INFLUENCE OF IMMERSION ON USER'S SPATIAL PRESENCE

AND MEMORY IN VIRTUAL ENVIRONMENTS

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α   Cronbach's index of internal consistency

df   Degrees of freedom

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 success in a binary trial

r   Estimate of the Pearson product-moment correlation coefficient

SE   Standard error

SD   Standard deviation

<   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   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

ABSTRACT

This study examines the influence of immersion on users' sense of spatial presence and spatial memory in virtual environments. The single factor was systematically manipulated in three conditions. A sample of 32 participants was used to test the study hypotheses. This study employed a between-subject design, and participants were randomly assigned to one of the three experimental conditions. The results from statistical analysis of covariance (ANCOVA) revealed the influence of immersion on the spatial presence and spatial memory.

The results of this study revealed that higher level of immersion including a wider field of view and the stereoscopic display did lead to a greater sense of presence and improved spatial memory performance. This study has practical implications across various domains including architectural design and visualization, developing virtual reality systems, and training simulators.

INTRODUCTION

Virtual reality (VR) is a 3D technology which offers the opportunity for users to experience and interact with the 3-dimensional computer-simulated environment while feeling that they are in a place different from where they are physically. Virtual reality systems are one of the most advanced forms of 3D technology with applications across various disciplines. Advances in VR systems focus on providing the user with an immersive experience. Several other factors relating to the user also contribute to creating a sense of immersion (Ermi & Mäyrä, 2005; Witmer & Singer, 1998). Many virtual reality systems are categorized based on the visual display system they use (Bowman, Datey, Ryu, Farooq, & Vasnaik, 2002). Virtual environments may be viewed using displays such as desktop monitors, head-mounted displays (HMD), and spatially immersive displays (e.g., CAVEs and screen-projected theaters). However, one of the critical challenges in the VR field is "choosing which display best fits each application" (Brooks, 1999, p. 27). Bowman et al. (2002) compared user's performance in different VR displays to map between an application's requirements and a display. There are several key VR system components that define the level of immersion including the field of view (FOV), resolution, stereo/non-stereo mode, and user interface (Ruddle, Payne, & Jones, 1999) among others. These different characteristics may lead people to perceive virtual environments in different ways.

Immersion is the key component that differentiates VR from the other existing media (Sherman & Craig, 2003). The virtual environment, as it relates to the subject of

immersion has been the focus of studies in various fields, such as computer science, human-computer interaction, architectural design, etc. "In general, the term virtual reality refers to an immersive, interactive experience generated by a computer" (Pimentel & Teixeira, 1993, p. 11). "Immersive" and "interactive" explain what makes the computer-assisted experience, an experience of reality. VR has been declared to change the way people might learn by the way they visualize and interact with objects. Since immersion depends on the extent to which the computer displays are extensive, surrounding, inclusive, vivid and matching, its factors are closely related to the devices that leads to realism in representation and projection of a three -dimensional picture.

The fidelity and quality of the information presented in a virtual environment are improving greatly. These improvements have the potential to impact user's spatial experience in the virtual environments. The literature on spatial experiences within virtual environments, however, is centered on the relationship between presence, immersion, and interactivity. Understanding and distinguishing between immersion and presence can help to clarify the importance of spatial experiences that VR systems can offer in virtual environments.

From a technological perspective, VR can be *immersive*, for example when using a head-mounted display and a position sensor that tracks, or *non-immersive*, where the virtual experience is presented via an external monitor that doesn't take up the entire field of view. The HMD is a display device that is worn on the head or as part of a helmet, it isolates the user's eyes from the real world and gives the illusion of three-dimensional space and depth of field by providing computer-generated images to each eye separately. When joined with a position tracking sensor, the HMD also becomes an input device that

communicates the user's movements to the computer that continuously update the virtual environments according to the user's point-of-view. Immersion provided by the HMD is assumed to play an essential role in creating a successful virtual experience (Slater, 2009). Witmer and Singer (1998) stated that virtual environments offering a higher level of immersion would lead to experience a greater sense of presence in the same way. Presence is the extent to which one feels present in the mediated environment, rather than in the immediate physical environment (Steuer, 1992). The term immersion is sometimes mistaken to describe the experience of presence. In fact, these terms refer to quite different things. The term immersion refers to the physical extent of the sensory information and technology characteristic of the sensory modalities, while presence is a perceptual parameter.

Immersive virtual environments are used in visualization as it is commonly expected that higher level of immersion should lead to a higher level of spatial understanding for complex 3D environments (Durlach & Mavor, 1995; Schuchardt & Bowman, 2007). Virtual reality can realistically simulate the natural everyday environment in which a person can navigate, move back and forth, and make 360 degree turns. Different disciplines have employed immersive VR systems to facilitate memorization and learning of real-world activities. Along with trainings applications such as drivers (Mahoney, 1997), pilots (Lintern, Roscoe, Koonce & Segal, 1990), medical operations training (e.g. Gallagher et al., 2005), military simulations (Goldberg, 1994; Goldberg, & Knerr, 1997), firefighter training (e.g. Bliss, Tidwell, & Guest, 1997) etc. Nevertheless, it is unclear if immersive VR technology is necessary or helpful for such learning-based applications or if typical, non-immersive displays would work just as well. Likewise, understanding how

we can effectively design VR applications that facilitate learning and improve memory is a demanding challenge. In this study, I evaluate how different components of immersion affect spatial learning. In other words, how different levels of immersion affect how the user acquires and retain spatial information from a VE.

One of the objectives of this study is to investigate how the level of immersion afforded by the VR system as a function of its technological characteristics affect user's everyday spatial memory. Along with investigating the impact of different level of immersion on user's sense of presence in virtual environments. This study can help to determine which VR affordances can enhance training applications. This study hypothesizes that higher levels of immersion will lead to better performance on spatial memory tasks in a 3D environment. To examine this hypothesis, I conduct a controlled experiment in which participants were asked to learn spatial information while navigating a virtual environment and then try to recall that information.

The overall objective of this study is to investigate the effects of levels of immersion on participants' memory recall as well as on their sense of presence in a virtual environment.

The proposal is structured as follows:

Chapter one further reviews the literature and explicates the concepts of immersion, sense of presence and spatial memory which are key concepts in the main research question. Based on literature review, hypotheses are proposed regarding the role of the level of immersion on a user's sense of presence and spatial memory.

Chapter two describes the research method. It also provides details of the controlled experiment carried out to address the research questions and hypotheses. Then, it goes

further to the operationalization of independent variables in the context of research and development of measures for the dependent variables.

Chapter three details the data analysis procedure and results of specific hypothesis and their interpretations.

Chapter four concludes the study with a discussion of the findings and their theoretical and practical implications, in addition to limitations of research and directions for future research.

CHAPTER 1: REVIEW OF THE LITERATURE

This chapter discusses the key concepts related to the two important characteristics of the virtual environment. The study's theoretical framework is centered on the concept of *immersion*. The focus here is to enhance our theoretical understanding of how the level of immersion affects the user's sense of presence and user's spatial understanding in virtual environments. This theoretical understanding will help us to investigate if a higher level of immersion provides benefits for a certain application. It also helps us to identify which component(s) of immersion is required to obtain these benefits. Therefore, each section of this chapter starts with definitions, dimensions, and meaning analysis of concepts carried out in the context, and then mapping out the theoretical model to pose the overall research question and generate specific hypotheses for conducting the study.

1. 1. Independent Variables

The following section provides background information about the concept of immersion as the independent variable in this study.

1. 1.1. Immersion

Immersion is a metaphorical concept derived from the physical experience and the state of being submerged in water (Murray, 1997, pp. 98-99). Immersion is not a new concept and has been studied in different disciplines including communication, psychology, education, computer science, human-computer interaction, and virtual reality. Immersion

has been used as a method of teaching a foreign language (Curtain, 1986). In this case, an environment of a foreign context is simulated to help second language learners being immersed in the context. In cognitive science, immersion refers to deep mental involvement in the specific activity. In recent research that focused on video games and virtual environments, immersion is used to describe the level of users' engagement with the game environment and gaming experience (e.g., Jennett et al., 2008; McMahan, 2003).

Perspective in painting can be seen as an introduction to the concept of immersion. The three dimensional-display of VR creates a sense of depth that connects the observer (spectator) into "pictorial space". The painting (perspective) simulates depth on a flat surface, but its physical barrier (canvas) doesn't allow the spectator to walk into the pictorial space. In the visual display of VR, the user finds herself surrounded by a virtual world which can be freely navigated (Ryan, 1999). Witmer and Singer (1998) describe immersion as a psychological state characterized by the perception of being "enveloped by", "included in" or "in interaction with" an environment that is offering a continuity of various stimulatory experiences. From a different viewpoint, immersion is defined as "the objective level of fidelity of the sensory stimuli produced by a technological system" (Slater, 2003). Other researchers have suggested that immersion is more likely a product of technology that enables the production of multimodal information sensory "input" to the user (Bystrom, Barfield, & Hendrix, 1999; Slater & Wilbur, 1997). Likewise, Slater and Wilbur (1997) proposed that the degree of immersion can be objectively measured as a characteristic of the technology and can be quantifiable regarding what the system can offer to the user.

From the above definitions, we can deduce that immersion refers to the physical or psychological degree to which a user within a virtual space feels a part of the space relative to the real-world environment (Emma-Ogbangwo, Cope, Behringer, & Fabri, 2014). In fact, users experience both physical and psychological aspects of immersion (Murray, 1997). Murray (1997) emphasized that user can experience immersion both physically and psychologically. Biocca and Delaney (1995) made these two aspects of immersion more distinguishable by stating that the physical aspects are related to the perception of sensory engagement. This is aligned with Sherman and Craig's (2003) perspective that immersion being a function of both physical (perceptual) and mental (psychological) aspects.

Perceptual aspects of immersion can be seen as the system's capacity to replicate the sensory experience of the real world within the virtual reality environment with which the user is interacting (Slater, 1999). To study immersion, it is important to understand which sensory channels through which individual gives, receives, and stores information. Several studies have considered various sensory stimuli that could be simulated through technology such as visual, auditory, tactile, olfactory, proprioceptive and thermal (e.g., Hayward, Astley, Cruz-Hernandez, Grant, & Robles-De-La-Torre, 2004). Successful virtual reality system can offer sensory stimuli that are realistic and enabling proper mapping between the sensory stimuli and appropriate response. Virtual environments created by the virtual reality system may be created in only single modality, such as a visual environment. Ideally, it should incorporate all sensory modalities (Slater, Usoh, & Steed, 1994). In real-life, humans rarely rely on a single sensory modality. Gonzalez-Franco, Maselli, Florencio, Smolyanskiy, and Zhang (2017) explore the influences of the

visual modalities over auditory selective attention. The results show a dominance of visual cues. Visual output (display technology) is the most important aspect of immersion in VR environments. All immersive virtual reality systems contain some aspect of visual stimuli. In fact, many aspects of display technology have been found to influence immersion (Bowman & McMahan, 2007). Slater and Wilbur (1997) also describe immersion as a function of technology which mainly concerned with the display of information to the user. Slater and Wilbur (1997) suggest that the dimension of immersion as being the extent to which a display system can offer to the user the illusion of reality at once being: inclusive (the extent to which physical reality is shut out), extensive (the range of sensory modalities accommodated), surrounding (the extent to which VR is panoramic rather than limited to a narrow field) and vivid (the resolution within a modality). Bowman and McMahan (2007) have identified several factors that influence visual perception in an immersive environment. These include the field of view (visual angles that is visible for users), the field of regard (the total size of visible environment for users while they explore the VR environment), display size, display resolution, stereoscopic view, head tracking, the level of realism, frame rate and refresh rate.

The psychological aspect of immersion is related to the user's cognitive ability to concentrate on the content being visualized (Oprean, 2014). Psychological immersion is related to working on a user's mental ability to be immersed, i.e., a user's emotional response to the content. The main dimensions of psychological immersion could be involvement, attention and affect (Ermi & Mäyrä, 2005; Robertson, Czerwinski, & Van Dantzich, 1997; Schuemie, Van Der Straaten, Krijn, & Van Der Mast, 2001).

The terms immersion and presence are often discussed together and used interchangeably in the literature leading to confusion. Presence and immersion are logically distinguishable, but empirically they are probably strongly related (Slater, 2003). Based on Slater (2003), immersion is a technological aspect of a VR system, which deals with different levels of sensory fidelity a VR system affords (Slater, 2003) whereas presence is a user's feeling and psychological response to being in a simulated environment (Schubert, Friedmann, & Regenbrecht, 1999). Slater and Wilbur (1997) in (Schuemie et al., 2001) also provided a definition in which immersion was the objective measure of the technology being used in a system. This definition distinguishes immersion from the more subjective aspect of presence.

1. 2. Dependent Variables

Following the previous section that focused on the explication of the independent variable, here the dependent variables of the research including a *sense of presence* and *spatial memory* are explained and explicated, and the dimensions of each of variables are discussed. This section begins with defining the sense of presence construct, then operationalizing each concept for measurement. This section also provides background information that improves understanding of the relationship between dependent and independent variables.

1. 2. 1. Sense of Presence

The concept of presence has been a subject of interest among many disciplines including human-computer interaction, psychology, philosophy etc. The sense of presence is defined as the psychological sense of "being there"- replacing the physical world with the virtual world (Slater & Wilbur, 1997, p. 605). There is a consensus among researchers that presence has a broad definition and multiple determinants even though each has added his/her distinctions to the definition.

The concept of presence has been used interchangeably with the term 'telepresence' coined by Minsky (1980). Sheridan (1992) makes a distinction by emphasizing that presence is the sense of being in a virtual world, while telepresence refers to the sense of being in a distant physical location. Presence has many sub-concepts and Heeter (1992) distinguishes three of them; self-presence, social presence (being with other users in a medium) and environmental presence.

Several studies explicated this concept, and they have identified different types of presence experienced by users of a variety of media such as games, and virtual reality systems. Schloerb (1995) distinguishes two types of presence: subjective presence, the possibility that the person judges himself to be physically present in the virtual environment; and objective presence, the likelihood that the specified task is completed successfully.

There also are six different presence conceptualizations found by Lombard and Ditton (1997) that can be grouped into two wide categories- physical presence and social

presence (IJsselsteijn, de Ridder, Freeman, & Avons, 2000). Physical presence refers to the feeling of being physically present somewhere. However, social presence refers to the feeling of being together with others in an environment.

Slater (1999) and colleagues, distinguished presence from the concept of immersiveness (e.g., Slater, Usoh, & Steed, 1994; Slater & Wilbur, 1997). They defined immersion as an objective attribute of technology (systems aspect such as field of view and resolution, etc.) that describes the extent to which the computer displays provide users with an illusion of reality and presence as a subjective measure including the feeling of being in a VE (Slater & Wilbur, 1997). Immersiveness is about differences among VR system's technologies, but presence is about differences among users and among situations. Presence is a psychological concept that can be affected by individual differences and psychological (user's state of mind) and environmental factors. Different users using the same VR system or a single user with the same system at different times and situations can experience different levels of presence (Bowman & McMahan, 2007).

Witmer and Singer (1998) also introduce a distinction between an attention side (involvement) and a spatial cognitive side (psychological immersion) of presence. Involvement is a psychological state experienced in the result of focusing one's attention on a related set of stimuli. Psychological immersion is a psychological state characterized by perceiving oneself to be "enveloped by," "included in," and "interacting with" a VE that provides a continuous stream of stimuli and experiences (Schubert et al., 1999a, p. 227). Both involvement and immersion are assumed to be essential for experiencing

presence. Witmer & Singer (1998) state that, by focusing attention, a person will get more involved and consequently will experience a higher sense of presence.

Schubert et al. (1999a) constructed the I-group presence questionnaire (IPQ) by combining Slater (1999) and colleagues and Witmer and Singer (1998) presence measures. They categorized presence related factors to immersion factors (report evaluation on technology and the interaction of the user with the VE) and presence factors (report on the subjective experience in the VE). In their model, they call psychological immersion "spatial constructive component" (spatial presence) and the involvement as attention component. Schubert et al. (1999a) also added "realness" as a third component. The factors concerning presence itself are: spatial presence (the relation between user's own body and the virtual space), involvement (the awareness devoted to the VE) and realness (the sense of reality attributed to the VE). Schubert et al. (1999a) also proposed the embodied presence which refers to a mental representation of one's own body movements in the virtual environment which include patterns of possible actions, based on perception and memory: "Presence is experienced when these actions include the perceived possibility to navigate and move the own body in the VE" (Schuemie et al., 2001, p. 186). In their second study, Schubert et al. (1999b) considered distinguishing spatial presence and attentional allocation.

 Slater, Usoh, and Steed (1994) also constructed an empirical model of sense of presence in relation to the external and internal factors. They identified external factors which result from the VE system (hardware and software) and refer to the extent of sensory information such as quality and resolution of displays (size of the visual field of view, the

frame and update rate, etc.), consistency of environment, the degree of interactivity, realistic self-representation, and simple connection between actors and effects. As well as, internal factors which are the user's perception of the VE (mental models, beliefs, personal capabilities). The strong relationship found between sense of presence (subjective score on presence) and internal factors. Users rely differently on visual, auditory and kinesthetic data to construct their model of reality (Barfield & Furness, 1995). Slater et al. (1994) noted that a subject might experience presence differently in different modalities.

Spatial presence definitions have been addressed in the immersion-based approach which focuses on sensory factors. Another point of view is based on activity and feedback which focus on opportunities for action (Balakrishnan & Sundar, 2011). Environmental presence proposed by Heeter (1992) refers to the extent to which the VE responds to the user action by modifying various aspects of the environment. In other words, presence develops when the user perceives his bodily actions as possible actions in the virtual world. Slater et al. (1994) call this self -representation a virtual body. The self-representation of the user, that is the user's virtual body, should correspond to the user's own body. "Sensors positioned on user's body map real body movements onto corresponding movements of their self-representations in the virtual world" (Slater et al., 1994, p. 2). Also, according to (Schubert, Friedmann, & Regenbrecht, 1999b, p. 1) "VEs are mentally represented as meshed sets of patterns of actions and that presence is experienced when these actions include the perceived possibility to navigate and move the own body in the VE".

Likewise, Wirth et al. (2003) in their "Two-Level Model of the Formation of Spatial Presence Experiences", consider spatial presence as a two-dimensional construct. "Perceived self-location" and "perceived action possibilities" are the two dimensions of presence connected to a mediated spatial environment. This definition agrees with most existing definitions that suggest a general model of spatial presence based on the combination of related concepts, such as attention and involvement (e.g., IJsselsteijn et al., 2000; Kim & Biocca, 1997; Lessiter et al., 2001; Schubert, Friedmann & Regenbrecht,1999; 2001).

Wirth et al.'s (2003) model of the formation of spatial presence results from two major steps. First, a "spatial situation model" (SSM) which refers to forming a spatial situation model in the mind based on the media cues and second one, which is called "medium-as-PERF-hypothesis" arose from the building the spatial situation model (SSM) and experiencing the environment as primary egocentric reference frame which indicates perceived-self location in the mediated environment.

Figure1: Two-step model of spatial presence formation proposed by wirth et al (2003)
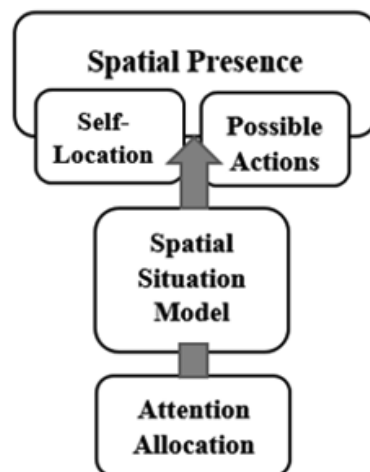
Constructing a mental model of the mediated situation is highly dependent on the user's attention allocation. Vorderer et al. (2004) state that self-location and possible action result from attention allocation and the formation of a spatial situation model. According to Biocca, Harms, and Burgoon (2003, p. 8)'s definition of telepresence, "the phenomenal sense of being there including automatic responses to spatial cues and the mental models of mediated spaces that create the illusion of place". To attract the users' attention, a media product (e.g., virtual environment) contains spatial cues. Users who mediate in the virtual environment, will construct a spatial mental model of the space through processing the spatial cues and their relevant spatial memories (McNamara, 1986 in Wirth et al., 2007). The definition of spatial presence by Wirth et al. (2007) defines two main dimensions of spatial presence which reflects a psychological process that takes place to experiencing presence. Therefore, this can be an appropriate approach for this study. On the other hand, Balakrishnan and Sundar (2011) suggest a two-step model of spatial presence formation that opposes the Wirth et al. (2007) model. Authors conducted a control experiment to examine the effect of subcomponents of navigability on spatial presence. Their result revealed that greater degree of steering motion control (traversibility) significantly enhances spatial presence without forming a mental model (SSM) of the depicted environment. In other words, SSM formation may not be necessary for spatial presence formation in environments that provide the user with "direct spatial cues" and "dynamic visual feedback".

In conclusion, this present study deals primarily with subjective sensation of "being there" experienced and reported by the user during exposure in an immersive VE, and this sensation is, in fact, part of most definitions. However, a significant result of

presence is that a user remembers the VE as a place rather than a set of images (Slater, Pertaub, & Steed, 1999). We will measure spatial presence based on its two primary dimensions that are identified from explication: spatial self-location and the possibility for actions. Spatial self-location dimension is the extent to which the user feels a part of the mediated virtual environment and forgets the immediate physical environment. In other words, users unconsciously switch from real environment cues to virtual environment cues to define their position and orientation (Prothero, Hoffman, Parker, Furness III, & Wells, 1995 as cited in Balakrishnan & Sundar, 2011). This method is based on a self-report measure that requires users to recall the extent of their self-location in the virtual environment (IJsselsteijn et al., 2000). The other dimension of spatial presence in this study is the perception the simulated space as 'real' known as reality judgement.

1. 2. 2. Spatial Memory

Spatial memory is a cognitive process that allows a person to store and retrieve the locations and relationships between objects in the environment. People typically associate things and their locations concerning other things. People use spatial memory to remember "where something is in relation to some other object" (Adamo-Villani & Johnson, 2010, p. 582). Examples include remembering that the wallet was left on the shelf by the front door or re-tracing your daily route to work. Developing spatial relations is key to enabling people to find and communicate to others the location of things and places efficiently.

Spatial memory is essential for everyday activities in different environments and situations and by different people with varying spatial abilities. Spatial memory weakens with age, elderly people complain about losing the ability to navigate in unfamiliar environments (Burns, 1999). A variety of studies show that older healthy adults perform poorer than young adults on tasks that require different components of spatial memory (e.g. Salthouse, Babcock & Shaw, 1991; Kirasic & Mathes, 1990; Kirasic, 1991; Cherry & Park, 1993). There are also, numerous research studies on gender differences in spatial memory (Postma, Jager, Kessels, Koppeschaar, & van Honk, 2004). Several studies demonstrated that men have a larger spatial working memory span compared to women (Orsini, Chiacchio, Chinque, Cocchiaro, Schiappa & Grossi, 1986; Capitani, Laiacona and Ciceri, 1991). In contrast, a study by Postma et al. (2004) discovered no gender differences while using the same task. Moreover, women have shown superiority in several object-location tasks i.e. spotting objects that have exchanged position (Eals & Silverman, 1994; James & Kimura, 1997). This indicates that the gender-differences on spatial working memory may be reasonably small.

Spatial memory consists of multiple components which are necessary for different everyday actions. Presson and Somerville (1985) distinguished between primary and secondary spatial learning. Primary learning is knowledge acquired from "direct" experience (particularly standing and walking) of an environment. Adamo-Villani and Johnson (2010, p. 582) state that "spatial memories are formed after people gather and process sensory information about their surroundings" which is considered as a direct source. Secondary learning results from using "indirect" sources which convey spatial information by exposing people to external representation or simulation of the

environment to which they refer (Montello, Waller, Hegarty, & Richardson, 2004).

Montello et al. (2004) also categorized indirect sources to static pictorial representations

(maps and pictures) and dynamic representations (movies, animations and virtual

environments). These different types of media may offer representation with different

qualities (Gale, Golledge, Pellegrino, & Doherty, 1990; Thorndyke & Hayes-Roth, 1982).

Sources such as "virtual environments" involving both the desktop and immersive

simulations which are considered a type of indirect source of spatial knowledge, have

been the subject of studies across different domains.

Spatial memory has been investigated in a variety of disciplines such as geography,

anthropology, linguistics, neurosciences and computer science. Since spatial memory is

crucial for efficient human performance, an increasing number of research studies use 3D

virtual environments (VE) to investigate human spatial memory in everyday

environments. Virtual reality can be used to create a realistic simulation of the natural

everyday environment in which a person can navigate. Researchers employed a strategy

to compare task performance in a virtual environment to the real world.

To understand the spatial memory, we need to investigate the spatial knowledge

acquisition in the real-world as well as virtual environments. In fact, several studies have

shown that VE can be employed as an effective instrument to help users acquire the

spatial knowledge. Investigating the spatial memory mechanism requires starting from a

part of human short-term memory which is called working memory. Working memory is

concerned with "immediate conscious perceptual and linguistic processing" (Oxford

dictionary). Spatial working memory is a part of working memory which involves the

ability to keep spatial information active for short periods of time to update or process this information (Asselen, 2005; Jonides et al., 1993).

The Baddeley, Baddeley, and Braddlely (1986) working memory model, suggests that there are two sub-components to spatial working memory. A "phonological loop" which holds auditory and speech-based information and a "visuospatial sketchpad" which holds visual and spatial information (Jones, Farrand, Stuart, & Morris, 1995). Spatial memory is a complex multidimensional process which includes a variety of components and mechanisms that help us to orient and act in space (Kessels, de Haan, Kappelle, & Postma, 2002; Postma, 2005).

One form of spatial memory, which is essential for travel from one place to another and for finding your way inside a building is route learning or spatial navigation (Asselen, 2005; Postma et al., 2004). Route learning includes wayfinding and navigating in familiar or new environments. It involves planning the route prior, and continuous updating of your spatial knowledge as the environmental stimuli will constantly change during a journey. Different strategies can be used for route learning. One strategy is generating a cognitive map of the environment in memory, which is necessary for navigating in space. The spatial layout of the environment is represented in mind (Asselen, 2005; Bohbot, Iaria, & Petrides, 2004). This strategy involves spatial learning where one learns the spatial relationship between elements (i.e., landmarks) in the environment. The concept of a cognitive map for wayfinding was coined by Tolman (1948), who suggested that this cognitive map indicates routes, paths, and environmental relationships.

Another strategy is response learning (Iaria, Petrides, Dagher, Pike & Bohbot, 2003; Bohbot et al., 2004; Van Asselen, 2005), in which a route is learned through repetition of rewarded behaviors. People learn to turn left or right in response to environments as it rewarded them by arriving at the destination.

The generating of cognitive maps, according to most studies, is an active process. Hazen (1982) studied the relationship between the active-passive mode of travel and the knowledge of the spatial layout of a museum. The results showed that those who actively explored the museum had a more accurate knowledge of spatial layout. Furthermore, the everyday environment can be viewed from different frames of reference: an egocentric or an allocentric frame of reference (Klatzky, 1998). An egocentric (self/viewer-centered) frame of reference is used to encode spatial information in relation to the position of the viewer while an allocentric (other/world-centered) frame of reference is an external reference frame, independent of the viewer's position which is used to encode spatial information relative to other locations and objects.

Another distinct form of spatial memory is an object-location memory. This is used for memorizing specific locations for certain objects (Kessels, de Haan, Kappelle, & Postma, 2001). Object-location memory is essential in everyday life as you must remember for example where you left your wallet or where you parked your car in a large parking lot. It consists of three distinct processes: memorizing the identity of an object, memorizing the location of an object, and memorizing the relation between identity and location (Postma et al., 2004).

Spatial relation between two objects in space can be encoded in two different ways. Kosslyn (1987) has proposed a distinction between the representations of categorical and coordinate spatial relations. categorical representation, which is abstract (concern relations stated in propositional terms, like "above" or "to the left of), and coordinately, which represents metric distance (involving the exact distances between objects like "two meters away") (Kosslyn, Chabris, Marsolek, & Koenig, 1992; van der Ham & Borst, 2011).

Figure 2: Two forms of spatial memory
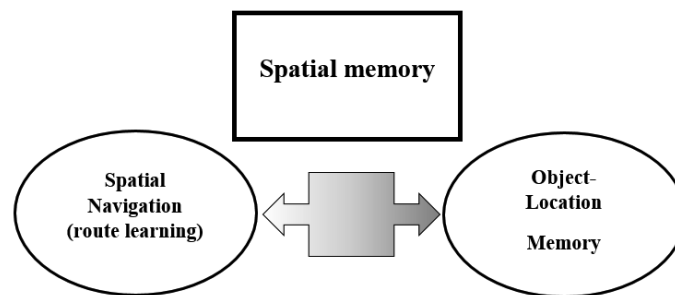
Spatial memory covers different types of interactions with our surroundings, like grasping, navigating, and memorizing objects locations. In this study, since we deal with a small-scale area (within one room), we make use of memorizing object locations, spatial relations between objects and between objects and ourselves. Small-scale spatial memory covers information about an area that can be viewed instantly from one single viewpoint such as the spatial layout of the room or the spatial organization of objects inside a shelf or cabinet. Objects in small-scale areas are normally seen as more manipulatable (they can be touched and moved) as contrasted with objects in large-scale space (cf. Hegarty, Montello, Richardson, Ishkawa and Lovelace, 2006). This lets people gather more detailed information about the objects in a small-scale space. In everyday

life, people recall specific locations for specific objects, such as a specific pen which is in the left office shelf and the car keys that are in the first drawer under the computer desk, etc.

Spatial memory in virtual environments

An increasing amount of studies use virtual environments (VEs) as instruments for exploring spatial knowledge (Péruch and Gaunet, 1998; Wilson, 1997). Several researchers have shown that spatial knowledge acquired in VEs is like that acquired in a real environment (O'Neill, 1992; Regian, Shebilske and Monk, 1992; Ruddle, Payne and Jones, 1997; Stanton, Wilson and Foreman, 1996; Tlauka and Wilson, 1996). In virtual reality, spatial memory works just like the real scale environment with some overlap of the wayfinding components and object location components (Darken & Sibert, 1996). In a VE, a person can perform similar spatial behavior as in the real-world environment. A VE can resemble the interior of a building, streets in a city or some other outside environment with as many landmarks or other objects and situations that can be in the real world. A practical method to measure the spatial memory performance relies on the observational judgments of the experimenter about the relative direction and objects' locations based on their memory of a spatial layout (Levine, Jankovic, & Palij, 1982).

Various factors affect spatial learning. These include the nature of the activity the spatial knowledge support (searching for objects or navigation and finding a way to a target), the type of environment (large or small scale, open or closed), and the mode of travel (active or passive). The current literature is mainly concerned with the physically active mode of navigating within the VE using a joystick or keyboard. Based on Wallet et al. (2011) in

physically active navigation the subject moves using the motor interactor. Plancher, Nicolas, and Piolino (2008) conducted a study to measure episodic memory in a virtual environment. Their results showed that users who actively navigated a VE acquired higher score on episodic memory than those who experienced passive exploration in a VE.

In the real world, spatial memory is responsible for the ability to navigate and locate objects in the environment. Likewise, in a virtually created 3D environment we need to define nature of the activity the spatial memory support including searching for objects or navigation (finding a way to a target). In other words, in navigation task, the user can walk through an immersive environment like a real, natural or built environment and find their way to their destination. Understanding orientation, direction, distance, size, and scale are components of navigation. In object location activity, users can recall and remember the location of a particular object during or after performing a specific task in the 3D virtual environment. The main focus of this study is on memory for object location in the environment. Therefore, it is reasonable to operationalize spatial memory as the accuracy of object 'location recall which can be measured through the number of objects that an individual recalled.

A commonly used method to test spatial memory is to have participants move through an environment to familiarize themselves with this environment. After such a learning phase, participants are asked to answer different types of questions, in the testing phase, regarding their spatial knowledge (the layout of the environment, route properties, and landmarks). This approach will also be used in the current study. Participants can

experience a dynamic three-dimensional simulation physically with an active travel mode in which participants have control of their movements, and have the freedom to choose from a variety of possible views in order to gain familiarity with the environment. And they are asked to memorize what they encounter on their way. Then they are tested on their knowledge of the environment. In this study, those tests will focus on the locations of objects and the spatial relation between objects.

1.3. Hypotheses

Three main variables were proposed for this study: (1) immersion as the independent variable and two dependent variables, (2) sense of presence and (3) spatial memory. In this section, we review theoretical links between the independent variable and dependent variables to find the potential causal relationship between the independent variable and dependent variables. Immersion was explicated as visual immersiveness which include two technology manipulations, stereoscopy, field of view. Sense of presence is explicated as spatial presence (spatial self-location, possibility for actions and vection) and reality judgement. Spatial memory is the other dependent variable which will be measured as the quantity of objects and accuracy of spatial information that recalled.

Immersion and presence

Immersion refers to the technical quality of the media, which to a certain degree determines the degree of presence experienced by users (Cummings & Bailenson, 2016). Importantly, presence in a VEs can be experienced through a range of devices, ranging

from non-immersive desktop computers to immersive head-mounted displays. With the less immersive system, the more mental workload is required for the user to believe that they are present in the VE (Slater 2009).

In current theoretical models, the sense of presence is assumed as the consequence of immersion. Most researchers in virtual environments field suggests a common assumption that increased immersiveness offers improvements in the user experience of presence. Slater and Wilbur (1997) consider some characteristics for an immersive system including providing high fidelity simulations through multiple sensory modalities and constantly mapping the user's virtual body movements to their physical body's corresponding movements. One method to achieve increased immersion is to use immersive displays. In other words, the more inclusive, extensive, surrounding and vivid the VE is, the users will experience the greater sense of presence (Slater & Wilbur, 1997), or the more similar the experiences in the VE are to those in the real world (Barfield & Hendrix, 1995; Bystrom, Barfield, & Hendrix, 1999), the greater the presence.

However, the relationship between presence and immersion, is influenced by user characteristics which act as a moderating variable in effect of immersion on the presence (Slater, 1999). Schubert, Friedman, and Regenbrecht (2001) pointed independently to the definition of immersion in the virtual environment context; presence seems to be moderated as much by external factors (system affordances) as by the internal attributes of the user. The user should be sufficiently immersed within the virtual environment to allow for the creating of a psychological sense of presence. Nevertheless, if the user

becomes distracted or remains in contact with the external world, the sensation of presence never develops or fails to develop strongly (Sadowski & Stanney, 2002).

Visual immersion and spatial presence

According to (Gibson, 1973) and Kebeck (1997), spatial presence can be experienced by external sensory information provided by media system. Also, IJsselstein (2004) conceptualized presence as the experiential part of immersion. Spatial presence is an experience which can be enhanced by sensory information such as visual, auditory, haptic, or proprioceptive characters and feedbacks (Gibson, 1973). The more senses a media system offers to the users, the more likely they feel like they "are in" the environment (Wirth et al., 2007). Accordingly, with the high immersive technologies (for example display and tracking technologies), the user may respond with feelings of spatial presence. As we discussed, user's attention allocation is prerequisite of constructing a mental spatial model that leads to experiencing the presence. Media system sensory modalities enable a stimulus to absorb users' attention. The underlying assumption is that an increase in sensory information input will enhance the user's attention allocation. Steuer (1992, p. 81) addressed this as "breadth" of information which is the number of the sensory modalities that a medium addressed and (Wirth et al., 2007) regarded as a factor of attention attraction. Also, the "depth" of presented information is "the amount of data the media product encodes within one given modality" (Steuer, 1992; Biocca, 1997 in wirth et al., 2007, p.500).

Spatial presence, based on Wirth et al.'s definition (2007), is a two-dimensional construct with perceived self-location and perceived action possibilities are forming the two

dimensions. Perceived self-location was defined as the sense of being physically located within the virtual environment. The dimension of perceived action possibilities states that the user realizes only those action possibilities that are pertinent to the mediated environment and will not perceive real environment actions (Wirth et al,2003). While experiencing the spatial presence, perceived self-location and action possibilities are linked to a mediated spatial environment. Both states can be improved (not depend on) by different sensory input and action responses.

Embodiment described by Biocca (1997) is the fundamental concept in perceiving self-location. Based on Biocca (1997), embodiment is a result of sensory engagement on different channels in a virtual environment. Sensory engagement with virtual environment occurs when a mental image is created from the sensory information.

Based on Balakrishnan and Sundar (2011), self-location is an immersion-based component of spatial presence. However, visual immersion was one of the perceptual immersion' components which provides the visual information of virtual environments. A continuous stream of highly detailed visual information is expected to maintain user's attention allocation more successfully than an interrupted and less detailed stimulus (Wirth et al., 2003). This presentation by virtual environments through the visual sense was known as visual engagement. The Biocca (1997) and Wirth et al. (2003)' mechanism suggests that an immersive virtual environment where the vision and other senses are expected to be involved, should provide a higher visual engagement and consequently higher sense of self-location.

Figure 3: visual immersion, visual engagement and self-location
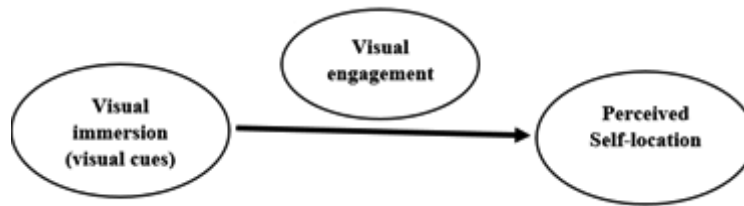
Visual immersion provides visual engagement which helps to perceive self -location. Greater visual cues (more visual information) offering by higher levels of visual immersion can help to generate more accurate mental representations (deeper visual engagement) and consequently increase the perceived self-location (Oprean, 2014). Embodiment also is important in perceive the possibility for action. Users who mediate in the virtual environment, will construct a spatial mental model of the space through processing the spatial cues and the memory for the interaction with similar objects and situations. In other words, the formation of the spatial mental model of the space is based on remembering "how one's body can move itself and manipulate objects" (Glenberg, 1997, p. 4). Perceived possible actions are based on to what extent our movement in the mediate environment is similar and corresponding with natural movement of the body in the real world. Along with visual immersion that helped in forming a visual representation of the virtual objects and situation, interactivity also plays a fundamental role in experiencing presence. Based on Balakrishnan and Sundar (2011) in the virtual environment with direct spatial cues and dynamic visual feedback (viewpoint movement) formation of spatial presence will be greatly enhanced. This follows along the Balakrishnan and Sundar rationale that interactivity plays a role in experiencing spatial presence.

Figure 4: Visual immersion, interactivity and spatial presence.
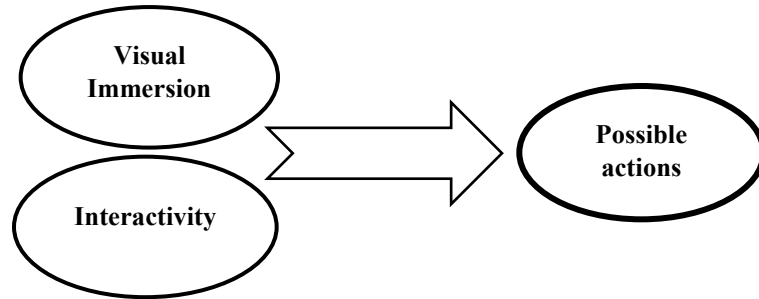
The literature needs to be reviewed on the effects of technology manipulation of visual immersion on self-reported levels of presence. In this study, Stereoscopic vision and field of view are presumed to contribute to spatial presence measures. Cummings and Bailenson (2016), reported that technological immersion has a moderate effect on presence. Their results show that increased levels of user-tracking, the use of stereoscopic visuals, and wider fields of view of visual displays have a more significant impact compared to improvements of other immersive system features.

Stereoscopic vision refers to whether a given system provides the user with monoscopic or stereoscopic visuals. Stereoscopy provides an illusion of three-dimensional depth from given two-dimensional images by presenting a different image to each eye (Freeman, Avons, Pearson, & IJsselsteijn, 1999; Lincoln, 2011). This technology can be used to create a virtual display. To achieve stereoscopic vision, the brain calculates the difference between the input it receives from both eyes to determine depth. This occurs because in the real world an object is slightly different distances away from each eye. In virtual reality, there are two separate images projected at alternating times, and shutter glasses are synced to the projectors such that each eye sees the appropriate image at the accurate time. This arrangement allows the brain to interpret a single image with 3D depth.

Hendrix, Barfield (1995), considered stereoscopy viewing and the field of view as the experimental manipulations of their study and concluded that stereoscopy and the FOV are important factors for a high sense of presence in virtual environments and wider fields of view resulted in significantly higher presence whereas realism ratings do not seem to be the most important factor. Authors explained that 3D depth cues presented by stereoscopic display add the illusion of depth which helps users to experience a greater sense of presence. Freeman, Avons, Meddis, Pearson, & IJsselsteijn (2000) investigated the effects of stereoscopy with a 20-inch stereoscopic display presenting a stereoscopic video and resulted that there is a significant difference between the stereoscopic and non-stereoscopic presentations. IJsselsteijn et al. (2001) also investigated the effects of stereoscopy, image motion, and screen size with a large projection display showing a rally car traversing. The result for stereoscopy was consistent with that found by Freeman et al. (2000). Other studies suggested that stereoscopic viewing can significantly enhance the subjective sense of presence (Baños, Botella, Rubió, Quero, García-Palacios, 2008; IJsselsteijn, de Ridder, Freeman, Avons, 2001).

There is also, a general agreement that a wide field of view can increase immersion in the VE; while, narrow field of view can decrease the sense of presence (Hendrix & Barfield, 1995a; Prothero, 1995). Lin, Duh, Parker, Abi-Rached, and Furness (2002) also conduct a study using a within the subject design and collected data from 10 subjects at four FOVs (60º, 100º, 140º, and 180º). Results indicated that presence varied as a function of display FOV. Subjects showed higher presence scores with increasing FOV.

The extent of vision of the human for both eyes (binocular FOV) is approximately 200 degrees horizontally and 135 degrees vertically (Gibson, 1979). Thus, using larger fields of view maintains a more unified visual experience of an environment, which creates a more realistic experience. Wider field of view increases the side vision (what is seen on the side by the eye when looking straight ahead) which increases the number of visual cues presented at any given time. Besides, with more range of side vision in a virtual environment, more of a real-world would be blocked and less visual distraction could interfere the experiencing of presence.

Stereoscopy and wider field of view increase the number of visual cues. Based on above discussion, visual immersion connected to both self-location and possible actions through forming a visual representation based on visual cues (i.e. color, depth, shape, etc.). therefore, in the presence of the more visual cues offered by higher level of VR system's visual immersion joined with interactivity (in the form of higher degree of freedom of steering control), the user can experience the greater sense of presence. Since in this study the interactivity variable remains constant in all conditions, I hypothesized that:

H1: Greater levels of visual immersion will increase the sense of presence.

Immersion and spatial memory

It was found that higher levels of immersion improve spatial understanding (N. Durlach et al., 2000; Schuchardt & Bowman, 2007; Tan, Gergle, Scupelli, & Pausch, 2006; Waller, Hunt, & Knapp, 1998). Several studies have explored whether users can memorize procedures and recall spatial information that they have learned through

interaction with a VE (e.g,.Ragan, Sowndararajan, Kopper, & Bowman, 2010; Waller et al., 1998). Spatial memory seems to improve when using an immersive virtual reality system (Carassa, Geminiani, Morganti, & Varotto, 2002; Plancher, Nicolas, & Piolino, 2008). Plancher et al. (2008) exposed users to a VR system with a higher level of immersion and users got better scores on episodic memory tests. Some researchers have hypothesized that content will be more memorable if students experience it directly in an immersive VE (Allison & Hodges, 2000; Salzman, Dede, Loftin, & Chen, 1999). Some other researchers such as Ragan, Sowndararajan, Kopper, and Bowman (2010) hypothesized that more realistic spatial cues provided by higher levels of immersion would offer the memorization performance improvements. Ragan et al. (2010) found that increasing the level of immersion can improve memorization tasks significantly compared to lower levels of immersion. Based on above studies, it is plausible to think that immersive virtual environments increases the user's engagement (Winn, Windschitl, Fruland, & Lee, 2002) and provides enhanced spatial cues (Ragan et al., 2010) which help users to improve spatial understanding and come up with more accurate spatial recalls.

Ragan et al. (2010) performed an experiment in which participants memorized procedures that involve conceptual learning and memorizing objects or locations in a 3D environment and then attempted to recall those procedures. Their results suggest that, for procedure memorization task, increasing the level of immersion can improve performance in comparison with lower levels of immersion. Ragan et al. (2010) postulated that spatial task performance improvement obtained by a higher level of immersion could be explained by enhanced spatial cues. Spatial cues associated with

immersion. Immersion in this study refers to the visual immersiveness and display characteristics of the system and includes stereoscopy and field of view. Metcalfe, Glavanov, and Murdock (1981) showed that spatial recall is better if the input modality is visual. Likewise, it has also been found that visual displays are more effective than auditory displays for tasks that demand spatial working memory (Wickens, Vidulich, & Sandry-Garza, 1984). More realistic spatial cues help users to attain greater spatial understanding comparing with comprehension levels achieved with traditional displays (deeper level of learning) (Ragan et al., 2010; Schuchardt & Bowman, 2007; Ware & Mitchell, 2005). Enhanced spatial cues can be provided by more immersive VR display characteristics (e.g., stereoscopy, field of view, motion parallax, etc.) that simulate real world experience. Sowndararajan, Wang, and Bowman (2008) suggest that spatial cues help memory for forming mental maps or representations of spaces. It is reasonable to expect that, stronger mental representation of the space (resulted from enhanced spatial cues like those found in immersive VR) will increase the likelihood of accurate spatial recall (Oprean, 2014).

Several researchers investigated the effect of various components of immersive VR on memorization of object information and spatial locations (Pausch, Proffitt, & Williams, 1997; Mania, Troscianko, Hawkes, & Chalmers, 2003). We need to investigate the effect of visual immersiveness on spatial memory performance. It seems that the stereoscopic virtual environment and the wider field of view (FOV) can improve memory and increase the sense of presence (Tan et al 2003, Lin et al 2003, and Czewiksi et al 2003). Both two-dimensional and three- dimensional displays use depth cues to create the depth illusion. There are two types of depth cues. The monocular depth cues including the object size,

height in the visual field, effects of light, etc and the binocular depth cues (convergence and divergence, binocular disparity, etc.) in stereoscopic displays which create the illusion of depth. In other words, 3D objects can be seen through binocular depth cues and from two eyes at multiple viewing angles (Levine, 2000). Three dimensional stereoscopic displays provide viewers with visually attractive representations of three-dimensional environments and when it comes to comparing these with two-dimensional display formats, they also provide viewers with a more accurate perception of the spatial relationships of objects located in the environment. Stereoscopic displays may help the viewer with reducing the mental workload for spatial tasks in forming an accurate mental model of the environment in which represented by the display (Hendrix & Barfield, 1995b).

A study by Kim (2006) found that using a 3D stereoscopic view (for viewing plate tectonics) enhanced students' learning outcomes when compared with the 2D visualization. Stereoscopy provides depth information about objects when compared to non-stereoscopic information. Sowndararajan et al. (2008) have stated that stereoscopy would improve the results of memory due to the enhanced spatial cues. Therefore, it is reasonable to think that due to detailed features of the space and objects using 3D stereoscopy would help individuals to remember a higher quantity of objects. In fact, more realistic spatial cues benefit improving spatial understanding. The rationale for this hypothesis is based on cues resulting from display characteristics including stereoscopic view, allowing the user to receive depth perception.

On the other hand, few studies failed to find any significant influence of stereoscopy on memory recall and memorization task (e.g. Baştanlar, Cantürk, & Karacan 2007). Hendrix & Barfield (1995) showed that stereoscopic viewing did not provide enhanced performance over perspective displays but did help subjects in making more consistent spatial judgements.

Field of view was also found to positively influence the accuracy of memory. In Ragan et al. (2010) study, wide FOV significantly improved procedure memorization and recall accuracy. The authors' explained that mapping steps in a procedure to spatial cues could help to remember the procedure successfully. Ragan et al. (2010) clarified that a wider FOV allowed the "user to see more of the environment at one time" (p. 530).

The main idea of our hypothesis is that higher levels of immersion provide more realistic spatial cues and a higher level of engagement that would result in better spatial understanding and will return the higher scores on a spatial memory test. It has been shown that increasing the quality of sensory modalities such as display characteristics will increase immersion and presence. A higher level of immersion replaces more of the real-world sensory stimuli with the virtual world. Besides, mimicking real-world tasks through increasing immersion and presence would result in increased performance on the memory test. (Dinh et al,1999). According to the above discussion we expect that there would be a positive and significant relationship between VR display characteristics including stereoscopy and a wider field of view and recall of objects, such that individuals who experienced high levels visual immersion that offer more realistic spatial

cues and a higher level of engagement, would recall the highest quantity of objects. So, I hypothesized that:
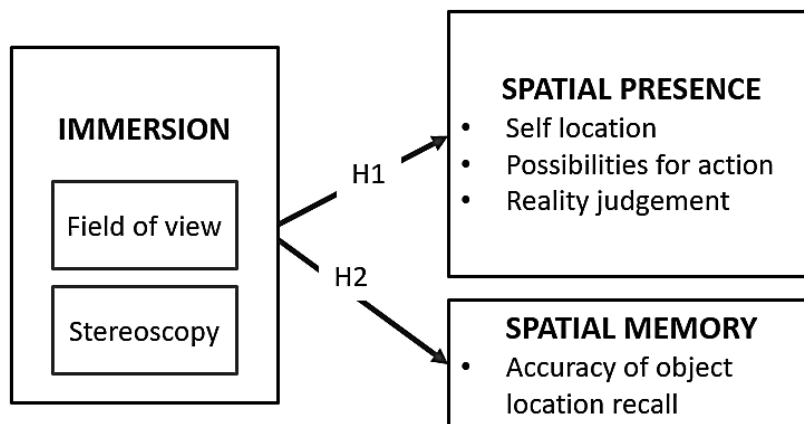
H2: Greater levels of visual immersion will improve spatial memory

1.4. Research Question:

What is the influence of the level of immersion on the sense of presence and spatial memory in a virtual environment?

Fig. 5 provides an overview of the hypotheses mapping indicating the relationship between the independent and dependent variables.

Fig. 5: main hypothesis

CHAPTER 2: RESEARCH METHODOLOGY

Building on the literature reviewed in Chapter 1, this chapter elaborates on the research methodology which provides the basis for operationalization and clarification of concepts and variables. It also provides a detailed description of experimental procedures, the stimulus, and measurements of dependent variables.

2. 1. Design of Experiment

This study aims to use a quantitative research approach with human subjects. A controlled experiment using a between-subjects design was used in this study (Charness, Gneezy, & Kuhn, 2012; Kirk, 1982). This research design randomly assigned participants to different conditions for the independent variable (immersion) and measured outcomes for the two dependent variables (DVs), see Table 1. To address the main research question and hypotheses, we operationalized the visual immersiveness. Visual immersion as an affordance of display technology can be varied at different levels. In this study, we manipulated several dimensions of visual immersion to study their impact on the presence and spatial memory. However, not all the VEs are offering using the same technology, and the level of immersion differs across settings.

Visual immersiveness can be examined as a function of technology components derived from the Bowman & McMahan (2007) taxonomy such as: field of view (FOV), field of regard (FOR), display size, display resolution, stereoscopy, head-based rendering, and realism of lighting, frame rate, and refresh rate. Ragan et al. (2010) operationalized high

and low level of immersion by manipulating the affordances including the display field of view and stereoscopy mode. A virtual reality content can be displayed on various platforms (e.g., cave, monitor, HMD, large TV screen, etc.). Although any media affordances can be manipulated to change the level of immersion, FOV and stereoscopic 3D vision are two main factors that affect the level of visual immersion. In low-level immersion condition this study employs a desktop computer, for a medium level of immersion; a large UHD TV and for a high level of immersion condition; a head-mounted display (Oculus Rift CV1) is employed.

In high immersion condition, the user benefits from reduced visual distraction offered by the HMD. However, in the other two lower immersion conditions (desktop and large TV screen), users may still be distracted by elements from the real world. Field of view (FOV) is the other technology manipulation of this study to investigate the effect of immersion on spatial presence. There are two separate types of FOV to consider when dealing with VR: camera field of view and a display field of view. In this study we concentrate on the display field of view. For the operationalization of narrow and wide field of view, we considered two different screen sizes and an oculus CV1 for the wider FOV. Also, for stereoscopic view, we consider the use of regular desktop monitor and large tv screen for non-stereo viewing conditions and Oculus Rift CV1 for the stereoscopic viewing condition.

Table 1: Variables of Study

Independent Variables	Dependent Variables
Immersion • Stereoscopy • Field of view	Sense of presence • Spatial presence • Reality judgement Spatial memory • Accuracy of spatial recall

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

Table 2: Experimental Conditions

Immersion		
High Immersion (HMD)	Medium immersion (TV)	Low immersion (Desktop monitor)
HMD (FOV 110º, stereoscopic)	65 inches TV (FOV 50º in 5 ft. viewing distance, non-stereo)	22 inches Dell full HD (FOV FOV 30º in 2.5´ ft. viewing distance, non-stereo)

2. 1. 1. Experimental Setting

The study were conducted at the research lab in the Department of Product Design at the University of Minnesota. Three virtual reality testing workstations were set up to test the three levels of immersion. Subjects in all three conditions were asked to start at a predetermined location in the 3D environment and navigate to goal objects located elsewhere in the environment. The navigation was unguided.

- Condition 1 (Low Immersion): This condition will employ A desktop system in which the user will view the environment through a conventional computer monitor. Subjects will be asked to navigate a virtual environment using an Xbox controller.

- Condition 2 (Medium Immersion): This condition will use a Sony 65" UHD TV, powered by a Dell Precision 3600 Desktop PC.

- Condition 3 (High Immersion: Subjects will be asked to navigate the same virtual environment as condition 1 and 2 via a head mounted display. The Oculus Rift CV1, powered by an Alienware laptop PC was set up for the high level of Immersion (Stereoscopic 3D).

2. 1. 2. Stimulus

For the study, we used a previously developed VE: the 3D interactive tour of a portion of the Gwynn Hall (first floor) at the University of Missouri which is fully digitally built and a photorealistic 3D reconstruction of the existing environment. The virtual HES

building spaces include several distinct spaces (outdoor, stair box, corridor lobby, hallway vitrine gallery and main exhibition room) in which participant could freely move in the spaces as shown in fig.2. The building model is unfamiliar to the participants as this helped to assess the task of spatial recall better since all participants had the same amount of knowledge about the building at the start of the study. The model was pretested for complexity and feasibility to engage the participants in a navigational task. The virtual environment incorporated constraints normally found in real life such as gravity, and barriers like walls and closed and locked doors. Using an Xbox controller, the user can move the viewpoint in the environment with six degrees of freedom (move forward and backward, rotate to left and right and move up and down).

Figure 6: Screenshots of the VE used in the study

2. 2. Measurement of Dependent Variables

Data for the dependent variables were collected through self-report and post-test measures. With virtual reality research, self-report and post-test performance measures have been a common method for collecting data about user experiences. Post-test questionnaires are easy to control and do not disrupt the virtual experience. The questions were designed to measure participants' sense of presence and retention of information about their environment. Several well-established instruments were adapted for each variable as described below.

2. 2. 1. Measures of Sense of Presence

Seeing as how presence is a subjective phenomenon, a common measurement approach is to use a questionnaire after the end of the experimental procedure (IJsselsteijn et al. 2000). Data for sense of presence were collected through a self-report, post-test questionnaire. This corresponds to the three proposed dimensions for dependent variable dimensions include spatial self-location, possibilities for action and reality judgement. These all were measured by adopting items from the Spatial Presence Questionnaire (MEC-SPQ) developed by Vorderer et al. (2004) called the measurement, effects and conditions. Three items on a 9-point Likert-type scale was adapted from the MEC-SPQ for spatial self-location (e.g. I felt as though I was physically present in the costume gallery environment) dimension. Possibilities for action dimension used three items adopted from the MEC-SPQ on a 9-point Likert-type scale (e.g. I felt like I could move

around among costumes in the gallery environment portrayed). For the measurement of the reality judgment, five items on a 9-point Likert-type scale were adopted from Baños et al. (2000) (For example, to what extent did you feel you "were" physically in the virtual world?). all these items showed good reliability in previous study by Balakrishnan and Sundar (2011): self-location (three items; Cronbach's α = 0.90), possibility for actions (three items; Cronbach's α= 0.81), and reality judgment (five items; Cronbach's α=0.94).

Lastly, for attention measures, three items on a 9-point Likert-type scale were adapted which captured perceived attentional allocation in relation to the spatial presence (e.g. I devoted my entire attention to the costume gallery environment).

Spatial memory in the virtual environment were measured by having participants explore a virtual environment actively and then asking questions that are based on both free recall and cued recall of spatial information such as their memory for object location and relation between objects. Six items were developed for free recall based questions including 3 items on a 4 points scale (e.g. how many costumes did you see in the virtual gallery that you just visited?) and 4 items on a confidence scale with five possible states ranging from no confidence (1) to certain (5) (e.g. How confident are you about seeing the wall art in the virtual environment that you just visited?)

The questionnaire included 5 cued recall-based questions that exposed participants to screenshots of some objects and asking them whether they saw a particular object during the exposure to stimuli. including 4 questions about relations between objects or placement of the objects which required matching the objects correctly to screenshots of

each of the spaces. This instrument was scored by assigning one point to each correct answer.

2. 2. 2. Measures of Spatial Memory

Spatial memory in the virtual environment will be measured by having participants explore a virtual environment actively and then asking questions that are based on both free recall and cued recall of spatial information such as their memory for object location and relation between objects. Six items were developed for free recall based questions including 3 items on a 4 points scale (e.g. how many costumes did you see in the virtual gallery that you just visited?) and 4 items on a confidence scale with five possible states ranging from no confidence (1) to certain (5) (e.g. How confident are you about seeing the wall art in the virtual environment that you just visited?)

The questionnaire included 4 cued recall-based questions that exposed participants to screenshots of some objects and asking them whether they saw a particular object during the exposure to stimuli. including 4 questions about relations between objects or placement of the objects which required matching the objects correctly to screenshots of each of the spaces. Cued recall items are on a 9-points scale ranging from 0 (no correct answer) to 8 (8 correct answers). This instrument was scored by assigning one point to each correct answer.

2. 2. 3. Other Measures

In addition to the dependent variables of presence and spatial memory, several demographic variables were gathered through self-report methods as potential control for confounding variables. All measures are in a Likert-type format with strongly agree (9) or strongly disagree (1) or similar adjectives as opposite ends. The demographic variables including gender, academic standing, and major of study were used as the control measures. Participant skill levels may vary and were controlled through a training session before data collection. In addition, previous experience with virtual reality and 3D 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 and video games consisted of four items developed for this study on a 9-point Likert-type format (e.g. How familiar are you with playing video games on Xbox, PlayStation, Nintendo, or PC?). Another measure was developed to control for individual's spatial abilities, a three items spatial memory abilities scale on 9-point Likert scale-type format (e.g. I am good at remembering interior spaces details and objects inside them).

2. 3. Sample

Students enrolled in graduate and undergraduate level classes at the University of Minnesota were asked to participate in the study for 10 minutes. Students were randomly assigned to one of the three conditions. The sample was included 33 students age 20-35

from college of design. There were 11 participants in each condition. Approximately the same number of men and women were allocated to all conditions. Each subject was participated in one of the three conditions described above.

2. 4. Pre-Testing

We pre-tested the manipulations as well as the measures to refine them before the final study is conducted. Pre-testing also provided insights for refining the questionnaire. Pre-testing were conducted with six graduate and undergraduate students from different colleges. Using these diverse groups provided insight into how people from different disciplines would react to different levels of immersion, so that refinements could be made.

2. 5. Experiment Procedure

A detailed research protocol was developed with verbal scripts for instructions to ensure consistency and avoid researcher bias. Following the scripted protocol, participants were greeted and briefed about the study. Once the participants indicate they understood what the study is about and what is expected from their participation, formal verbal consent were obtained in compliance with the Institutional Review Board specifications. The procedure included four main parts: filling out a demographics questionnaire, training on the Oculus Rift head-mounted display or the joystick, listening to the narrative for task instructions, performing the task, and filling out the post-test questionnaire.

2. 5. 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 will last from zero to two minutes until the participant could confidently navigate with the joystick. The participant will be shown how the joystick works 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 were asked to use the joystick to move around a virtual environment freely. During the free exploration, more explanation and tips on use of the joystick were provided.

2. 5. 2. Study Task

Following the training, participants were asked if there are 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 were explained. In order to help with psychological immersion, it is important to help the participants maintain attention on the task. A scripted narrative was presented using a hard copy printed paper to provide details of the task to the participant. The refined script from initial pre-testing were provided participants with the task details in written format.

Following the splash-screen, the environment for the task were loaded, and participants were told they can start the task. The instructions indicated there were a five-minute time limit. The five-minute time limit was used to help control for the amount of time spent in

the environment so it would remain consistent for all participants. During the five-minute

task, the researcher noted any use of the joystick manipulation or VR headset and any

issues encountered. The task was started out at the entrance of the human environmental

science college virtual environment.

The task involved the comprehension and memorization of three-dimensional spaces and

objects within the virtual environment. Participants completed these tasks under

conditions of varying fields of view and with stereo and mono displays. After

completion, participants completed a series of standardized questionnaires designed to

measure spatial memory and degree of presence, and some other general information.

Figure 7: Experiment set-up.

2.6. 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

visual immersiveness on spatial presence measures and spatial memory, 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 presence and spatial memory 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 dependent variable dimension. To analyze the results of the technology manipulations on spatial presence and spatial memory, individual ANCOVAs were conducted to see if group differences existed in each dependent variable. Also, a t-test was conducted to check the stereoscopy technology manipulation impact on each dependent variable.

CHAPTER 3: ANALYSIS & RESULTS

This chapter reports the results of data analysis from the experiment. The first section discusses data screening and testing for assumptions. The next sections detail the results of statistical tests to address the research question and hypotheses. Specifically, this study investigated the influence of visual immersiveness on spatial presence and spatial memory. The analysis was conducted using SPSS statistical analysis software. To address the overall research question and hypotheses, several statistical tests were conducted on each of the dependent measures. The analysis consisted of multivariate analysis of covariance (MANCOVA) and analysis of covariance (ANCOVA) to address how the technology affordance manipulations impacted each of the dependent measures.

3.1 Sample Characteristics and Demographics

Participants (N = 32) from a mid-western university from Product design and architecture courses volunteered to participate in this study. The average age was M= 23.25 with 17 males and 15 females.

3.2 Data Screening

Before testing the hypotheses, data was first screened for missing values and outliers, both univariate and multivariate. No missing data points were found across the dependent variables and covariates.

The univariate outliers were detected by visual inspection of histograms with normal curves. In addition, skewness and kurtosis values were evaluated for normality with values below ±2.0 treated as acceptable. Most cases fell within the normal range and were not detected as outliers. Two outliers were detected for spatial presence. One in the medium immersion (TV) condition and the other in the high immersion (Oculus Rift HMD) condition. In this case, the participant's responses were treated as special case. After examining them individually, it was decided to employ the winsorizing method to replace those extreme values (3 standard deviations from the mean cutoff) to preserve the sufficient power for data analysis (Salkind, 2010).

Mahalanobis distance through a chi-square distribution was used to detect multivariate outliers. There were no multivariate outliers. Then, the data were tested for the assumptions of independence of observations, normality (Shapiro-Wilk's W test), homogeneity of variance-covariance matrices (Box's M test), measurement error of covariates, linear relationships between covariate and dependent variables, and homogeneity of regression. To test the normality, a visual inspection of histograms, and normal Q-Q plots were used. The examination showed that all data were normally distributed. Assumptions were checked by visually observing histograms, skewness and kurtosis values. A summary of means for the dependent measures, as well as their standard deviations, skewness, and kurtosis values are summarized in Table 5 under descriptive statistic section.

Reliability of the covariates and dependent variables was examined using Cronbach's α. Scatter plots were used to assess the linearity of the covariates and dependent variables. Homogeneity of variance-covariance matrices was evaluated using Levene's test.

Homogeneity of regression was checked to see if any interaction existed between the independent variables and covariates. The relationships between the independent variable and covariates were found to have no significant interaction in all instance

3.3 Reliability Analysis for Dependent Variables and Covariates

Spatial presence was measured using three dimensions including self-location, possibilities for action and reality judgement. Indices for these dimensions were constructed by averaging individual items on the respective scales and each showed good reliability: self-location (three items; Cronbach's $\alpha = 0.86$), possibility for actions (three items; Cronbach's $\alpha=0.73$) and reality judgment (five items; Cronbach's $\alpha= 0.91$). The index created for spatial memory (ten items; Cronbach's $\alpha= 0.67$) also had good internal consistency. In addition to all dependent variables, indices for covariates were constructed by averaging individual items on the respective scales and showed good reliability: attention allocation (three items; Cronbach's $\alpha=0.91$), and 3D familiarity (four items; Cronbach's $\alpha=0.70$) see Table 3.

Table 3: Reliability for dependent variables and covariates

	Cronbach's α	Mean	Std. Deviation
Self-location	0.86	5.07	0.1
Possibilities for action	0.73	5.23	1.32
Reality judgement	0.91	5.18	0.35
Attention Allocation	0.91	6.68	0.1
Spatial memory	0.67	3036	2.13
Familiarity with 3D	0.70	5.78	1.25

3.4 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 4). These correlations informed the use of covariates for the analysis.

Table 4: Correlations between dependent variables and covariates.

			Correlations				
	1	2	3	4	5	6	7
1. Familiarity_with_3D	-						
2. Involvement	.100	-					
3. Self-Location	.308	-.508**	-				
4. Possibilities for Action	.216	-.105	.664**	-			
5. Reality Judgement	-.008	-.445*	.840**	.580**	-		
6. Attention Allocation	.203	-.207	.449**	.444*	.433*	-	
7. Spatial Memory	-.010	-.296	.540**	.518**	.681**	.220	-

*significant at the $p<0.05$, **significant at the $p<0.01$.

3.5 Descriptives

Descriptive statistics of covariates and dependent variables after adjusting for missing values and outliers are listed below in Table 5.

Table 5: Descriptive of covariates and dependent variables.

	N	Mean	Std. Deviation	Skewness	Kurtosis
Age	32	23.25	4.01	1.67	2.17
Gender	32	0.56	0.50	-.26	-2.06
Familiarity with 3D	32	5.78	1.54	.19	-.58
Involvement	32	5.74	1.13	-.48	-.31
Self-Location	32	5.07	1.82	-.23	-.42
Possibilities for Action	32	5.27	1.53	-.04	-1.18
Reality Judgement	32	5.13	1.68	-.41	-.00
Attention Allocation	32	6.56	1.74	-1.17	2.39

3.6 Hypothesis Testing

The data were examined using SPSS statistical analysis software for evidence to support the hypotheses at a significance level of 0.05. Multivariate Analysis of Covariance (MANCOVA) used for experimental research designs to test for statistical differences among groups when there are 1) more than one independent variables, 2) one or more covariates incorporated into the design, and 3) multiple correlated dependent variables while controlling for the correlation among the dependent variables (Tabachnick & Fidell, 2001).

3.6.1 Spatial Presence Measures

Spatial presence measures included three dimensions: possibilities for action, self-location, and reality judgment. All three 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 immersion on all the spatial presence measures. The MANCOVA included two covariates: gender and attention. Attention was a scaled measure included in the spatial presence questionnaire as a control variable. In this analysis, attention was therefore used as a covariate. The MANCOVA analysis revealed a significant main effect for immersion, Wilks' $\lambda = 0.48$, F (6, 31) = 3.75, p<.05, partial $\eta^2 = 0.31$, see table 6.

Table 6: Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[d]
Intercept	Wilks' Lambda	.69	3.80[b]	3.00	25.00	.02	.31	11.41	.75
Gender	Wilks' Lambda	.86	1.42[b]	3.00	25.00	.26	.15	4.26	.33
Attention allocation	Wilks' Lambda	.80	2.09[b]	3.00	25.00	.13	.20	6.26	.47
Immersion	Wilks' Lambda	.48	3.75[b]	6.00	50.00	.004	.31	22.49	.94

Factorial analysis of covariance (ANCOVA) was conducted as a follow-up to the multivariate analysis to examine the impact of immersion on each of the three dimensions

of spatial presence. These results indicate that immersion significantly impacted all spatial presence dimensions. On all dimensions of spatial presence, a higher immersion level increased the reported sense of presence. For spatial self-location, there was a significant main effect for immersion, $F(2,32) = 14.88$, $p<0.001$, partial $\eta^2= 0.51$; those in the higher immersion level condition felt greater self-location in the virtual environment (adj. $M = 6.36$, $SE = 0.38$) than those in the medium (adj. $M = 5.30$, $SE = 0.42$) and low immersion level (adj. $M = 3.30$, $SE = 0.42$) conditions. On the possibilities for action component of spatial presence, there were significant main effects for immersion, $F(2, 32) = 6.92$, $p < .05$, partial $\eta^2 =0.32$. Participants in the higher level of immersion condition felt that they had greater possibilities for action (adj. $M = 6.11$, $SE = 0.38$) in the virtual environment compared to participants in the medium (adj. $M = 5.47$, $SE = 0.41$) and low immersion conditions (adj. $M = 4.07$, $SE = 0.41$). On reality judgment, there was a significant main effect for immersion, $F(1, 32) = 6.55$, $p < .05$, partial $\eta^2= 0.31$. Participants in the higher level of immersion condition scored higher on the reality judgment scale (adj. $M = 5.93$, $SE = 0.42$) compared to medium (adj. $M = 5.50$, $SE = 0.46$) and lower level of immersion conditions (adj. $M = 3.78$, $SE = 0.46$).

Table 7: Tests of Between-Subjects Effects for Spatial Presence.

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[d]
Immersion	Self-location	51.861	2	25.931	14.884	.000	.507	29.768	.998
	Possibilities for action	23.356	2	11.678	6.917	.003	.323	13.834	.895
	Reality judgement	27.337	2	13.669	6.554	.004	.311	13.108	.877

Table 8: Estimated Marginal Means

Dependent Variable	Immersion conditions	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Self-location	Desktop (Low Immersion)	3.300	.417	2.446	4.154
	TV (Medium Immersion)	5.300	.417	4.446	6.154
	Oculus (High Immersion)	6.361	.381	5.582	7.140
Possibilities for action	Desktop (Low Immersion)	4.067	.411	3.226	4.907
	TV (Medium Immersion)	5.467	.411	4.626	6.307
	Oculus (High Immersion)	6.111	.375	5.344	6.878
Reality judgement	Desktop (Low Immersion)	3.780	.457	2.846	4.714
	TV (Medium Immersion)	5.500	.457	4.566	6.434
	Oculus (High Immersion)	5.933	.417	5.081	6.786

A post hoc comparison test was conducted to compare the effect of immersion on all three spatial presence dimensions. For self-location, post hoc comparisons using the Bonfferoni test indicated that the mean score for the high immersion (stereoscopic 3D and wide FOV) condition (M = 6.36, SD = 1.45) was significantly different than the low immersion (non-stereoscopic and narrow FOV) condition (M = 3.30, SD = 1.21). However, the medium immersion (non-stereoscopic and medium FOV) condition (M = 5.30, SD = 1.26) did not significantly differ from the high immersion condition. For possibilities for action dimension, the mean score for the high immersion (stereoscopic 3D and wide FOV) condition (M = 6.11, SD = 1.42) was significantly different than the low immersion (non-stereoscopic and narrow FOV) condition (M = 4.07, SD = .68). However, the medium immersion (non-stereoscopic and medium FOV) condition (M = 5.47, SD = 1.59) did not significantly differ from the high immersion and low immersion conditions.

For reality judgement, the mean score for the high immersion (stereoscopic 3D and wide FOV) condition (M = 5.93, SD = 1.39) was significantly different than the low immersion (non-stereoscopic and narrow FOV) condition (M = 3.78, SD = 1.24). Though, the medium immersion (non-stereoscopic and medium FOV) condition (M = 5.50, SD = 1.68) did not significantly differ from the high immersion condition.

3.6.1.1 Hypotheses Set I: Spatial Presence

These results help to support hypothesis H1 which predicted that greater levels of visual immersiveness would increase spatial presence. The results of each of the individual tests should be considered together to address the study's hypotheses.

H1: Greater levels of visual immersiveness will increase spatial presence
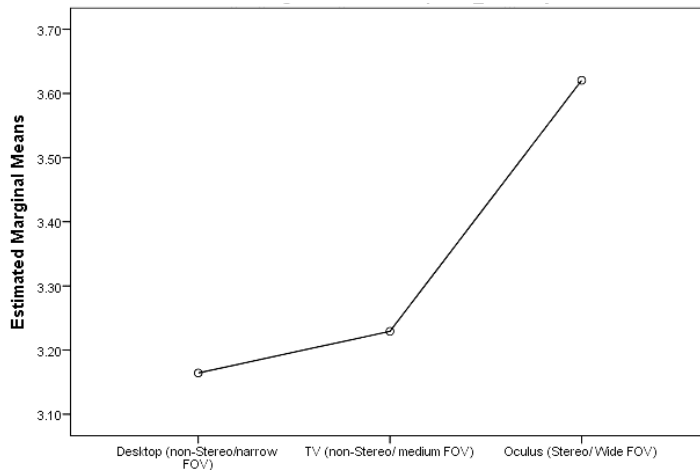
3.6.2 Spatial Memory Measures

An ANCOVA test conducted on spatial memory controlling for gender. Object memory is the single measure for spatial memory in this study. The measure was defined as the number of correct answers in recalling the objects location.

For spatial memory, the results showed a significant main effect for immersion when controlling for gender $F_{(2, 31)} = 3.78$ $p<.05$, partial $\eta^2 = .21$, see Table. 9. The findings indicate that object memory performance is greater in the high level of immersion (wide field of view and stereoscopic display) condition (M = 3.57, S.E. = .61) compared to the medium level of immersion (medium field of view and non-stereoscopic view) condition (M =3.31, S.E. = 0.39) and low level of immersion (narrow field of view and non-stereoscopic display) condition (M =3.15, S.E. = 0.39).

Table9: Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2.890ᵃ	3	.963	5.437	.004	.368
Intercept	180.04	1	180.04	1016.08	.000	.97
Gender	1.89	1	1.89	10.65	.003	.28
Immersion	1.34	2	.67	3.78	.035	.21
Error	4.96	28	.18			
Total	368.19	32				
Corrected Total	7.85	31				

Figure 8: estimate marginal means for spatial memory

Another ANCOVA was conducted on cued object recall measure of spatial memory. Cued recall measure used screenshots of the stimulus to cue participant's memory on the object 'locations and relationship between objects in the environments. There were 4 items in cued recall measure with possible scores ranging from 0 to 8. The minimum score of 0 means no correct answer and maximum score of 8 means all 8 answers were correct. For cued recall, there was a significant main effect for immersion, $F_{(2,31)} = 4.05$ $p<0.05$, partial $\eta^2 = .22$. The findings suggest that with a high level of immersion (wider field of view and stereoscopic display) (adj. M = 5.56, S.E. =0.56), resulted in more accurate cued recall when compared to medium immersion (M = 5.10, S.E. = 0.58) and the low immersion condition (M = 4.93, S.E. = 0.50).

Further analysis, a separate post hoc test was conducted to compare the effect of immersion on spatial memory. Post hoc comparisons using the Bonfferoni test indicated that the mean difference score for the high immersion (stereoscopic display and wide FOV) condition (M = 3.57, SD = 0.61) and the low immersion (non-stereo and narrow

61

FOV) condition (M = 3.15, SD = 0.39) was small. Also, the medium immersion (non-stereoscopic and medium FOV) condition (M = 3.31, SD = 0.39) did not significantly differ from the high immersion and low immersion conditions.

3.6.2.1 Hypotheses Set II: Spatial Memory

The results of ANCOVA test and Post hoc support the study's hypotheses:

H2: Greater levels of visual immersiveness will improve spatial recall.

A wider field of view and stereoscopic display was found to improve spatial recall.

CHAPTER 4 – 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.

4.1 Summary of Results

The analyses showed that overall, the manipulation of immersion had a significant impact on various dimensions of spatial presence and spatial memory. As predicted, individual analysis of each spatial presence dimensions revealed that a higher level of immersion did lead to experiencing greater sense of spatial presence. In all cases a higher level of immersion accounted for higher feelings of spatial presence in each dimension.

In breaking down the results of spatial presence, wide field of view and stereoscopic display when compared to narrow field of view and non-stereoscopic display increased spatial presence.

Statistical significance was found for the impact of immersion on spatial memory (H2: greater levels of visual immersiveness will improve spatial memory performance). Further analysis revealed that mean difference for wide field of view/ stereoscopic

display condition and narrow field of view/ non-stereoscopic display condition is small,

additional subjects could have improved the statistical power of the study that could have

detected the smaller effects.

Figure 9: Hypotheses for spatial presence and spatial memory are significant while controlling for covariates.
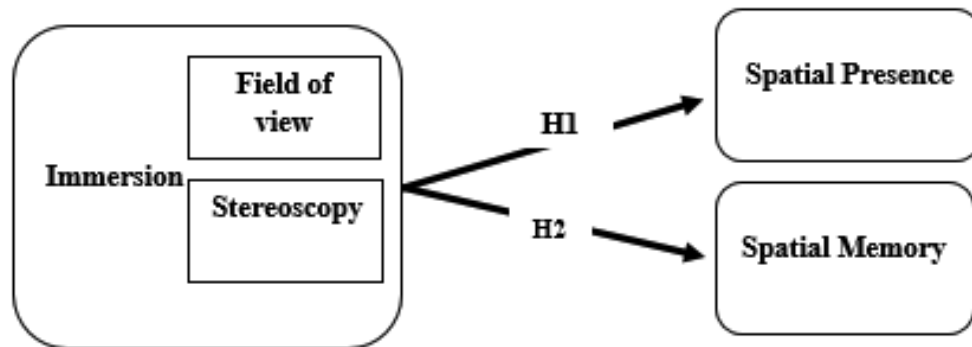
4.2 Interpretation of Results

Considering the findings, insight can be gained from the interpretation of the significant

and insignificant influences of the technology affordances including field of view and

stereoscopy on each of the dependent variables including spatial presence and spatial

recall). These insights can help to inform an understanding of the relative impact of

technology affordances 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 with spatial presence and spatial memory.

4.2.1 Impact of Visual Immersiveness on Spatial Presence

The findings from the analysis confirmed that visual immersiveness did significantly impact perceptions of spatial presence. 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). The results from this study indicated that visual immersiveness alone was sufficient in influencing spatial presence when controlling for attention, and gender. With stereoscopy display when the field of view was wide, the sense of presence was enhanced for each dimension. A wider field of view can provide an individual with more peripheral vision, thus blocking out the immediate physical environment to concentrate on the virtual space. Experiencing the sense of being in a simulated environment occurs due to the focus of the user on the virtual space. Moreover, Stereoscopy provides visual depth cues to existing images (Crone, 1992).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 the significance of the influence of visual immersion on spatial presence support influence of field of view and stereoscopy on spatial presence.

4.2.2 Impact of Visual Immersiveness on Spatial Memory

The influence of immersion on spatial memory while controlling for gender confirmed the prediction that a higher level of immersion would increase the number of accurate recalls. Further analysis revealed that the mean differences were relatively small between

the high immersion (wide field of view/ stereoscopic display) condition and low

immersion (narrow field of view/ non-stereoscopic display) contrition.

Similar to the mechanism of how visual immersiveness affect spatial presence, wider

field of view is able to provide more visual cues described by Crone (1992) at any given

time and to provide more peripheral view reducing the amount of external visual

distraction and also making better association of the object to each space. The wider field

of view allowed the participants to see more of the spaces at any given time and receive

more spatial cues. Obtaining more spatial cues can help participants to generate

landmarks for remembering spaces. In stereoscopic display, depth cues help users to

receive cues similar to what we see in the real world, enhancing memory.

4.3 Practical Implications of the study

This study has practical implications across different domains including architectural

visualization, virtual reality technology development, and for training programs.

4.3.1 Implications for Architectural Visualization

One of the practical implications of this study is in architectural visualization. Findings of

this study can help to improve the virtual reality system as a tool to experience and

evaluate unbuilt architectural spaces which are still in the design phase. Understanding

the impacts of virtual reality technology on design students, designers, and clients, can

improve it further as a tool for presenting and communicating architectural design.

The immersion helps users to understand spatial qualities during different stages of the design process (Campbell & Wells, 1994). Immersive virtual environments can be used for visualization of objects and environments in different contexts. It is commonly expected that higher level of immersion leads to a higher level of spatial understanding of complex 3D environments (Durlach & Mavor, 1995; Schuchardt & Bowman, 2007). The finding from testing of the two components of immersion (field of view and stereoscopy) has improved our understanding of spatial memory and experience of presence in the virtual environments.

4.3.2 Implications for Virtual Reality Technology Development

The other practical implication of this study is for design and development of virtual reality systems. An immersive VR head mounted display like the Oculus Rift or HTC Vive can greatly benefit from the findings of this study. These immersive head-mounted displays can provide a better user experience and workflow for professional applications by reducing the gap that exists between the FOV that they offer and the human's natural FOV. This study confirmed the positive combined effect of field of view and stereoscopy on different dimensions of spatial presence. So, a virtual reality system such as the Oculus Rift could benefit more with the understanding of how these feature works collectively on both spatial presence and spatial memory.

4.3.3 Implications for Training Programs

This study also has practical implication for immersive virtual reality training applications involving spatial contexts. It would help trainees to develop specific skills and activities that require trainee's spatial memory. Findings of this study can provide direction to the ongoing development of training simulators. Some simulators such as the surgical training simulator requires a high level of users' task performance and memory. These types of training programs use high fidelity simulators, screen-based virtual reality VR system or CAVE VR systems to place a person into a simulated environment that looks and feels like the real world. Users in these virtual environments can internally develop a sense of self-location. The head and body movement enables users to have a more realistic experience of the VR environment which eventually gives them a feeling that they can interact with the objects in the environment. With advancing technology, more affordable VR systems such as Oculus Rift has a potential for simulation training. Simulated training environments presented through immersive head-mounted displays can provide a better sense of presence, realism and smoother movement compared to screen-based simulation. 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. These findings for improving spatial presence could be used to enhance the efficiency and effectiveness of current systems without adding to the cost of acquiring an expensive system.

Some other of training programs focus on the acquisition of spatial knowledge to develop spatial skills. In these cases, the acquired spatial knowledge should be transferred into the

real-world settings (Stanney et al., 2013). Some of these applications (e.g., police and military VR training, or flight simulator) require users to remember the spatial information by role playing in those serious games. The higher levels of immersion in the VR training applications will enable users to memorize and remember the location of objects and spaces more efficiently.

4.4 Potential Threats to Validity and Limitations of the Study

This study confirmed the impact of two technology affordances on spatial memory and sense of presence. But, there are still some limitations that threat the validity of this study. The major potential threat is the small sample size. Although the results confirmed the impact of independent variables on dependent variables, recruiting more participants would improve the statistical power, that eventually leads to the better generalizability of findings.

In addition to sample size, there are some limitations that are directly related to characteristics of virtual reality systems. Motion sickness and disorientation have a negative impact on users' performance and comfort in the virtual environment. To reduce this potential threat, we can design shorter tasks for the experiments. In addition, employing virtual reality displays with smaller FOV could reduce the feeling of motion sickness (Jex, 1991). However, the larger FOV has a positive impact on other aspects of comprehension such as the sense of presence and spatial memory. Natural body movement in the virtual environment is another factor that was not considered in this study. The head-mounted display condition of this study provides some possibilities for

head and body movement and rotation. But, participants in the desktop and TV condition use the joystick for navigating in the VR environment.

4.5 Conclusion & Future Directions

This study investigated the influence of the visual immersiveness on spatial presence and spatial memory in the virtual environments. The design of the study then looked specifically at two key technology aspects of a virtual reality system: a) the field of view and b) stereoscopy. The results of this study confirmed that visual immersiveness field of view and stereoscopy view plays a significant role in all measures of dependent variables. The other direction for future research could be investigating the combined impact of other technology affordances on spatial memory and sense of presence. New immersive virtual reality systems provide the opportunity for free movement and body tracking for users. The natural body movement could be another topic of investigation for researchers in this area. Immersive collaborative environments enable users to interact and communicate in the virtual environment. Future research could be focused on the impact of social presence and communication of spatial memory. Virtual reality is a growing field with many potential impacts on different aspects of people's lives and society. Future investigation in this area can improve the workflows and processes of practical implications in different industries. It can also benefit user of technology as well as society, by improving the efficiency and usability of virtual reality solutions.

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APPENDIX A-EXPERIMENTAL PROTOCOL

EXAMINING THE INFLUENCE OF LEVEL OF IMMERSION ON USERS' SENSE OF PRESENCE AND SPATIAL MEMORY IN VIRTUAL ENVIRONMENTS.

Research Protocol:

Responsibilities: Day Before the study

Zhaleh should send an email to subject with the following information

Time slot signed up for:

Directions to come to the Rapson Hall & wait in the chair outside until the ongoing session is over. Then she will come out and let you in at the right time. Please wait for at least 5 minutes before knocking on the door in case an ongoing session runs is running late.

Before the subjects are seated at the study

- Hang sign outside the door- "Research Session in Progress. Please do not enter! Have a seat and the researcher will meet you there after the current session is over".
- Turn all displays and computers on and launch one of the three experimental conditions based on the randomized experimental runs
- Ensure interactive stimuli is working

- Have the sign-in sheet ready

- Have a pen for participants and one for self with and an extra pen as a back-up.

- Have 2 copies of informed consent forms ready to hand out.

- Have 2 questionnaire ready

    Demographics

    Presence and Spatial Memory

- Mark the experimental condition number on the questionnaire

(O___ T___ D___)

O: High Immersion (Oculus)

T: Medium Immersion (TV)

D: Low Immersion (Desktop Pc)

High Immersion	Medium Immersion	Low Immersion
(Oculus)	(TV)	(Desktop Pc)

Welcome & Overall instructions

On arrival of participants for a given session

Greet the subjects

Show participants to their seats

give an overview of the study

Script*:*

Thanks for coming in today. We really appreciate your participation. If you can please turn your mobile phones off or put it on mute, we can start with the study which will take around 30 minutes.

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. You will then be requested to walkthrough a main virtual environment on (Oculus CV1 Virtual Reality Head-mounted Display / large TV/ PC monitor) and explore the interactive virtual environment for 5 minutes. You are encouraged to explore the building environment including entrance, hallway, and the room. After this, you will complete a brief questionnaire about your experience and memory of the objects in the virtual environment. Overall, this study should take approximately 30 minutes. Please undertake the tasks in relaxed manner, as you would normally explore a game environment, taking as much time as you need.

Informed Consent Form

Go through the consent form explaining the purpose of the study, procedures to be followed, confidentiality protections in place and risks as well as benefits. Answer any questions

Get signature on consent form. Hand one signed copy back to the subject for their records.

Administer the experiment stimulus

Script:

Okay, now you can go ahead and explore the virtual environment. 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 explore the virtual environment, 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?

Administer Questionnaire

If the subject is running late, check on the next subject and start with the study while the current subject is completing the questionnaire.

Debriefing & Thank You!

On completion thank the subjects for their participation; clarify any further questions regarding the experimental procedures, data analysis or use of data.

Post Experiment session

File the Informed Consent forms in the folder assigned for the same.

Mark serial number (Experiment Condition) and date on the questionnaires used in the experimental session and file them in the folder assigned for the same.

Lock up the Informed Consent Form and Completed Surveys in the lab cabinet.

Check sufficiency of consent forms, questionnaire for next session / next day. (If insufficient, print required copies)

APPENDIX B-DEMOGRAPHIC QUESTIONAIRE

Part – 1 Demographic and Control Measures

> **Condition # (O___ T___ D___)**
>
>   **1**   **2**   **3**
>
> **Please do not write in this box**

1. Age: _____

2. Gender: □ Male   □ Female

3. Academic Standing: □Freshman   □Sophomore   □Junior   □Senior   □Graduate

4. Academic Major: _____

5. Are you Architectural Studies student?   □ Yes   □ No

Please indicate <u>how familiar</u> 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, Nintendo, or PC?

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

2. How familiar are you with watching 3D movies? (this can include theaters, and 3D TV)

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

3. How familiar are you with 3D online virtual world? (e.g. second life, Wonderland, etc.)

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

4. How familiar are you with 3D modeling software? (e.g. Rhino, AutoCAD, SolidWorks, CATIA, SketchUp, 3Ds Max, Solid Thinking, Pro Engineer, etc.)

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

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

1. 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**

2. 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**

3. 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**

4. 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**

Thank you for completing this survey!

APPENDIX C-POST-TEST QUESTIONAIRE

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

1. I felt like I was actually there in the costume exhibition environment.

    Not at all 0　　1　　2　　3　　4　　5　　6　　7　　8　　9 Very much

2. I felt as though I was physically present in the costume exhibition environment.

    Not at all 0　　1　　2　　3　　4　　5　　6　　7　　8　　9 Very much

 3. It seemed as though I actually took part in the action in the costume exhibition environment.

    Not at all 0　　1　　2　　3　　4　　5　　6　　7　　8　　9 Very much

---

4. I felt like I could move around among costumes in the exhibition environment portrayed.

    Not at all 0　　1　　2　　3　　4　　5　　6　　7　　8　　9 Very much

5. The objects portrayed in the costume exhibition environment gave me the feeling that I could do things with them.

    Not at all 0　　1　　2　　3　　4　　5　　6　　7　　8　　9 Very much

6. It seemed to me that I could do whatever I wanted in the costume exhibition environment portrayed.

    Not at all 0　　1　　2　　3　　4　　5　　6　　7　　8　　9 Very much

---

7. In your opinion, how was the quality of images in the virtual environment?

Very low 0   1   2   3   4   5   6   7   8   9 Very high

8. To what extent did your interactions within the costume exhibition environment seem natural to you, like in the real world?

Not at all 0   1   2   3   4   5   6   7   8   9 Very much

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

Not at all 0   1   2   3   4   5   6   7   8   9 Very much

10. How real did objects portrayed in the costume exhibition environment seem to you?

Not at all 0   1   2   3   4   5   6   7   8   9 Very much

11. To what extent was your experience in the costume exhibition environment congruent to other experiences in the real world?

Not at all 0   1   2   3   4   5   6   7   8   9 Very much

---

12. I devoted my whole attention to the costume exhibition environment.

strongly disagree 0   1   2   3   4   5   6   7   8   9 strongly agree

13. My attention was claimed by the costume exhibition environment.

strongly disagree 0   1   2   3   4   5   6   7   8   9 strongly agree

14. I dedicated myself completely to the investigation task in the costume exhibition environment

strongly disagree 0   1   2   3   4   5   6   7   8   9 strongly agree

Please indicate how well you identify with each of the following questions. Please circle a single number between 1 and 9 (where 1 = strongly disagree and 9 = strongly agree).

15. I was able to imagine the arrangement of the rooms in the virtual environment very well.

strongly disagree 0   1   2   3   4   5   6   7   8   9 strongly agree

16. I had a precise idea of the spatial surroundings in the virtual environment.

strongly disagree 0   1   2   3   4   5   6   7   8   9 strongly agree

17. I was able to make a good estimate of the sizes of various objects in the virtual environment.

strongly disagree 0   1   2   3   4   5   6   7   8   9 strongly agree

18. I still have a concrete mental image of the virtual environment where I carried out the investigation task.

strongly disagree 0   1   2   3   4   5   6   7   8   9 strongly agree

19. I was able to make a good estimate of how far apart things were from each other in the virtual environment.

strongly disagree 0   1   2   3   4   5   6   7   8   9 strongly agree

Please provide directions to best of your ability to answer each question. Please do NOT flip back to previous pages as this questionnaire is focused on obtaining your first impressions.

20. How many exhibitions did you see in the virtual environment?

0   1   2   3

21. How many women's costumes did you see in the main (large) exhibition room?

| 1-2 | 2-4 | 4-6 | 6+ |

22. How many costumes did you see in the corridor display?

| 1-3 | 3-5 | 5-7 | 7+ |

23. How confident are you about seeing the wall art in the virtual environment that?

| no confidence | low confidence | moderate confidence | confident | certain |

24. How confident are you about seeing men's costume in the virtual environment?

| no confidence | low confidence | moderate confidence | confident | certain |

25. How confident are you about seeing windows to outside in the virtual environment?

| no confidence | low confidence | moderate confidence | confident | certain |

26. How confident are you about seeing this costume in the virtual environment?

| no confidence | low confidence | moderate confidence | confident | certain |

27. Have you seen any of these costumes in the virtual environment?

1	2	3	4
☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
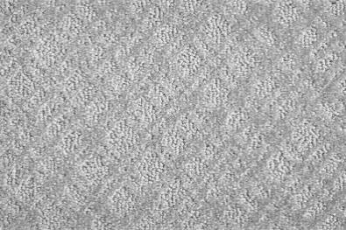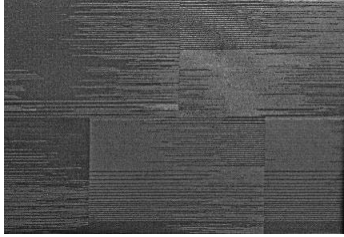
5	6	7	8
☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No

28. Have you seen any of below floor materials in the virtual environment?

☐ Yes ☐ No **Hardwood**	☐ Yes ☐ No **Stone**
1	**5**
☐ Yes ☐ No **Ceramic Tiles**	☐ Yes ☐ No **Marble**
2	**6**
☐ Yes ☐ No **Carpet**	☐ Yes ☐ No **Carpet**
3	**7**
☐ Yes ☐ No **Mosaic**	☐ Yes ☐ No **Mosaic**
4	**8**

29. Where each dress was located in the virtual environment (A or B)? Please see the building floorplan.

1	2	3	4	5	6
☐ A ☐ B	☐ A ☐ B	☐ A ☐ B	☐ A ☐ B	☐ A ☐ B	☐ A ☐ B

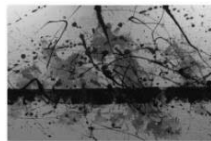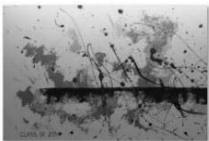| 7	8
☐ A ☐ B	☐ A ☐ B

A

B

Entrancec

94

30. Match the items to the corresponding room by drawing a line to connect the pictures or by marking the right answer.

☐☐☐
A B **C**

☐☐☐
A B **C**

☐☐☐
A B **C**

A

B

C

Thank you for completing this survey!