these two constructs, concepts of visual immersiveness and navigability were examined in terms of key technology affordances of a virtual reality system. The design of the study then looked specifically at three key technology features of a virtual reality system: field of view, stereoscopy and navigability. Based on the findings that within visual immersiveness field of view played a significant role in all the measures but, with adverse findings from what was predicted, further study should be conducted. To investigate possible reasons for the adverse findings, one possibility would be to look closer at the role of primary versus secondary tasks in development spatial knowledge.

Another direction for furthering this line of research is to take into consideration the existing taxonomy of display technology attributes created by Bowman and McMahan (2007). The existing taxonomy consists of several features yet to be fully tested within a virtual reality system. In addition to the two measures of visual immersiveness used in this study, there is strong evidence for other technology features such as level of detail, realism, head-tracking, and field of regard. Level of detail and realism have been examined and suggested to influence spatial knowledge in virtual environments (Stanney, et al., 2013). Further support for realism comes from the study conducted by Balakrishnan et al. (2012) where a photorealism versus hidden line manipulation was found to impact width estimations of a virtual environment. Head-tracking has been highly cited for its contributions to better self-location and influence on accuracy of spatial knowledge (Stanney, et al., 2013). Lastly, field of regard has been cited as an alternative manipulation to field of view as it encompasses more of the human peripheral vision thereby blocking out more of the real world (Bowman & McMahan, 2007).

This study only looked at a few key factors of virtual reality system that create a compelling spatial experience. Given the complex nature of virtual reality systems and the large number of parameters, further research is necessary. Testing more of these different attributes is necessary to gain a better sense of the overall impact of such technology on spatial experiences and understanding.

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APPENDIX A – EXPERIMENTAL PROCEDURE PROTOCOLS

Welcome & Overall instructions

Preparation

- Check with Bimal on iLab schedule for available times/days.
    - Start-up iLab system.
    - Have randomized conditions run for the day.
    - Have selected condition loaded on computer, minimized.
    - Have training environment loaded on computer, minimized.
    - Have a list of participant ID's ready for when participants arrive.
    - Check that 3D glasses are on and working for the Stereo conditions.
        - Have a back-up pair of glasses ready.
- Have copies of consent form ready to hand out.
- Have 2 questionnaires ready on clipboards.
    - Demographics
    - Presence and Spatial Memory
- Have a pen for participants and one for self with and an extra pen as a back-up.
- Have blank "In-Session Signs" and tape to place on iLab door once participants arrive.
    - Make sign inter-changeable for days/times to reuse.

On arrival of participants for a given session

- Greet the subjects.
- Show participants to their seats.
- Once participant is seated, shut the door and place In-Session Sign on iLab door with Time marked on it.

Script: *Thanks for coming in today. I really appreciate your participation in my study and if you can go ahead and please turn your phone off or put it on mute, we can get started.*

I am conducting this study to understand how virtual reality system set-ups impact user experience. After a brief questionnaire, you will be given a short training session on using a joystick in a virtual environment. When you have finished the training, you will then be able to navigate through the main virtual environment in order to complete a simple task. Once you have completed the given task, you will complete a second questionnaire about your experience and memory of the virtual environment. Overall, the study should take approximately 1 hour.

Informed Consent Form

- **Hand each participant a consent form.**
    i. **Go through the consent form – all points.**
- **Ask each participant individually if he/she agrees to consent and see if he/she has any questions.**
- **Be sure to indicate a copy of the consent form is for them to keep.**

General Instructions

Script: *For this experiment, I am interested in what you experience when you navigate through a virtual environment while completing a simple task in different conditions. In order to do this, I am going to provide you with a task to complete while moving around in a virtual environment. Following the task completion, you will be asked to complete a final questionnaire about your experience. Are you clear about what I want you to do?*

[Answer any questions]

Further Instructions

Script: *I do ask that you do not discuss this research outside of this room with others, as everything should remain confidential. Lastly, the questionnaires and main task are not a test, so please take this experiment in a relaxed manner. Nothing you do in this experiment will be used to judge you as an individual.*

- Hand out demographics questionnaire to participant.

Script: *To start, please fill out this brief questionnaire. Please do not write in the box on the top right corner.*

- Hand out pens once you have finished speaking.
- Once the participant has finished, collect the questionnaire and fill in the participant ID.

Training Instructions

Script: *Good, now I will have you go through a short training session to familiarize yourself with both virtual environments as well as using a joystick to move around.*

- Maximize the training environment (make sure the environment matches the specified condition).
- If condition is Stereo, provide 3D glasses just before allowing participant to move through environment.
    - Screen for potential motion sickness from experience with watching 3D movies.
        - If issue with 3D movies is indicated, move participant to next non-stereo condition.

Script: *Now please take a look at this diagram of how the joystick works.*

- Go through the joystick instructions.

Script: *Okay, now you will need to turn around and face the screen, making sure your chair fits in the box on the floor, you will need to hold the joystick in your lap.*

- Dim the lights as participant turns to face the screen.
- Explain details about moving with the joystick and have participant go through all basic movements, cautioning them about the speed.

Script: *Now please try moving around this virtual environment until you feel comfortable moving around the space.*

- Keep first attempt to 1-2 minutes, then provide direction to endorse the use of all joystick motions.

Script: *Good, now I would like you to move around the space looking for [specify object].*

- Continue training for 3-5 minutes as needed.

Script: *Okay, do you feel comfortable using the joystick to move around a virtual environment?*

- If the response is yes, move on to next step.
- If the response is No, provide extra guidance as needed. DO NOT GO BEYOND 10 minutes of training!
- Close training environment.

Experiment Instructions

Script: *Okay, now that you are comfortable with using the joystick, I am going to provide you with a simple task to perform in a different virtual environment.*

- Hand participant noise-cancelling headphones.

Script: *From this point on, you will need to follow the instructions provided in the following screens. I will be here to answer any questions you may have as well as to keep track of the time. If you need to stop at any time please let me know right away. You will have 10 minutes to complete the task, you will be notified when 10 minutes are up. After that turn around and you can begin filling out the last questionnaire. Are you clear on the task and are you ready to begin?*

- Start the Narrative PowerPoint slideshow.
- If Yes, then move to next step.
- If No, then clarify any questions then move to next step.
- Put final questionnaire and colored pencil on table behind participant.
- On the second to last slide, start the video camera recording.
- When slide show completes:
  - Open the office environment in the correct condition.

Script: *You may begin now.*

- Click the ESC key to start the timer.
- Make observational notes about path taken, issues or interruptions, and number of times the joystick manipulation is utilized.
- After 10 minutes are up, stop video recording.
  - If simulation does not end after 10 minutes automatically, let participant know time is up.
- Close virtual environment and narrative slideshow while participant fills out the questionnaire.
  - Load up the training environment for the next participant.

****Administer Questionnaire**

- If subjects are running late, check on the next participant and make sure he/she has time to complete the experiment.
- If next participant does not have time, move the previous participant to the side and begin with the next participant's debriefing.

Debriefing & Thank You !!

- On completion of the last portion of the questionnaire, **thank** the subjects for their participation; clarify any further questions regarding the experimental procedures, data analysis or use of data.
    - ***Script:*** *Thank you for your participation, and if you have any further questions, please feel free to contact me. Also, please remember this study is confidential so do not discuss it with others.*
- Collect questionnaires from table once participant has finished.
    - Mark the ID number for each participant in box on the questionnaire and file in the provided folder.
- Exchange sign on door if necessary for next participant.

Post Experiment Session

- Double check ID number is on the questionnaire for each participant.
- File the questionnaires.
- Close out all open programs and shut down computer if no other participants are expected.
- Check that all Stereo glasses are shut off and put away.
- Remove sign from iLab door.
- Lock up the following in Bimal's office Cabinet
    - Completed Surveys
    - Extra consent forms
    - Extra In-Session Signs
- Check sufficiency of all form types (consent forms, questionnaires, and In-Session Signs), pens and clipboards for next session / next day.
    - If insufficient, print required copies.

APPENDIX B – NARRATIVE POWERPOINT SLIDES

You are a firefighter in training who has been assigned to investigate an office that was evacuated due to a fire in the building. Several people were evacuated who left personal items behind. You will investigate the office space and locate but not collect these items.
You need to meet with the Fire Chief to learn what items should be located.


Let's see, it looks like when you go behind a wooden partition there's another office with one window and no door. Apparently, it's close to the front desk. There were several items left there:
• a laptop
• a camera
• and a hat


Next, you should find an unused office that connects to a large corner office with three windows. There are three glass walls shared with different spaces across both rooms. Between the two spaces look for:
• an iPad
• a toy rocket
• a purse
• and a box of crackers


According to our information there should be another corner office with one window and two glass walls. It sounds like it was near the restroom. That office had:
• a cellphone
• and a pair of sunglasses


Now, the last office is between the restroom and a corner office. It sounded like it was pretty narrow and had only one window. It was somewhere near the sitting area. Look for:
• a shoe
• and a hat


Well, that's all the information I have. Make sure you take mental notes when you find these items and be sure you remember where you found them so we can fill out the report when you finish.
Well, if you're ready, I'll take you up. I can only give you 10 minutes to search. I'll let you know when we need to leave.

APPENDIX C – DEMOGRAPHICS QUESTIONNAIRE

Condition No.______________

Please do not write in this box

Please complete the following questions:

1. Age: _______ years
2. Gender: ☐ Male ☐ Female
3. Academic standing: ☐ Freshman ☐ Sophomore ☐ Junior ☐ Senior ☐ Graduate
4. Academic major: ____
5. Are you an Architectural Studies student: ☐ Yes ☐ No
   a. If **Yes**, estimate how long you have been in the Architectural Studies program.

   I have ________ semesters experience being in the Architectural Studies program.
6. Please estimate your experience with 3d-modelling with computer aided design softwares (Rhino, AutoCAD, SketchUp, 3dStudio Max, etc) in general.

   I have _______months OR ________ years experience in 3d modeling with computer aided design software.

Please indicate how *familiar* you are with each of the following. Please circle a **single number** between 1 and 9 (where 1 = not at all familiar and 9 = very familiar).

1. How familiar are you with playing **video games on Xbox, Playstation, or Nintendo** consoles?

   Not at all familiar 1 2 3 4 5 6 7 8 9 Very familiar

2. How familiar are you with playing **personal computer (PC) games**?

   Not at all familiar 1 2 3 4 5 6 7 8 9 Very familiar

3. How familiar are you with playing **games on your mobile phone**?

   Not at all familiar 1 2 3 4 5 6 7 8 9 Very familiar

4. How familiar are you with participating in **3D online virtual worlds**? (For example: Second Life, Wonderland, etc.)

   Not at all familiar 1 2 3 4 5 6 7 8 9 Very familiar

5. How familiar are you with watching **3D movies**? (This can include theatres, IMAX, and 3D televisions)

   Not at all familiar 1 2 3 4 5 6 7 8 9 Very familiar

6. How familiar are you with working with **3D software packages**? (3D Studio Max, Maya, Lightwave, Blender, Rhino, etc.)

   Not at all familiar 1 2 3 4 5 6 7 8 9 Very familiar

Please rate your confidence level in using the following software: **(please circle a <u>single number</u>)**

Image Editing / Drawing Packages

Adobe Photoshop

Not at all confident 1 2 3 4 5 6 7 8 9 Very confident

Adobe Illustrator

Not at all confident 1 2 3 4 5 6 7 8 9 Very confident

<u>CAD / Modeling / Drafting Packages</u>

SketchUp

Not at all confident 1 2 3 4 5 6 7 8 9 Very confident

Autodesk AutoCAD

Not at all confident 1 2 3 4 5 6 7 8 9 Very confident

Autodesk 3D Studio Max

Not at all confident 1 2 3 4 5 6 7 8 9 Very confident

Autodesk Revit

Not at all confident 1 2 3 4 5 6 7 8 9 Very confident

Rhinoceros (Rhino 3D)

Not at all confident 1 2 3 4 5 6 7 8 9 Very confident

Autodeak Maya

Not at all confident 1 2 3 4 5 6 7 8 9 Very confident

Please indicate how well you identify with each of the following questions. Please circle a **<u>single number</u>** between 1 and 9 (where 1 = not at all and 9 = very much).

1. Do you easily become deeply involved in movies or TV shows?

   Not at all 1 2 3 4 5 6 7 8 9 Very much

2. How good are you at blocking out external distractions when you are involved in something?

   Not at all 1 2 3 4 5 6 7 8 9 Very much

3. How excited have you gotten during a chase or fight scene on TV or in the movies?

   Not at all 1 2 3 4 5 6 7 8 9 Very much

4. To what extent have you ever become so involved in doing something that you lose all track of time?

   Not at all 1 2 3 4 5 6 7 8 9 Very much

5. To what extent have you ever remained apprehensive or fearful long after watching a scary movie?

   Not at all 1 2 3 4 5 6 7 8 9 Very much

6. To what extent have you ever gotten scared by something happening on a TV show or in a movie?

   Not at all 1 2 3 4 5 6 7 8 9 Very much

7. To what extent have you ever had dreams that are so real that you feel disoriented when you awake?

   Not at all 1 2 3 4 5 6 7 8 9 Very much

8. To what extent have you ever become so involved in a daydream that you are not aware of things happening around you?

   Not at all 1 2 3 4 5 6 7 8 9 Very much

9. Do you frequently find yourself closely identifying with the characters in a story line?

   Not at all 1 2 3 4 5 6 7 8 9 Very much

10. To what extent have you ever become so involved in a movie that you are not aware of things happening around you?

    Not at all 1 2 3 4 5 6 7 8 9 Very much

11. To what extent have you ever become so involved in a television program or book that people have problems getting your attention?

    Not at all 1 2 3 4 5 6 7 8 9 Very much

Please indicate to what extent you agree or disagree with each of the following statements. Please circle a **<u>single number</u>** between 1 and 9 (where 1 = strongly disagree and 9 = strongly agree).

1. I am good at remembering routes I use to travel.

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

2. I can easily orient myself using a map.

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

3. I can give good directions.

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

Have you ever attended any presentations or have presented in the Immersive Visualization Lab (iLab) before?

☐ **Yes** ☐ **No**

If YES, please answer the following questions below. Please circle a **single number** between 1 and 9.

a. If **Yes**, how often have you been in the Immersive Visualization Lab (iLab) for presentations?

Very rarely 1 2 3 4 5 6 7 8 9 Very often

b. If **Yes**, how often was the technology in the iLab used for the presentations you gave or attended?

Very rarely 1 2 3 4 5 6 7 8 9 Very often

c. If **Yes**, how was your overall comfort level in presenting or attending a presentation in the iLab?

Not at all comfortable 1 2 3 4 5 6 7 8 9 Very comfortable

Thank you for completing this survey!

APPENDIX D – POST-TEST QUESTIONNAIRE

Condition No.________________
1 2 3 4 5 6 7 8
Please do not write in this box

Please indicate the extent to which you identify with the following statements that refer to your experience. Please circle a **single number** between 1 and 9 (where 1 = not at all and 9 = very much).

1. I devoted my whole attention to the office suite I just viewed.

   Not at all 1 2 3 4 5 6 7 8 9 Very much

2. I concentrated on the office suite I just viewed.

   Not at all 1 2 3 4 5 6 7 8 9 Very much

3. The office suite I just viewed captured my senses.

   Not at all 1 2 3 4 5 6 7 8 9 Very much

4. I dedicated myself completely to the office suite I just viewed.

   Not at all 1 2 3 4 5 6 7 8 9 Very much

5. I felt like I was actually there in the environment of the office suite I just viewed.

   Not at all 1 2 3 4 5 6 7 8 9 Very much

6. It was as though my true location had shifted into the environment in the office suite I just viewed.

   Not at all 1 2 3 4 5 6 7 8 9 Very much

7. I felt as though I was physically present in the environment of the office suite I just viewed.

   Not at all 1 2 3 4 5 6 7 8 9 Very much

8. It seemed as though I actually took part in the action in the office suite I just viewed.

   Not at all 1 2 3 4 5 6 7 8 9 Very much

9. I felt I could participate in the environment of the office suite I just viewed.

   Not at all 1 2 3 4 5 6 7 8 9 Very much

10. I felt I could have some influence on the environment of the office suite.

    Not at all 1 2 3 4 5 6 7 8 9 Very much

11. I felt like I could move around among the objects in the office suite I just viewed.

    Not at all 1 2 3 4 5 6 7 8 9 Very much

12. The objects in the office suite I just viewed gave me the feeling that I could do things with them.

    Not at all 1 2 3 4 5 6 7 8 9 Very much

13. I had the impression that I could reach for the objects in the office suite I just viewed.

Not at all 1 2 3 4 5 6 7 8 9 Very much

14. It seemed to me that I could have some influence on things in the office suite I just viewed, as I do in real life.

Not at all 1 2 3 4 5 6 7 8 9 Very much

15. It seemed to me that I could do whatever I wanted in the environment of the office suite I just viewed.

Not at all 1 2 3 4 5 6 7 8 9 Very much

Please indicate your level of agreement with each of the following statements. Please circle a <u>**single number**</u> between 1 and 9 (where 1 = disagree and 9 = agree).

1. I found viewing the office suite fun.

   Disagree 1 2 3 4 5 6 7 8 9 Agree

2. I enjoyed viewing the office suite.

   Disagree 1 2 3 4 5 6 7 8 9 Agree

3. Viewing the office suite was pleasant.

   Disagree 1 2 3 4 5 6 7 8 9 Agree

Please answer the following questions about your experience searching the office suite. Please circle a <u>**single number**</u> between 1 and 9.

1. Indicate your **experience** locating the <u>objects</u> in the office suite:

   Very frustrating 1 2 3 4 5 6 7 8 9 Very enjoyable

2. Indicate the **difficulty** in locating the <u>objects</u> in the office suite:

   Very difficult 1 2 3 4 5 6 7 8 9 Very easy

3. Indicate your **overall performance** locating the <u>objects</u> in the office suite:

   Very poor 1 2 3 4 5 6 7 8 9 Very good

4. Indicate your **experience** using the <u>joystick</u> to move around the office suite:

   Very frustrating 1 2 3 4 5 6 7 8 9 Very enjoyable

5. Indicate the **difficulty** in using the <u>joystick</u> to move around the office suite:

   Very difficult 1 2 3 4 5 6 7 8 9 Very easy

6. Indicate your **overall performance** using the <u>joystick</u> to move around the office space:

   Very poor 1 2 3 4 5 6 7 8 9 Very good

Please indicate to what extent you agree or disagree with each of the following statements. Please circle a **single number** between 1 and 9 (where 1 = strongly disagree and 9 = strongly agree).

1. My sense of movement inside the office environment was very compelling.

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

2. I could examine the objects in the office environment from multiple viewpoints.

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

3. My sense of movement inside the office seemed very natural.

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

4. I felt a compelling sensation of self-motion within the office environment.

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

Please indicate to what extent you agree or disagree with each of the following statements. Please circle a **single number** between 1 and 9 (where 1 = strongly disagree and 9 = strongly agree).

1. To what extent was what you saw in the virtual world similar to reality?

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

2. To what extent did you feel you "were" physically in the virtual world?

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

3. In your opinion, how was the quality of the images in the virtual world?

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

4. To what extent did you feel you "went into" the virtual world?

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

5. To what extent did the experience seem real to you?

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

6. To what extent did your interactions with the virtual world seem natural to you, like in the real world?

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

7. How real did the virtual objects seem to you?

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

8. To what extent what you experienced in the virtual world was congruent to other experiences in the real world?

   Strongly Disagree 1 2 3 4 5 6 7 8 9 Strongly Agree

Please provide directions to best of your ability to answer each question.

How do you get from the entrance to the large corner office that has three windows?

How do you get from corner office with one window to the desk behind the partition?

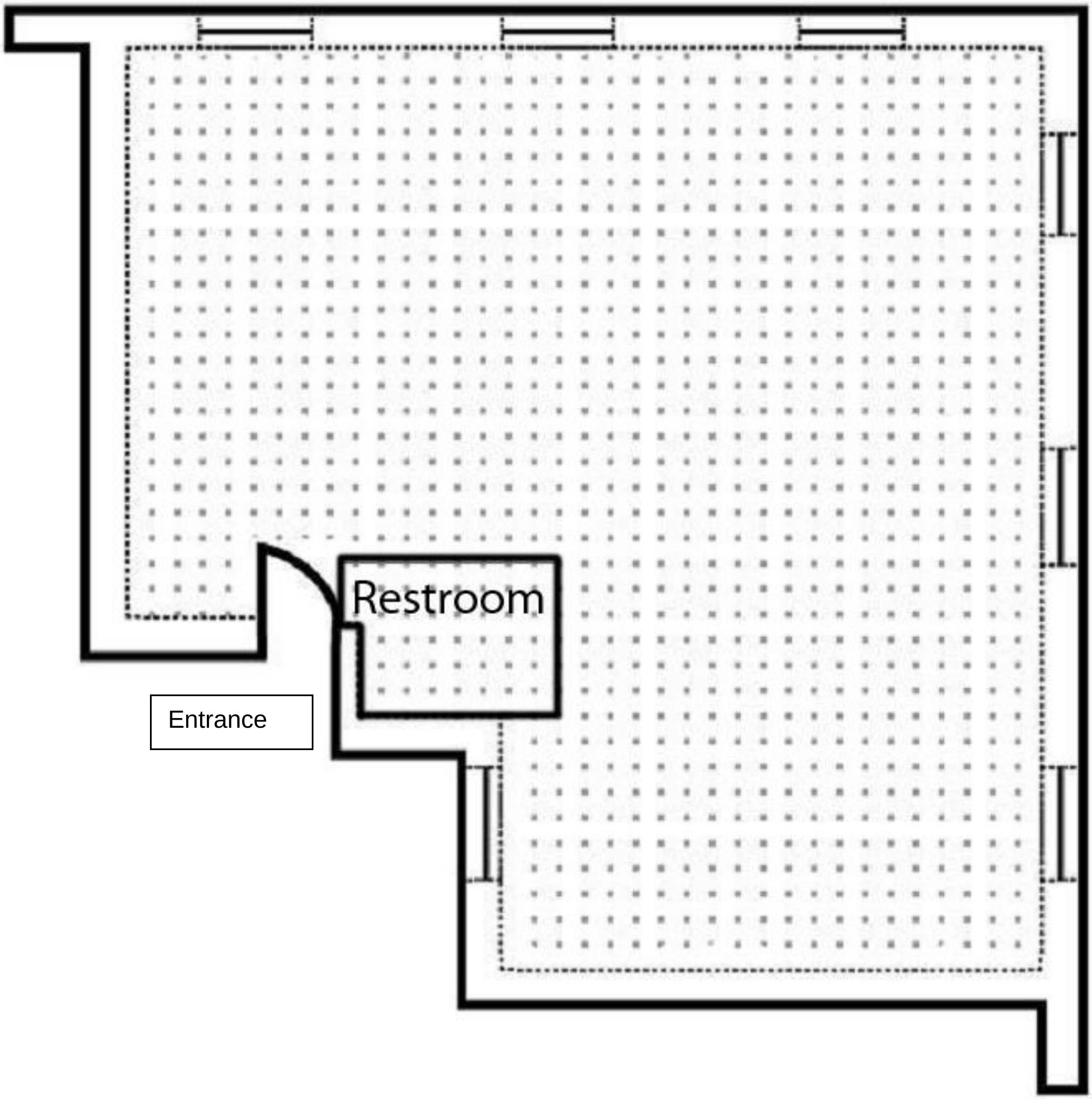
How do you get from the unused office to the sitting area?

How do you get from the narrow office by the restroom to the welcome desk?

Please do NOT flip back to previous pages as this questionnaire is focused on obtaining your first impressions.

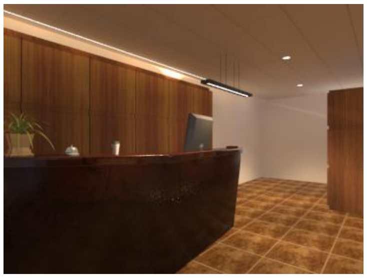
In the grid below, perform the following 3 actions:

1) **Draw** each of the room boundaries (walls) **proportionately** to divide the space into the area you just explored.
2) **Mark numbers 1- 7** to ***indicate the order*** in which you visited each of these rooms for the **first time**.
3) Using the **colored pencil, draw** the **path** you took to visit each of the rooms starting from the **entrance** and ending with the **last room you visited.**

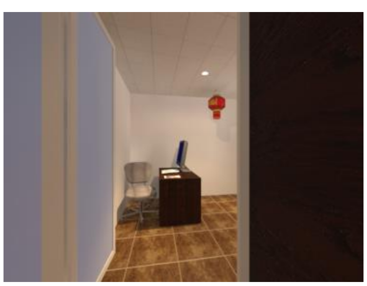
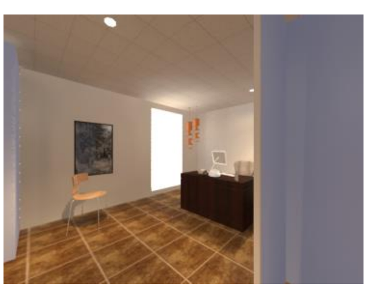


Please do NOT flip back to previous pages as this questionnaire is focused on obtaining your first impressions.

Please **match the items** to the corresponding rooms by **drawing a line to connect** the pictures. *Items can be paired with more than one room*.













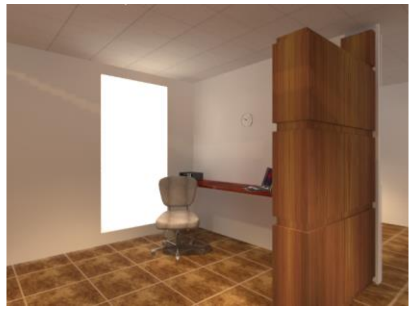


Please do <u>NOT</u> flip back to previous pages as this questionnaire is focused on obtaining your first impressions.

Please mark **numbers 1- 7** to ***indicate the order*** in which you visited each of these rooms for the **<u>first time</u>**.

______

______



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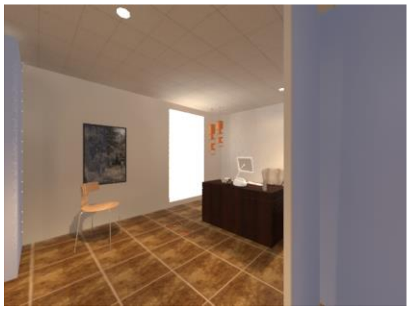
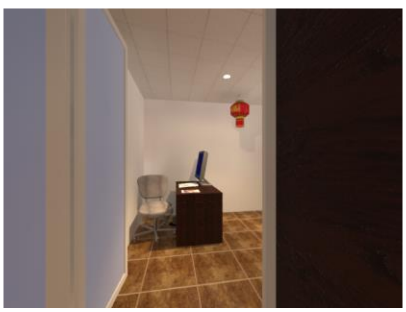


______

______



______

Thank you for completing this survey!

APPENDIX E – SCORING GUIDES FOR COGNITIVE MAPS

Scoring Guidelines Drawing Convex Boxes (Length and Width from Provided Grid)

Wall thickness: If 2 lines were drawn for walls take midpoint and count .5 for between grid spaces

Furniture and Labels: use furniture as a guide for where walls are located as well as delineation of spaces (i.e. using end of a wall line as the boundary between 2 labeled spaces)

Crooked lines: take midpoint between the 2 furthest points, can also be .5 if between grid spaces

Numbered spaces without boundary: make the midpoint a boundary between numbered spaces, if numbers listed closely together for large area, divide up space evenly between the number of labels provided

Non-square room shapes: use furthest points to define 'box' shape *except* when overlapping with adjacent spaces (i.e. L-shaped rooms) then count closest box shape and treat extra as corridor space

Overlapping spaces: box spaces cannot overlap, rooms must be distinct from other spaces, no space between boxes

Doors: note doorways when drawing boxes for easier reference in J-Graphs

Corridors: mark out corridors as adjacent rectangles and squares, but don't count the dimensions (needed for j-graphs)

Uneven walls: take the mid-point between the two walls unless the distinction is obviously showing two spaces sharing one wall (then take the shorter wall)

Dimension starting point: count from the first dot on the graph, do not start from the outer walls

Room dimensions: use the furthest points to determine room length and width of each room

Scoring Guidelines Layout Legibility/Accuracy (8 points)

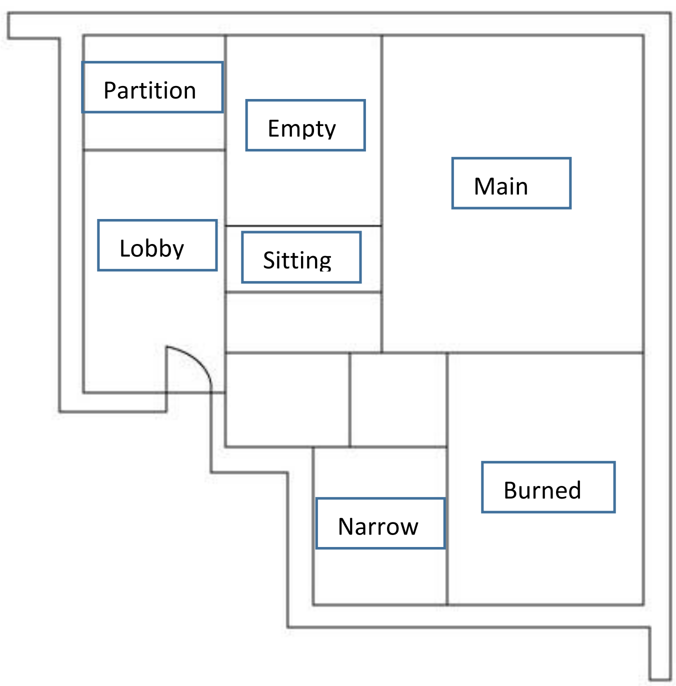
Room placement: 7 spaces defined by placement on specific corners of the outlined walls, 1 point per space correctly placed

Misplaced rooms: split the entire office space in half, if the room are located on the left they will either be lobby or partition, if they are located to the right of the line they are either main or burned, central spaces are empty, sitting and narrow.

Combined rooms: multiple rooms in the same area where only 1 room should be located, deduct .5 points

Extra rooms: Extra spaces added that increase the number of spaces beyond 7, if interfering with one space deduct .5 points, if interfering with two spaces deduct 1 point

Orientation: If plan is rotated 90 degrees, deduct 1 point



Scoring Drawing J-Graphs (Integration Value, Mean Depth)

Room labels: match room number labels to original plan for consistency, use furniture, labels, placement of walls, and location of windows to help identify rooms

Root or 0: should always start outside the entrance

Linking rooms: use drawn doorways or gaps to link rooms

No doors: use drawn path to see how to move from space to space, if both doors and path are missing assume that spaces are connected by nearby corridor spaces or numbers indicating order

Combined rooms: If a combined space is located where 2 spaces should be, use for space the room takes the most space for ** (for example, if the unused office and main office positions are marked by just one large office space, check to see if more of the space is in the unused office or main office location and then count as the one with the most space taken)

Multiple rooms in one space: use corners and windows to indicate room to closest correct position ** (for example, if the main office is split into two offices, use the office that is in the originating corner as the correct one)

Extra rooms: label as extra spaces so integration value is considered, treat as corridor space

Corridors: count corridors when one must be used to access a particular area, label as corridor 1, 2, 3 etc.

VITA

Danielle Oprean is originally from Etowah, North Carolina. She earned a Bachelor's of Science in Visualization in Digital Media from East Tennessee State University. She went on to earn a Master's of Science in Engineering Technology from East Tennessee State University. Following her graduation, she joined the Ph.D. program in Design with Digital Media in Architectural Studies at the University of Missouri. During her academic program she completed both a Master of Arts in Design with Digital Media in Architectural Studies and her Ph.D. in Human Environmental Sciences from the University of Missouri. She holds research interests in human-computer interaction, design tools and cognition, and visualization techniques. She is well versed in conducting research, both quantitative and qualitative, and has experience in the design of experiments. She enjoys experimenting with new technology and testing their usefulness to various disciplines.