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# The Design of Wayfinding Affordance and its Influence on Task Performance and Perceptual Experience In Desktop Virtual Environments

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# The Design of Wayfinding Affordance and its Influence on Task Performance and Perceptual Experience In Desktop Virtual Environments

**by**

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## Dedication

I dedicate my dissertation to my parents and children, Changwoo and Samuel

## Acknowledgements

I could not have completed this dissertation without the support and encouragement of many people. I give special thanks to my advisor, Dr. Randolph Bias and my former advisor, Dr. Hsin-liang Chen, for providing guidance throughout my graduate studies with much support through the dissertation process. I wish to thank the other members of my dissertation committee, Dr. Andrew Dillon, Dr. Mary Lynn Rice-Lively, Dr. Luis Francisco-Revilla, and Dr. Liu Min, for their helpful suggestions and encouragement. I would also like to express my particular thanks to Joanne Click for insightful advice and ideas. Finally and most importantly, I want to acknowledge and thank my parents, my husband, and my children, Changwoo and Samuel, for their endless support and love.

**The Design of Wayfinding Affordance and its Influence on**
**Task Performance and Perceptual Experience**
**In Desktop Virtual Environments**

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For the past few years, virtual environments (VEs) have gained broad attention from both scholarly and practitioner communities. However, in spite of intense and widespread efforts, most VE-related research has focused on the technical aspects of applications, and the necessary theoretical framework to assess the quality of interfaces and designs has not yet been fully developed. This research, as a response to such challenges, concerns the usability of three-dimensional VEs. More specifically, this study aims to investigate the effects of wayfinding affordance design on users' task performance and perceptual experience in 3D desktop VEs.

For this purpose, four different wayfinding affordance conditions were set up: Fixed Detached Affordance Cues (FDAC) condition, Switchable Detached Affordance Cues (SDAC) condition, Portable Embedded Affordance Cues (PEAC) condition and Fixed Embedded Affordance Cues (FEAC) condition. Maps and directional cues were employed to implement wayfinding affordance.

The results show that the design of wayfinding affordance has significant effects on users' perceptual experience as well as their task performance. Task performance was significantly better where the maps and directional cues were provided independently from the VE interfaces (FDAC, SDAC). With regard to perceptual experience, the effect was significant only in simple environments. In these environments, the fixed and, therefore, stable interfaces (FEAC, FDAC) were found to provide a better sense of presence for users whereas the manipulative interfaces (PEAC, SDAC) offered a greater state of playfulness. The research findings also indicated that the design of 3D interfaces had a greater impact on non-expert users than on expert users.

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# Chapter 1 -- Introduction

A three-dimensional virtual environment (3D VE) is a computer representation of a real or an imaginary space through which and in which users can navigate and actively interact with objects in real time (Furness & Barfield, 1995; Shafieloo, 2005). With rapidly changing advances in technology, VEs provide a means of simulating real world places and activities in computer-generated spaces, where users can feel immersed and become involved in opportunities that are not otherwise possible in the real world (Witmer, Bailey, & Knerr, 1996).

For the past few years, VEs have gained much attention from both scholarly and practitioner communities (Bowman, Gabbard, & Hix, 2002). In spite of intense and widespread efforts, most VE-related research has focused on the technical aspects of applications. By contrast, the necessary theoretical framework needed to assess the quality of interfaces and designs has not yet been fully developed (Sayers, 2004). The concepts and interactions associated with VEs are considerably different from those of traditional two-dimensional applications, and new environments for VEs cannot rely solely on principles and guidelines developed for standard two-dimensional user interfaces (Sutcliffe & Gault, 2004).

Because there are few comprehensive and systematic approaches with regard to the design of new applications, a need exists to address the challenges posed by the development of many new VE systems and to create a theoretical basis for the design of VE interfaces (Kaur, Maiden, & Sutcliffe, 1996; Sutcliffe & Kaur, 2000). New theoretical approaches need to be concerned with the usability of three-dimensional VEs. This study seeks to address some of these issues by investigating the effects of wayfinding affordance design on users' task performance and perceptual experience in 3D desktop VEs.

### 1.1. DESIGN OF VE INTERFACE: ENHANCING WAYFINDING AFFORDANCE

A crucial aspect of interaction with VEs is navigation (Jul & Furnas, 1997). Navigation in VEs is important not only because it is the most universal and common interaction task but also because it often supports other primary tasks (Bowman, Kruijff, LaViola, & Poupyrev, 2005). Navigation consists of both cognitive and motor components, and the cognitive part of navigation is called wayfinding (Bowman et al., 2005). Wayfinding in VEs is more difficult to support than in the real world because VEs lack many of the real world physical cues and affordances (Elvins, 1997). For this reason, one of the major challenges has been the design and development of VE systems created to assist users in navigating virtual spaces (Darken & Sibert, 1996). Without effective means of moving through VEs, it is not possible for users to maximize their performance and experience.

One potential approach for addressing this problem is the enhancement of cognitive or perceptual affordances: that is, the addition of perceptual cues to virtual spaces (Bowman et al., 2005). Well-designed affordances reduce the perceived wayfinding complexity of VEs and positively affect users' performance and experience (Stanney, Mourant & Kennedy, 1998). Against this theoretical background, the purpose of this study is to examine the effects of four different wayfinding design approaches: fixed detached affordance cues (FDAC), fixed embedded affordance cues (FEAC), switchable detached affordance cues (SDAC), and portable embedded affordance cues (PEAC).

*Fixed detached affordance cues* refers to the affordance cues that are provided as a graphical user interface (GUI) separate from a 3D world and that are fixed on the screen whereas switchable detached affordance cues are independent from a 3D world but that can be controlled by users in terms of visibility and location on the screen. *Fixed embedded affordance cues* means that the affordance cues are designed as an inclusive element of the 3D environment so that they are not always visible to users whereas *portable embedded affordance cues* are objects built into the 3D world but that are always available to users. Those four approaches have their own advantages and disadvantages, and their unique features were found in this study to have different effects on users' wayfinding performance and perceptual experience.

Of the various wayfinding cues - including maps, signs, compasses, trails and landmarks - this study focuses mainly on maps with signs that show users their current locations and orientations. Maps are among the most widely and efficiently used affordance cues in VE design (Chittaro & Burigat, 2004; Edwards & Hand, 1997; Ruddle, Payne & Jones, 1999).

This study examines, in particular, the effects of different wayfinding affordances implemented by maps on users' task performance and perceptual experience. For that reason, attention needs to be redirected from the system side toward the users' perspective as another important aspect of usablity research.

### 1.2. USERS' PERCEPTUAL EXPERIENCE

Few studies have addressed the question of benefits that people derive from using VE's, based on users' own viewpoints. Research suggests that task benefits offered by VEs do not necessarily outweigh users' cognitive costs, at least with current technology (Stanney, Mourant, & Kennedy, 1998). Therefore, it appears likely that people use VEs for reasons other than task performance.

According to Riva (1999, p.87), the soul of virtual reality (VR) is a perceptual experience[i], that enables users to believe that they are "being there" in the virtual world. VE technologies enhance the cognitive and perceptual capabilities of users by extending the presentation of information to three dimensions and by supplementing this information with other sensory stimuli and temporal changes (Wann & Mon-Williams, 1996). With the help of VE technologies, users experience compelling illusions of being in a virtual space and becoming a part of electronically generated environments (Biocca, 1997).

In spite of the importance of users' perceptual experiences, most studies of VE design have relied upon observations or experiments that have reported expert interpretation of users' errors or users' performance data, along with problems of VE technologies (Sutcliffe & Gault, 2004). Only limited consideration has been given to users' experiences when they interact with virtual environments. Therefore, the purpose of this research is to investigate the influence of interface design on the users' perceptual experience, specifically, on their sense of presence and playfulness in navigating virtual spaces.

### 1.3. SCOPE OF THE STUDY

This research focuses particularly on three-dimensional VEs in a two-dimensional desktop application. Although the majority of current industry applications are represented with desktop VEs, not many studies have investigated VEs in a desktop environment (Sayers, 2004). Desktop VEs offer new possibilities and challenges for innovative user interfaces that can be realized only when VEs are balanced against the usability challenges from which most current three-dimensional VE systems suffer (Johnson, 1998).

### 1.4. RESEARCH QUESTIONS

The questions that guided the research were the following:

1. What are the effects of wayfinding affordance design on the wayfinding task performance?
2. What are the effects of wayfinding affordance design on users' perceptual experience, particularly in terms of presence and playfulness?

3. What is the relationship between users' perceptual experience and wayfinding task performance?

4. What is the relationship between presence and playfulness? Are these two experiences interdependent?

For this study, the wayfinding affordance design was manipulated by maps and signs that show current location and orientation of participants. Figure 1 illustrates four research questions in the relationship of an independent and dependent variables.

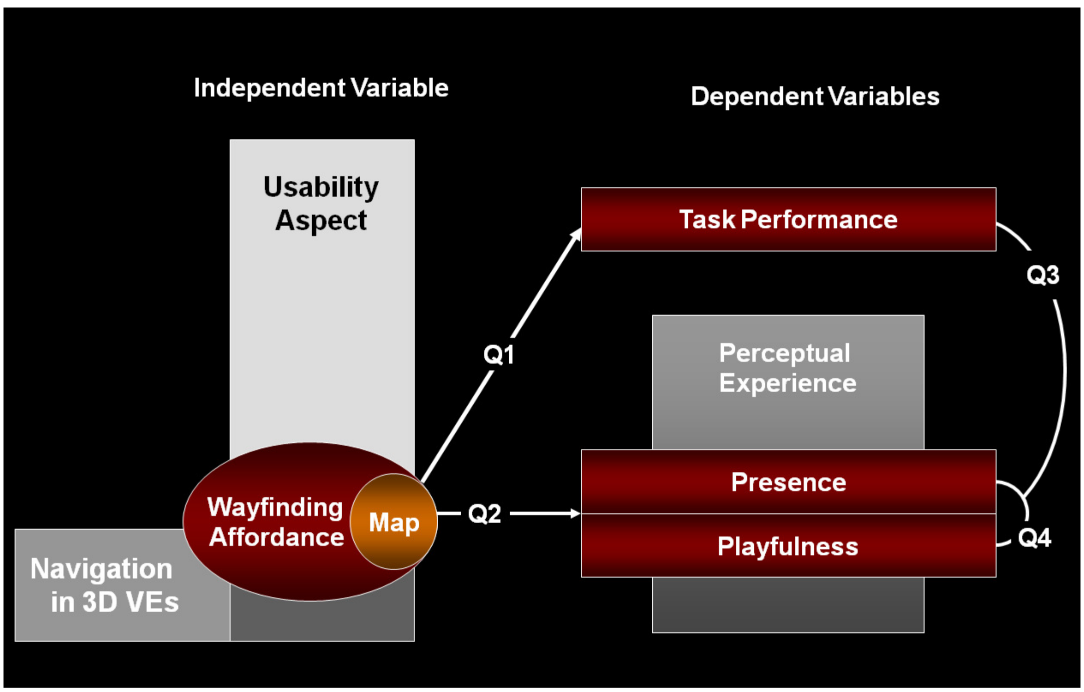



Figure 1. Overview of the Research

### 1.5. SIGNIFICANCE OF THIS RESEARCH

Research on the design and usability of 3D VE interfaces is essential for both theoretical and practical reasons. Theoretically, this research deepens the understanding of and refines theories of users' performance and perceptual experience in 3D virtual spaces that, in turn, provides background information for more practical purposes.

Practically, this research offers evaluation guidance and recommendations to developers for the creation of novel and effective interfaces for VEs. There is an ongoing need to formulate more specific and empirically based guidelines for the design of 3D user interfaces and on-screen VEs (Parush & Berman, 2004). The knowledge gained through this research will, therefore, offer better opportunities for the creation of more usable and efficient virtual environments and evaluation of the advantages and disadvantages of VE interfaces.

## 1.6. STRUCTURE OF THE DISSERTATION

The remainder of this study is structured in six chapters. Chapter 2 presents the history of 3D VEs, various applications of 3D VEs, and the advantages of 3D interfaces. Chapter 2 also addresses major issues for more practical and efficient VE interfaces.

Chapter 3 looks at key issues related to navigation and wayfinding in 3D virtual spaces and then provides an overview of affordance concepts as a theoretical framework to resolve wayfinding problems in 3D VEs. Chapter 3 also introduces four design approaches to support wayfinding in VEs with the application of the affordance concept: Fixed Detached Affordance Cues (FDAC), Fixed Embedded Affordance Cues (FEAC), Switchable Detached Affordance Cues (SDAC), and Portable Embedded Affordance Cues (PEAC).

Chapter 4 describes users' perceptual experience in 3D VEs. This chapter particularly focuses on two concepts, namely, presence and playfulness, and each of these concepts is explained in terms of definitions, influencing factors, effects, and empirical measures of each experience.

Chapter 5 proposes methodology for the study that includes participants, experimental design, measurement, equipment, procedures and data analysis.

Chapter 6 describes the results from the study conducted for this study. Chapter 7 discusses the overall findings, implications and limitations of this research as well as possible improvements for future research.

# Chapter 2 – Potential and Current Applications of VEs

This chapter briefly provides an overview of the history and current applications of 3D VEs and addresses, also, the main advantages of 3D interfaces and issues that need to be resolved in order to develop more practical and efficient VE interfaces.

## 2.1. The Definition of VEs: The Development of 3D User Interfaces

Virtual environments were first envisioned in 1968 by Ivan Sutherland, who built a head-mounted display (HMD) that presented to the user a computer-generated 3D scene, such that the user perceived an impression of looking at a stationary 3D object when the user's head moved (Vince, 1998). However, the development of VE technology has taken much longer than many people expected.

The first commercial VE applications appeared in the 1980s with real-time computer graphics, an HMD and an interactive glove (Vince, 1998). Visualization of 3D scientific datasets, real-time walkthroughs of architectural structures, and VE games were a few of the interesting and useful applications in this early period, and they offered various research challenges (Bowman et al., 2005). The most dominant form of VEs, the HMD, however, faced much resistance due to the user's sensation of isolation and tiredness, and this drawback led to a combination of immersive and non-immersive techniques (Vince, 1998).

In the 1990s, PCs supported navigation and interaction with real-time images of 3D environments that were obviously VEs, although not as powerful as other VE systems (Vince, 1998). From that time forward, VEs have been commonly classified in two categories: immersive VEs in which users wearing an HMD are totally surrounded by enclosed VEs, and non-immersive VEs that are conveyed mostly by desktop or laptop computers (Mills & Noyes, 1999). The following is a summary of the main attributes of VEs (Wilson, 1997).

- Computer-generated simulated environments are experienced as three-dimensional by the participants.
- Objects in the VE are themselves three-dimensional, with orientations and locations independent of the participants' viewpoint.
- Objects are assigned some "intelligence" or feature: e.g., gravity and friction.
- Participants interact in real-time with the environment and objects.
- Environments are recreated "continuously" in real-time according to the participants' behavior.
- Interaction is as intuitive as possible through a variety of sensory channels.
- Freedom and support are provided for participants to navigate around the VE.
- Feelings of presence and involvement are generated for participants in the VE.

Nowadays, there are numerous varieties of 3D technologies currently in development that make 3D virtual objects part of the real world. Table 1 (p. 10-11) shows examples of emerging VE technologies. As an example, augmented reality (AR) proposes to supplement real-world and physical spaces via computer-generated sensory information, with images, sounds and smells to create interactive virtual spaces embedded in the physical world (Bowman et al., 2005). The most critical aspect of AR systems is its ability to provide relevant or helpful information to the existing real world with virtual elements (Botella, 2005). As a result, it is important that adjustment of virtual objects be appropriate at all times to fusion to the real world in all its dimensions (Botella, 2005).

| Technology | Description | Features |
| --- | --- | --- |
| **Simulators** | Projected display, sound (and vibration) and replica of physical surroundings (e.g., cab or flight deck) | Often expensive, usually dedicated to specific application, high quality experience |
| **Head Mounted Display (HMD)** | Screens and lenses fitted in goggles, glasses or helmet, giving stereoscopic, binocular or monoscopic (usually LCD) display; frequently have earphones for auditory environment; head and head trackers allow continual updating of display for user movement and orientation | Range from cheap to relatively expensive; use with range of sophistication in VE software and graphics engine |
| **Head Coupled Display** | CRT (cathode-ray tube) monitor and controls supported on universally jointed stand, held and moved as if a large, heavy pair of binoculars | Improved graphics, fast tracking, increased comfort; expensive |
| **Mixed Reality** | Use of HMD with some replication of ‘hard’ features of environment (e.g., seat, steering wheel) | Approaching a flexible simulator |
| **Augmented Reality** | Information from computer system overlaid onto view of real world, for instance ‘see through’ displays on windscreen or helmet visor | Probably not a virtual environment |

| | | |
|---|---|---|
| **Artificial Reality** | Video cameras capture participant body movements that are included within large display of the generated virtual environment | Inflexible |
| **Desktop VEs** | Virtual environment displayed on desktop display screens; control via variety of '3D' input devices | Improved graphics quality, flexibility and user comfort over HMDs, possibly at the expense of 'presence'. Range of software and hardware options, from very cheap to very expensive. Can have HMDs fitted for necessary applications |
| **Wall Mounted** | Same as for desktop but display enlarged and projected on all | Greater sense of immersion than for desktop; less display quality unless very expensive. Inflexible |
| **Spatially Immersive Display (SID)** | Same as for wall mounted but across several walls, ceiling | Same as for wall mounted |

Table 1. Types of Virtual Environment Technology (recreated based on Wilson, 1997)

Although AR was originally proposed as an alternative to VEs, the two have been developed as complementary technologies, each with its own advantages and range of applications (Bowman et al., 2005). The VE systems submerge the user inside a computer-generated world whereas AR employs physical objects in coordination with virtual objects to enhance users' real-world activities, rather than to replace real environments (Bowman et al., 2005).

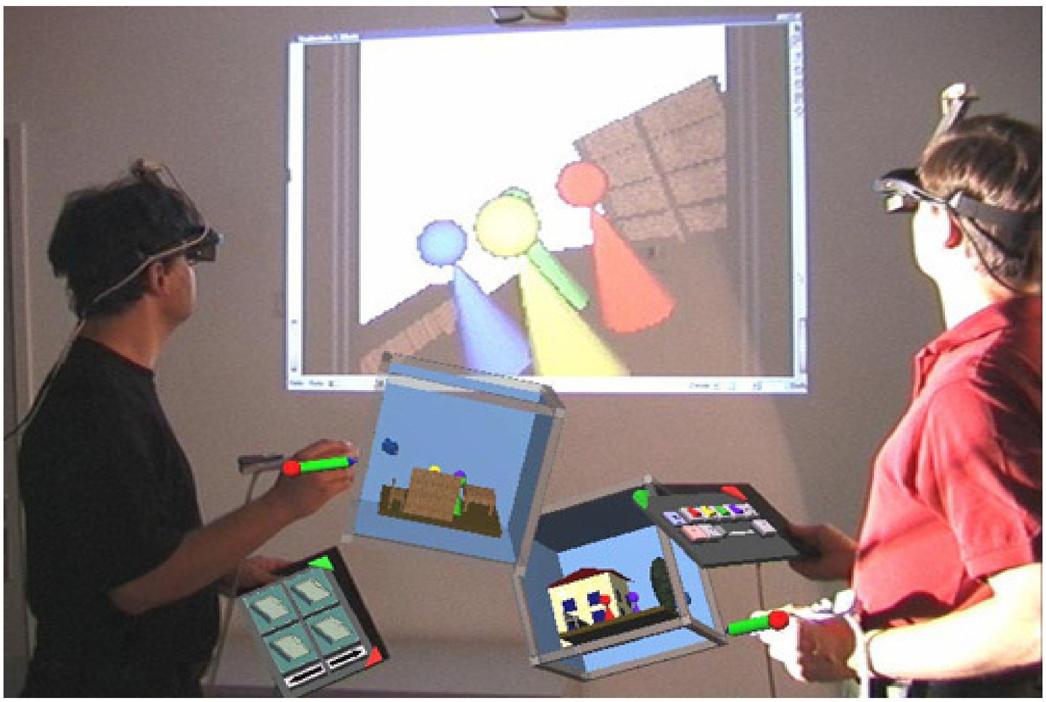


Figure 2. An Example of Augmented Reality (AR) (Reitmayr & Schmalstieg, 2003)

The advantages of AR over other types of VE systems are that AR can improve users' perceptions by providing information that the users cannot detect directly with their own senses and that help users to carry out tasks in the real world (Botella, 2005). On the one hand, AR interfaces may increase the complexity of physical environments but, on the other hand, VEs provide highly flexible and controlled spaces that are not affected by the physical environment (Bowman et al., 2005). Figure 2 shows an example of an AR system.

In addition to ARs, a collaborative virtual environment (CVE) invites remote users to a commonly accessible environment in which they can interact with each other using a network connection such as the Internet (Lau & Zyda, 2004). CVEs help geographically separate users to achieve common tasks through a shared virtual environment (Lau & Zyda, 2004). Among the characteristics offered by CVEs are: 1) a communication channel, including audio, text or both, 2) shared spaces, such as shared objects and 3) virtual embodiments or avatars that allow expression of nonverbal behaviors (Tromp, Steed & Wilson, 2003). The virtual embodiments enable users to collaborate in the same virtual space, regardless of the actual geographic locations, as illustrated in Figure 3 (Tromp et al., 2003).

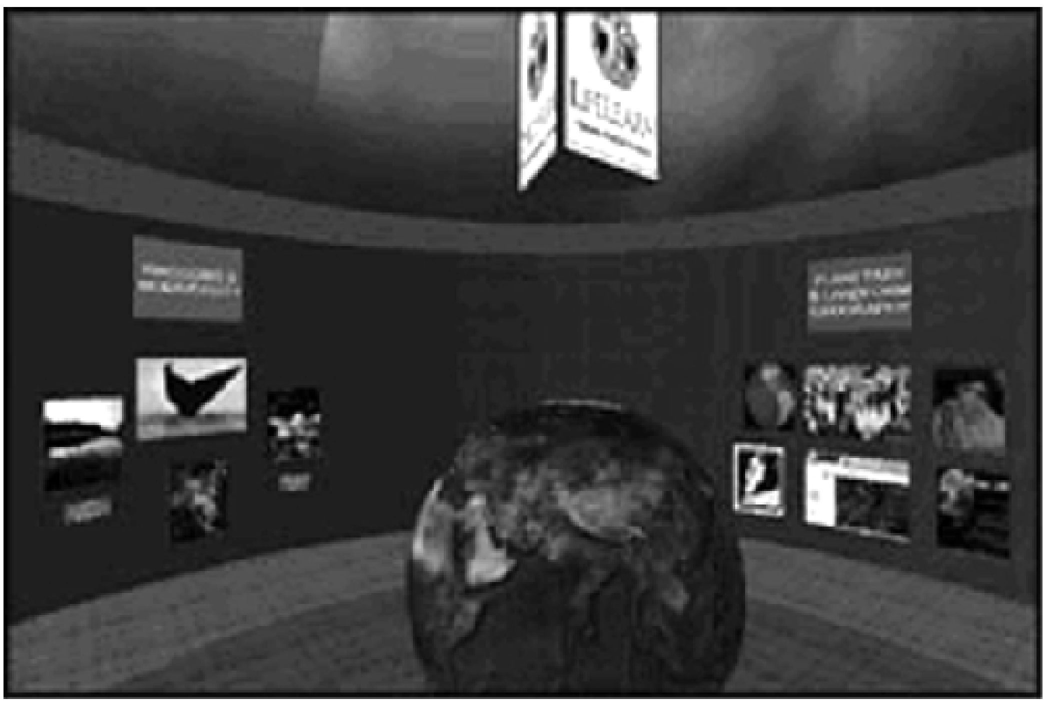


Figure 3. An Example of CVE: BioLearn's Global Simulation Center (Corbit & DeVarco, 2000)

Collaboration presents a multitude of challenges, including awareness (who is here? where are they? what are they doing?), communications (speech, pointing, facial expressions), and floor control (who is working on that object? how do I get the object?)

(Bowman et al., 2005). Collaborative design, collaborative gaming, and remote training are a few examples of CVE applications (Lau & Zyda, 2004).

Contemporary research agendas on CVEs are concerned with the development of all possible technologies, such as mobile, mixed reality, ambient, pervasive, ubiquitous and wearable computing systems (Crabtree, Rodden & Benford, 2005). For example, as a new form of entertainment, collaborative games are combined with location-based games. Traditionally, location-based games are played out on the city street with the aid of handheld or wearable interfaces that provide information about the user's current context, location and tasks (Crabtree et al., 2005). In collaborative games, this information can be transmitted to other players on the streets or player who are online (Crabtree et al., 2005).

Since the first introduction of VEs, the advancement of technology has been dramatic and the application of existing HCI knowledge has helped to improve VE usability (Bowman et al., 2005). There exist, however, additional questions about VEs for which traditional HCI does not provide adequate answers (Bowman et al., 2005). In parallel, other technologies, including 3D Desktop VEs, mixed reality, and artificial reality, are also in development and propose many other challenges (Bowman et al., 2005).

## 2.2. ADVANTAGES AND DISADVANTAGES OF VES

VEs represent a giant leap over traditional computer systems because VEs break down the barrier between the user and the world inside the computer, thereby allowing users a new way to interact with computers (Kloppers, 1995). Vision, sound and tactile information are presented as part of the natural environment of user experiences (Pimentel & Teixeira, 1994). In this environment, users can be totally immersed in the computer-generated world such that they feel they are inside a world rather than merely observing images (Kloppers, 1995).

There are several reasons that VEs are different from conventional 2D interfaces. First, three-dimensional VEs can provide high media richness, that is, high levels of representation quality and volume of content in a mediated environment (Suh & Lee, 2005). The degree of media richness is determined by sensory depth that refers to the quality of information within each channel and the breadth of an interface, meaning the number of sensory dimensions simultaneously presented (Steuer, 1995; Suh & Lee, 2005). VEs have the capability to increase sensory depth, particularly in terms of the visual sense, because they can transmit more detailed 3D images through zoom and rotation functions (Klein, 2003). In the same way, VEs can also increase the breadth of a sensory interface with multiple sensory channels (Suh & Lee, 2005).

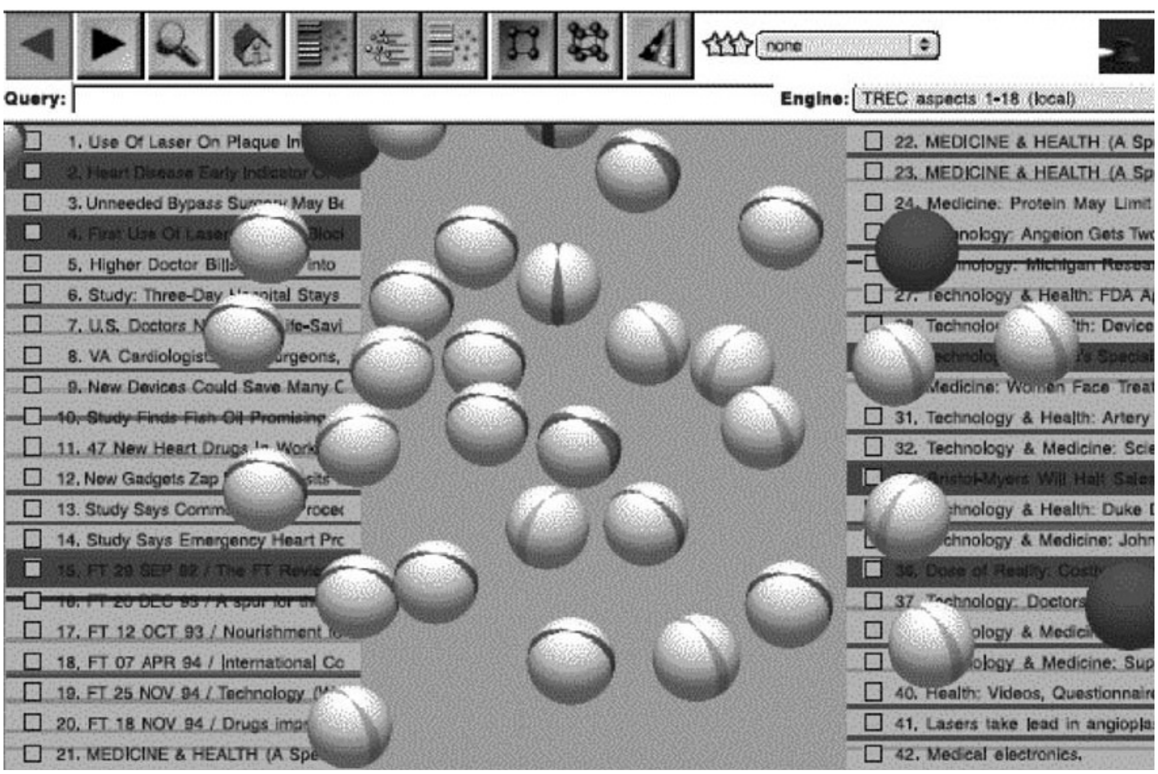



Figure 4. An Example of Information Visualization Using 3D VEs: Lighthouse (Allen, Leuski, Swan & Byrd, 2001)

Second, VEs can provide high interactivity and engagement: that is, VEs can offer a high level of control over the form and content of environments in real time according to the users' interests and concerns (Pimentel & Teixeira, 1994; Suh & Lee, 2005). Through high media richness and interactivity, users are likely to feel a sense of natural interaction and an illusion of being present (Klein, 2003; Mania & Chalmers, 2001), that transforms a virtual world from a passive experience into an engaging and interactive one (Burrill, Evans, Fokken, & Vaananen, 1994). When users feel a sense of presence, they are likely to feel as if "inhabiting" a new place, rather than looking at a picture (Furness & Barfield, 1995). Users, when immersed in three-dimensional VEs, also tend to concentrate more on the message without being aware of the medium (Furness & Barfield, 1995).


Figure 5. An Example of Information Visualization Using 3D VEs: Lighthouse (Robertson et al., 1998)

Finally, 3D interfaces provide a new avenue to represent complex information with improvements in the way data and dynamic processes are visualized (Furness &

Barfield, 1995). For example, images imported from medical scanning procedures can be displayed section-by-section while three-dimensional reconstruction of these images provides additional benefits for effective prognosis, thus offering more user viewpoints and more inspection possibilities (Wann & Mon-Williams, 1996). As another example, three-dimensional complex data-sets, such as scientific simulations, are likely to reach a level of complexity unattainable through two dimensional data-sets; moreover, three-dimensional representations offer a more appealing alternative. In such cases, three-dimensional depictions of data also require users to move through the structure, thus creating the potential for insightful interpretation (Wann & Mon-Williams, 1996).

For this reason, there have been numerous attempts to display information in 3D VEs including: Data Mountain Interface (Robertson et al., 1998), Lighthouse (Allen et al., 2001), GeoVRML (MacEachren et al., 1999), PathSim Visualizer (Polys et al., 2004) and Molecular Visualizer (Davies et al., 2005). Figures 4 and 5 show examples of 3D information visualization and Figure 6 is a medical dataset visualized with a VE system.

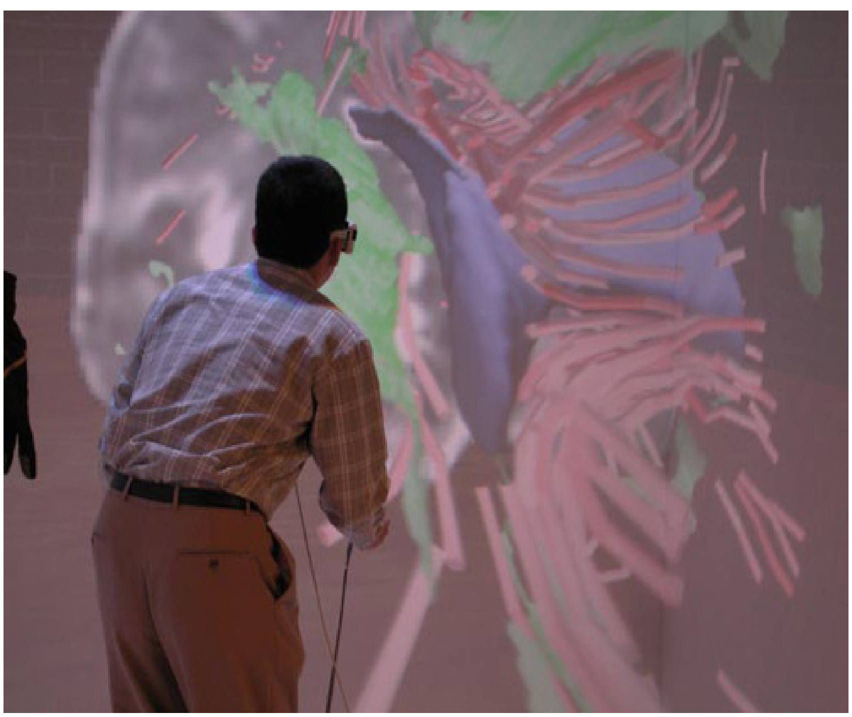


Figure 6. A Set of Geometric Models Representing Medical Dataset (Zhang et al., 2001)

Over the past few years, VEs have become a major area of interest in numerous fields, such as art, simulation, training, design, commerce, medicine, education, entertainment, and scientific analysis. With VEs, architects build a model of a building though which users can walk in real time (Tasli, & Sagun, 2002). In the business environment, many organizations are using VEs as a cheaper and more effective way to plan and project the future, make sales and train employees (Fuchs, Poltrock, & Wojcik, 1998). In the medical field, VEs already have a strong record of applications for complex surgery, dentist training, and treatment of various psychological disorders (Koročsec et al., 2005).

VEs are also envisioned as a new and more effective means for information services (Hawkins & Brynko, 2006; Kloppers, 1995; Newby, 1993). For instance, VE applications are used to provide bibliographic data with graphical displays (Kloppers, 1995). The potential for a VE library, in which a computerized information space replicates the physical library and diminishes the distinction between shelf access and the catalogue, has been investigated. (Hawkins & Brynko, 2006; Poulter, 1993).

However, several problems need to be overcome before VEs become a viable alternative to current 2D interfaces. First, immersive VE applications are extremely expensive, and that is the main reason that they are rarely available in commercial enterprises or applied in everyday office tasks (Kloppers, 1995). At the current level of development, VEs are predominantly used only in the entertainment arena (Kloppers, 1995).

Moreover, immersive VE applications have several ergonomic and usability problems (Kloppers, 1995). As an example, HMDs cause loss of real-world vision that isolates users from the real world (Kloppers, 1995). In office environments, people are likely to be interrupted by their colleagues but HMDs do not allow users to turn quickly from and to the virtual world (Kloppers, 1995). Most VE equipment is also cumbersome (Mills & Noyes, 1999).

In addition, 3D representations are subject to the additional computer processing and human cognitive load associated with three-dimensional representation and navigational procedures (Wilson, 1997). The physical world provides many more cues for understanding and affordances for action that cannot be represented accurately in a computer-simulated world (Bowman et al., 2005). Therefore, great care must go into the design of user interfaces and interaction (Bowman et al., 2005).

The following lists a few of the important problems with three-dimensional VEs, that are related mainly to human factors and usability (Furness & Barfield, 1995):

1. The need to develop a theoretical basis and conceptual models for VE development
2. The need to develop a solid understanding of the human factors and design implications of virtual interfaces
3. The need to develop ways to measure the quality of virtual environments, and
4. The need to develop a method to track the internal or psychological states and behaviors of VE users

## 2.3. DEVELOPMENT OF DESKTOP VES

The desktop VE, or window-on-world (wow) VE, is the virtual world that is 1) created with animated and simulated interactive 3D graphics, 2) presented on desktop displays without head tracking, and 3) manipulated with a keyboard and a mouse (Robertson, Card, & Mackinlay, 1993). Desktop VEs are characterized by on-screen small-scale virtual spaces that provide users with an immersed perspective from an ego-centric viewpoint (Parush & Berman, 2004).

Desktop VEs have been popularized since the Virtual Reality Modeling Language (VRML) opened up VE technology to a wide range of users on popular Internet browsers (Sayers, 2004). VRML is basically a 3D file interchange format that includes hierarchical transformations, light sources, viewpoints, basic animation, material properties, and texture mapping (Koročsec et al., 2005). In short, VRML is a language for publishing 3D web pages by integrating images, 3D objects, text and sound into three dimensions (Koročsec et al., 2005).

With the increasing number of 3D user interfaces and small-scale virtual environments on personal computers (PC), desktop VEs are used in games, simulations, and many other applications (Parush & Berman, 2004). Some examples of desktop VEs include Microsoft's Task Gallery for management of operating and file systems, divided spaces for task management on desktop computers (e.g., 3DNA Desktop), electronic commerce websites, an internet-based Multi-User Virtual Environment (MUVE) such as ActiveWorlds, and Entropia Universe, Second Life. Figures 7 and 8 show examples of 3D desktop VEs.


Figure 7. Win3D for Window Operation (Screen Shot from www.otal.umd.edu)

In recent years, online MUVEs, especially Second Life (SL), have become increasingly popular (Bell & Peter, 2007). Online MUVEs is a computer-based simulated environment intended for users to create their own content and objects and to interact via digital surrogates called avatars (Bell & Peters, 2007; Johnson, 2007). The origin of MUVEs lies in Massively Multiplayer Online Games (MMOG, MMO), such as World of Warcraft, Ultima Online and Everquest II.

In MUVEs, users can see, interact with and communicate (via chat) with other MUVE users. Users can also own real estate, purchase items, and even start a business. For example, users in Second Life have built museums, galleries and cultural sites and these simulations continue to expand. According to Gartner Group, 80% of all Internet users will be involved in various forms of MUVEs by 2011 (Johnson, 2007). MUVEs will evolve as a critical means to learning, entertaining, social networking, creating new knowledge in the future of the Internet (Johnson, 2007).

A common criticism of Desktop VEs is a reduced sense of presence caused by the lack of peripheral vision that prohibits users from being aware of their surroundings or location in virtual space (Robertson et al., 1993). Robertson and his colleagues (1993) claim, however, that users in Desktop VEs can be drawn into mental and emotional immersion with proper visual cues and interactive activities because users can control a VE and their focus on it. Another challenge specific to MUVEs is a steep learning curve (Johnson, 2007). For example, Second Life is in the early developmental stage, and therefore slow and undependable (Johnson, 2007).

In spite of these disadvantages, Desktop VEs also have several advantages over other types of VE systems (Robertson et al., 1993). First, the tools needed for Desktop VEs are commonplace and the machine itself is a large, installed base into which Desktop VEs can be introduced. Second, Desktop VEs use familiar tools for display and input (e.g., keyboard and mouse). Third, the start-up costs of Desktop VEs are much cheaper compared to other types of VE systems that require special equipment, such as head-mounted displays, graphic accelerator hardware, and six-degree-of-freedom input devices. Finally, the stress factors in Desktop VEs are the same as those for general computer use, and both psychological and physical stresses are likely to be much less than those found in other types of VEs.

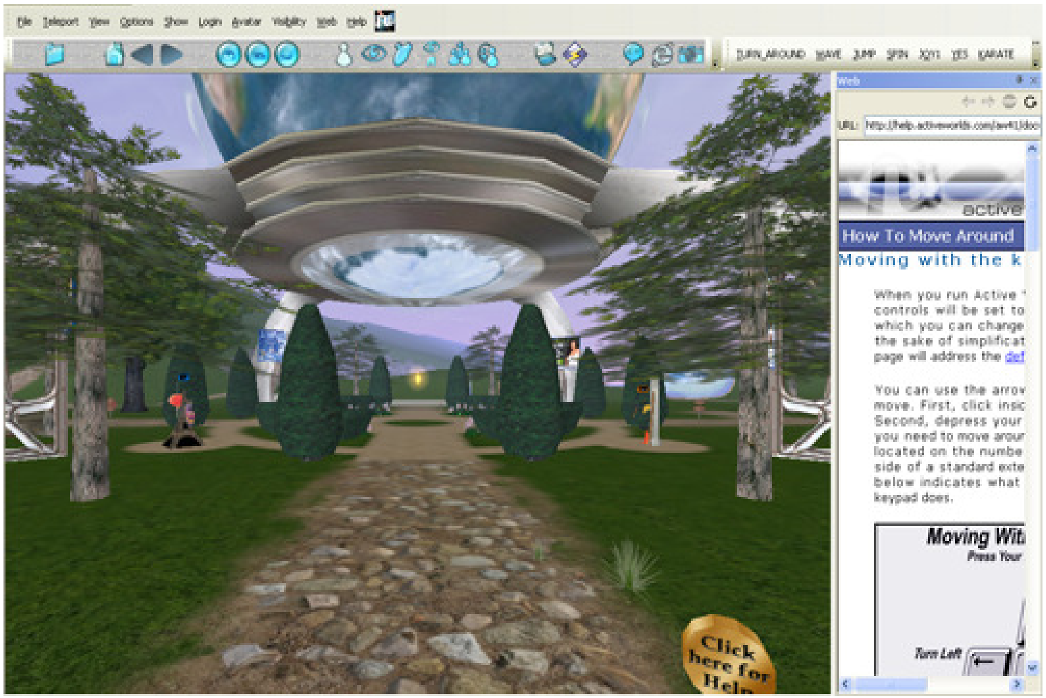



Figure 8. An interface of a 3D web browser where users can navigate and interact with a system and other users (ActiveWorlds)

Desktop VEs have an extensive and profound potential to be applied to numerous areas due to the advantages thus far discussed. In spite of these advantages, Desktop VEs cannot be fully exploited without particular interface requirements. To maximize the productivity of Desktop VEs, it is therefore necessary to understand usability and design principles of Desktop VEs.

### 2.4. SUMMARY

Chapter 2 described the evolution and current applications of 3D VEs. This chapter also addressed the advantages and possibilities of 3D interfaces and the challenges for more practical and efficient VE interfaces.

One of the major issues to be addressed for future 3D environments is design and usability. For this reason, Chapter 3 looks at the affordance concept as a theoretical framework and introduces four possible design approaches to support navigation in 3D spaces. Chapter 4 introduces two concepts specifically related to users' perceptual experience in 3D VEs. Chapter 5 presents the methodology for this study and Chapters 6 and 7 give a summary of the results and discuss the implications of the findings.

# Chapter 3 -- Enhancing Wayfinding with Affordances

This chapter looks at key issues related to navigation and wayfinding in 3D virtual spaces, and then provides an overview of the affordance concept as a theoretical framework to resolve wayfinding problems. Finally, this chapter introduces examples of design approaches to support wayfinding in VEs.

## 3.1. NAVIGATION IN VES

People move through real-world environments for the purpose of reaching a destination or simply to explore. When this common task is transferred to a virtual world, complications and difficulties arise due to the absence of real world constraints such as gravity, the sense of time flow and realistic motion cues (Elvins, 1997).

Navigation in VEs refers to "the task of moving the viewpoint within a 3D space" (Bowman et al, 2002, p. 281). According to Bowman et al. (2005), there are two major reasons that navigation in VEs has emerged as one of the most critical issues in VE research. First, navigation is the most universal and common interaction task in 3D user interfaces. Second, it often supports other tasks and this secondary nature of the task increases the need for usability.

Navigation is especially important in large-scale environments where the users' viewpoint does not encompass the whole environment yet users are required to navigate extensively (Darken & Sibert, 1996). Small-scale spaces can be viewed from an immediate vantage point at a single point in time whereas large-scale spaces extend beyond one standpoint and must be explored across time (Siegel, 1981).

Users, in large-scale environments, therefore, need to construct a coherent mental representation of the environment from sequential and isolated viewpoint information that is often termed a *cognitive map* (Chase, 1986). A cognitive map is "an internal representation of an environment gained by a comprehensive set of observations" (Elvins, 1997, p.15). Once a cognitive map is formed, navigators can rely on it to move through the environment (Rovine & Weisman, 1989).

A cognitive map is composed of three levels of representation or knowledge: route, survey and landmark knowledge (Parush & Berman, 2004). Route knowledge, also called procedural knowledge or a propositional representation, is a procedural and sequential description of the route between points in an environment (Hintzman, O'Dell, & Arndt, 1981). Route knowledge identifies all the locations where an action needs to be taken and the direction of that action. Route knowledge is formed with a route list that is primarily verbal in nature (e.g., turn right or left), requiring only sparse visual information (Gale, Golledge, Pellegrino, & Doherty, 1990; Hintzman et al., 1981).

The notable difference between real and virtual environments, indicated by previous studies, is that VE users need more time to develop route knowledge than do users in an equivalent real environment (Witmer et al., 1996). It is assumed that the difference can be attributed to the users' limited VE experience, and, therefore, can be minimized by increasing experience and familiarity with VEs (Ruddle, Payne, & Jones, 1998).

In contrast to route knowledge, survey knowledge, also called analog representation, is the configurational or topological representation of the whole landscape (Bowman et al., 2005). Survey knowledge relays information about elements in the geographical area and the spatial layout or relationship of these elements (e.g., object locations, intro-object distances, object orientation) (Hintzman et al., 1981). Survey knowledge is map-like and, therefore, can be enhanced with a map (Hintzman et al., 1981). Of the three types of spatial knowledge, survey knowledge represents the highest level of knowledge and also takes the longest time to construct mentally (Bowman et al., 2005).

Apart from route and survey knowledge, cognitive maps have a third form of knowledge called landmark knowledge. Landmark knowledge is the visual representation of prominent landmarks in an environment (Bowman et al., 2005). Visually salient objects play an important role in developing landmark knowledge but other visual features such as shape, size, and texture also form parts of landmark knowledge. Landmark knowledge is acquired when people encounter and learn about a new and unfamiliar environment (Parush & Berman, 2004). At the beginning of knowledge process, landmarks constitute a part of route knowledge, where landmarks are points that create routes. Later, the landmarks comprise objects in survey knowledge by constructing a layout and relational configuration of elements in the environment (Heth, Cornell, & Alberts, 1997). Because of the importance of landmark knowledge for route and survey knowledge, researcher have focused on the impact of landmarks and most of the studies have found that, in general, a lack of landmarks degrades navigation and orientation (Vinson, 1999).

Currently, most research regarding navigation is based on studies of real world situations because similarities have been found to exist between spatial knowledge development in VEs and in the real world (Ruddle, Payne, & Jones, 1998). These similarities suggest that the same principles can be applied to the study of VE navigation (Ruddle, Payne, & Jones, 1998).

### 3.2. ENHANCING WAYFINIDNG IN VES WITH AFFORDANCES

Navigation consists of both cognitive and motor components. The cognitive part of navigation is called *wayfinding,* and it is defined as "the cognitive process of defining a path through an environment, using and acquiring spatial knowledge to build up a cognitive map of an environment, aided by both natural and artificial cues" (Bowman et al., 2005, p. 227). Wayfinding is a decision-making process that involves the processing of multiple sources of sensory information from the environment and the use of this information to produce movement along a trajectory (Bowman et al., 2005).

Wayfinding in VEs is more difficult to support than in the real world because of the difference between real environments and virtual spaces (Bowman et al., 2005). However, there are several ways to support wayfinding and one possible solution is to enhance wayfinding affordances that will described in the next section.

### 3.2.1. Affordances and Their Implications to Interface Design

Affordance was first introduced by ecological psychologist, Gibson, J. and has been popularized as one of the most important principles in usability and interface design. This and the following sections represent affordance as a core concept in ecological psychology and provide a detailed description.

#### *Information Processing Viewpoint and Ecological Approach*

Cognitivism, more specifically an information-processing approach, has exerted strong influence on the study of Human Computer Interaction (HCI) since the discipline was established for purposes of examining the design of interfaces between people and computers (Aboulafia & Bannon, 2004). HCI proceeds from a metaphorical understanding of humans as information processors and investigates schematic models, maps or representations as a way of understanding uses and interaction (Bærentsen & Trettvik, 2002; Galotti, 2003).

In this paradigm, it is essential to understand the abilities and limitations of humans in order to maximize human efficiency and productivity (Galotti, 2003). Practically, cognitivsm implies that humans are a special variant of computers and HCI is essentially based on a computer-computer interaction (CCI) (Bærentsen & Trettvik, 2002). From a more philosophical point of view, humans are understood as a separate from the physical and social world in which they reside (Bærentsen & Trettvik, 2002).

As an alternative framework, Gibson, J. introduced ecological psychology and the concept of affordance. An ecological approach (Gibson, J., 1986) assumes that the environment is perceived in terms of what the observer can do with and in the environment. The mutuality and interaction of observer and environment is, therefore, a crucial point of Gibson's theory that differentiates an ecological approach from cognitivism (Bærentsen & Trettvik, 2002).

Gibson. J. (1966) posited that perception is designed for action and the goal of perception is decision-making. Perception, in his view, has a primacy over sensation. According to Gibson, J. (1966), sensations are the subjective reports of what organisms feel and, thus, egocentric and passive. Perceptions, on the other hand, are an active function of organisms and form fallible knowledge about objects and events in the world. According to Gibson's explanation, perceptions are inseparably connected with action and they mutually support each other. "Perceptually guided activity and actively guided perception (e.g., investigation and exploration) are the ecological psychologist's paradigm cases of perception" (Reed & Jones, 2002, p. 196).

People perceive surfaces for walking, spaces for navigating, and tools for manipulating (Ware, 1999). According to ecological psychology, information provides such a noticeable property of the environment that uniquely specifies perceiving and acting (Bærentsen & Trettvik, 2002; Heft, 1989; Gibson, J., 1966; Zahorick & Jenison, 1998). Gibson, J. (1966) coined the term *affordance* to describe this perceivable information of the environment. "The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill" (Gibson, J., 1986, p. 127).

Based on Gibson's theory, affordances are the relationships between physical artifacts in the world and an actor that show possible actions with artifacts. This relational concept of affordance refers to both the environment and the actor. As Gibson, J. (1986) stated:

> An affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behavior. It is both physical and psychical, yet neither. An affordance point both ways, to the environment and to the observer. (p.129)

It is evident from these citations that affordances are accomplished from the interaction between observer and environment. They can be achieved only when observers are actively living in and acting upon their environments (Bærentsen & Trettvik, 2002).

As such, affordance is both objective and subjective. Affordance can be objective as a fact of the environment: that is, the physical characteristics of an object (Heft, 1989). Affordance is not dependent upon value, meaning, or interpretation of an actor (McGrenere & Ho, 2000). On the other hand, it is subjective because an actor is still needed as a frame of reference (McGrenere & Ho, 2000). Affordance, therefore, does not neatly fit into either of those ontological categories; instead, it is relational in nature (Heft, 1989).

### *Affordances in the HCI Community*

This general affordance concept was introduced to the HCI community by Donald Norman in 1980s and popularized as one of the most fundamental principles in designing user interface. Norman, in his book *The Psychology of Everyday Things (POET),* amplified and extended Gibson's basic precepts in a more useful way to human computer interaction (HCI). Norman (1988) described affordances as follows:

> …the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used. A chair affords ('is for') support and, therefore, affords sitting. (p. 9)

Norman argues that affordances provide strong clues to the operation of things and the range of possibilities and, therefore, if affordances are well taken advantage of, users will know what to do with physical objects without additional instructional help.

| Gibson, J. | Norman |
|---|---|
| - Offering or action possibilities in the environment in relation to the action capabilities of an actor<br>- Independent of the actor's experience, knowledge, culture, or ability to perceive<br>- Existence is binary-an affordance exists or it does not exist | - Perceived properties that may or may not actually exist<br>- Suggestions or clues as to how to use the properties<br>- Dependent on the experience, knowledge or culture of the actor<br>- Make an action difficult or easy |

Table 2. Key Points of Affordances Described by Gibson, J. and Norman (McGrenere and Ho, 2000, p. 181)

Norman differentiated actual or physical affordances from perceived ones. To Norman, actual affordances are physical characteristics of interface that permit its operation whereas perceived affordances are characteristics in the appearance that shows clues for its proper operation (1999). The distinction between actual and perceived affordances implies that a perceived property is independent from the actual one; perceived affordances may not indicate the actual property of a thing and, therefore, differences occur in designing the affordances of an object and designing the way in which affordances are conveyed to the user of the objects (1999). Explained in this way, Norman stresses the importance of perceived affordances in determining usability and user experience on a computer screen as follows (1988):

> It is very important to distinguish real from perceived affordances. Design is about both, but the perceived affordances are what determine usability. (p. 123)

| Author | Terminology for Affordance | | |
|---|---|---|---|
| **Hartson** | Physical affordances | Cognitive affordances | Sensory Affordances |
| **Gibson, J.** | Affordances | Perceptual information about an affordance | Implied |
| **Norman** | (Real) affordances | Perceived affordance | Implied |
| **McGrenere & Ho** | Affordance | Perceptual information about an affordance | Indirectly included in perceptibility of an affordance |
| **Gaver** | (Perceptible) affordances | Perceptual information about an affordance, also apparent affordance | Indirectly included in perceptibility of an affordance |

Table 3. Comparison of Affordance Terminology (Hartson, 2003, p. 317)

Since Norman's introduction of the affordance concept to this field, it has been popularized in numerous studies. In a paper entitled "Technology Affordances," Gaver (1991) describes affordances with respect to the strengths and weaknesses that technologies can offer people. Gaver (1991) differentiated affordances from perceptual information that specifies the affordance of the artifacts, as Gibson, J. originally proposed. Gaver (1991) uses the term "apparent affordances (or design)" to refer to such perceptual information and explains apparent affordances (or design) in relation to usability as follows:

> In general, when the apparent affordances of an artifact match its intended use, the artifact is easy to operate. When apparent affordances suggest different actions than those for which the object is designed, errors are common and signs are necessary. (p. 80)

Along with physical and perceived affordances, Hartson (2003) suggests two additional types of affordances that play an important role in designing and evaluating the interface: sensory affordances and functional affordances. Sensory affordances help users with their sensory actions and functional affordances bind usage to usefulness (Hartson, 2003). As a counterpart to *perceived affordances* in Norman's terms, Hartson (2003) defines cognitive affordances as "design for the cognitive part of usability, ease-of-use in the form of learnability for new and intermittent users" (p. 317). Table 3 summarizes the terminology proposed by these researchers.

As a creator of the affordance concept, Gibson, J. uses the term affordances to indicate action possibility and claims that affordances are independent from the information that specifies them. Norman, in contrast, embraces such perceptual information as the part of (perceptual) affordances and differentiates it from actual affordances. Since Norman's introduction of perceptual affordances, several different terms including *apparent affordances* and *cognitive affordances* have been proposed to differentiate perceptual information from the actual affordances. It is critical to distinguish these two aspects of affordances in the design of useful affordances because it suggests that usability can be enhanced by clearly designing the perceptual affordances that help users understand the purpose and operation of its components (Hartson, 2003).

Nowadays, the concept of affordances is used with considerable variability. While affordance has been investigated in numerous studies, there is rarely a study based on empirical data (Norman, 1999). As Norman (1999) pointed out, the concept of affordance has been used with more enthusiasm than knowledge. Recently, McGrenere and Ho (2000) conducted a survey of the literature and analyzed how the concept *affordance* was extended and elaborated in the HCI field. They found that affordance has been used for three different meanings; action possibility, a perceived suggestion, and deviation from both meanings. Table 4 summarizes the use of the affordance concept in three high-level categories.

| Meaning of Affordance | Target of Affordance | Research Examples |
|---|---|---|
| Action Possibility (Gibson's Affordances) | Software Object | Ackerman et al. (1996)<br>Bers et al. (1998)<br>Gaver (1991)<br>Smets et al. (1994) |
| | Physical Object | Harrison et al. (1998)<br>Schilit et al. (1998)<br>Sellen et al. (1997)<br>Zhai et al. (1996) |
| Perceived Suggestion (Norman's Affordances) | | Conn (1995).<br>Johnson (1998)<br>Kohlert & Olsen (1995)<br>Mihnkern (1997)<br>Nielsen & Wagner (1996)<br>Perkins (1995) |
| Deviation | Interface Object | Mohagreg et al. (1996) |
| | Unclear Usage | Moran et al. (1997)<br>Shafrir & Nabkel (1994)<br>Tamura & Bannai (1996)<br>Vaughan (1997) |

Table 4. Meaning of Affordances in Three High-Level Categories (McGrenere & Ho, 2000)

Against that theoretical background, this study will now look at the application of the affordance concept to 3D environments, especially focused on navigation or wayfinding.

### 3.2.2. Enhancing Wayfinding with Affordance Cues

Since there are no clear physical affordances on screen-based interfaces, designers of VEs can control only perceptual affordances to create more efficient and effective interfaces and to make users' tasks easier (Ware, 1999). The challenges in designing three-dimensional VE applications are, therefore, to identify principled rules governing users' experience with perceptual cues in virtual space. Numerous types of virtual environments have been created to evaluate and observe usability and operation of VEs and researchers have suggested many different types of affordance cues.

With regard to wayfinding, affordance cues can be classified into four different categories in accordance with the functions they perform[ii].

1) Cues that display users' current position
2) Cues that display users' current orientation
3) Cues that record users' movements
4) Cues that show environmental information

You-Are-Here (YAH) maps and compasses are typical examples of Categories 1 and 2. Both categories are critical in wayfinding because users cannot perform tasks without accurately maintaining location and orientation information. For those two categories, the most difficult issue may be in determining the best way to incorporate affordance cues into VE interfaces in such a way that most effectively aids users' wayfinding (Chen & Stanney, 1999).

Trails are typical affordance cues in the Category 3. Trails help users retrace their steps in an environment or to indicate which parts of the world have been visited (Bowman et al., 2005). Trails can be simple lines or markers with directional information (Bowman et al., 2005). Trails can be placed directly in the environment or exhibited on a separate map (Grammenos, Filou, Papadakos, & Stephanidis, 2002). With trails, users can easily check a history of their movements.

Different from the other three categories, affordance cues in Category 4 collect environmental information of 3D space as well as assist users in their spatial orientation. Space-nodes (Ramloll & Mowat, 2001) show an example of Category 4. Space-nodes provide snapshots of the environment in order to reduce the cost of navigation (Ramloll & Mowat, 2001). Some snapshots are automatically generated while users navigate through the space, although users can also capture snapshots whenever necessary (Ramloll & Mowat, 2001). Ramloll and Mowat (2001) claim that space-nodes enable the system to store mental representations of the environment for future inspection. Figure 9 shows a space-node representation of a transport museum.

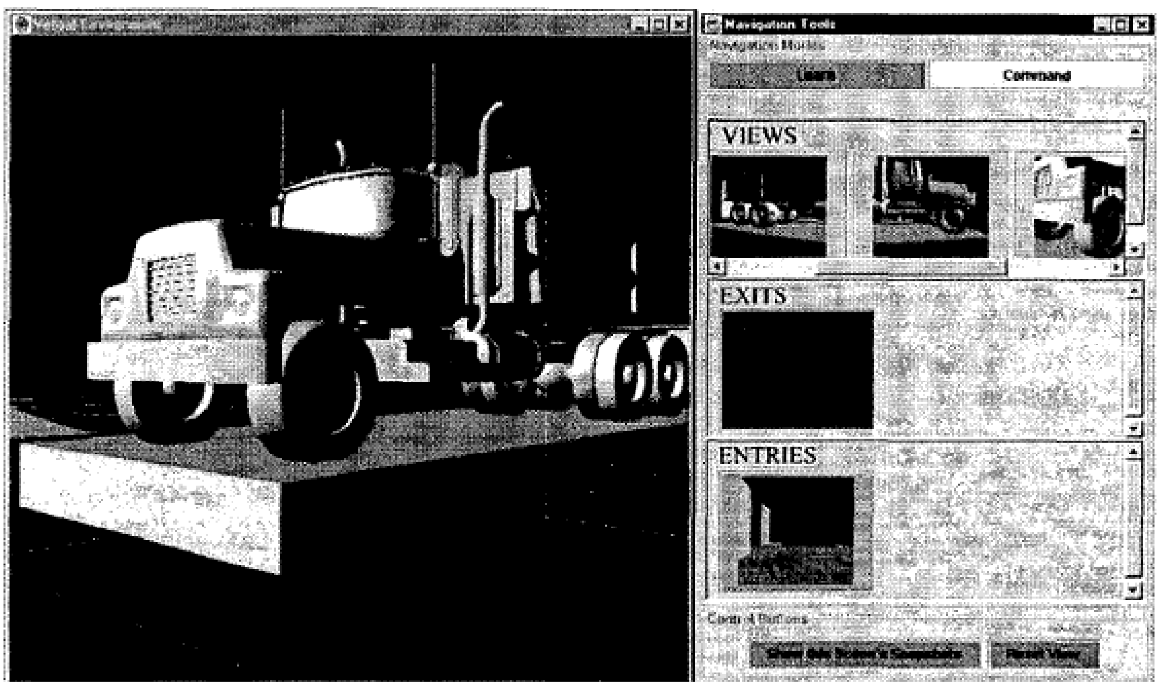



Figure 9. A Space-node Representing a Transport Museum (Ramloll & Mowat, 2001)

Maps are the most popular cues of this type. In order to provide out-of-sight spatial information, maps should clearly specify paths, intersections, landmarks, districts and boundaries (Lynch, 1960). As an example of a 3D map, Stoakley, Conway and Pausch (1995) introduced World in Miniature (WIM). WIM is a 3D map that shows a 3D small-scale version of the VE. The main advantage of WIM is that users can manipulate the map or the environment to simultaneously modify the other (Stoakley et al., 1995). However, there are two disadvantages of WIM. First, the miniature representation overlaps the environment and thereby reduces the users' visual access. Second, WIM cannot be applied to large-scale VEs unless the rendering is very low-detailed (Stoakley et al., 1995). Figure 10 shows a WIM interface.

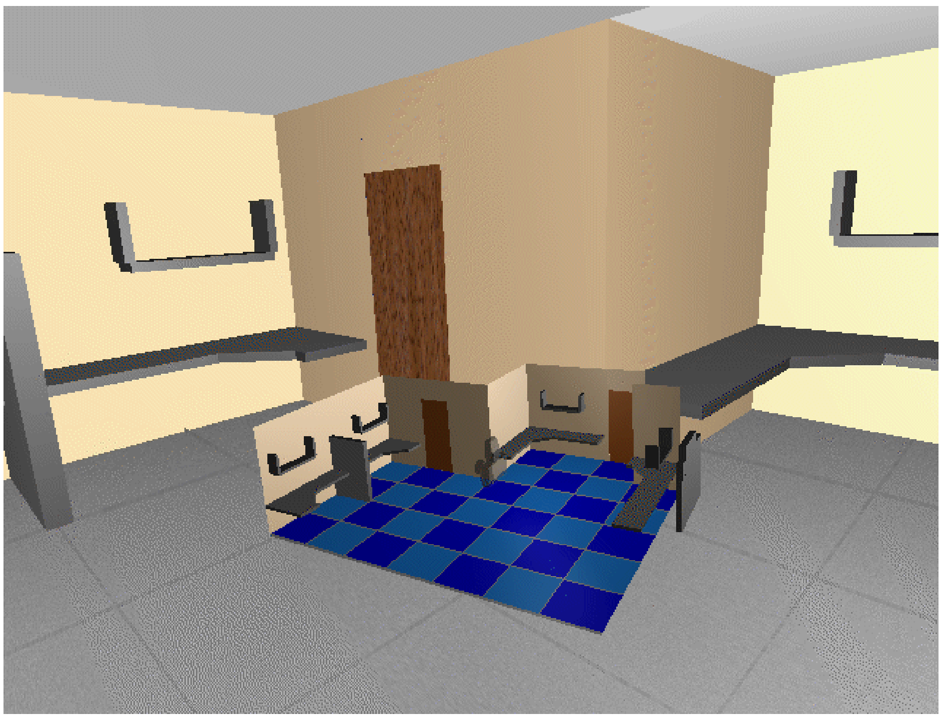


Figure 10. World in Miniature (WIM) Interface (Stoakley, Conway & Pausch, 1995)

### 3.2.3. Enhancing Wayfinding Affordances with Maps

Maps serve as a useful tool for the acquisition of spatial knowledge. Maps improve search and navigation performance by helping with the formation of survey knowledge that usually requires extensive navigation of environments (Chittaro & Burigat, 2004; Ruddle, Payne, & Jones, 1999).

Maps are invaluable tools for wayfinding because they help users obtain survey knowledge directly that otherwise requires extensive navigation effort (Edwards & Hand, 1997). The integration of maps into VEs offers numerous possibilities for developing new forms of maps and map use that can utilize the unique characteristics of VE features, such as user-map interactivity, user-environment immersion and varying information intensity in the display (Jürgen & Kersting, 2000). However, the use of maps requires repeated switches between the egocentric and exocentric perspectives as well as mental rotations that, in turn, require significant mental efforts and, for that reason, are difficult to perform (Chittaro & Burigat, 2004).

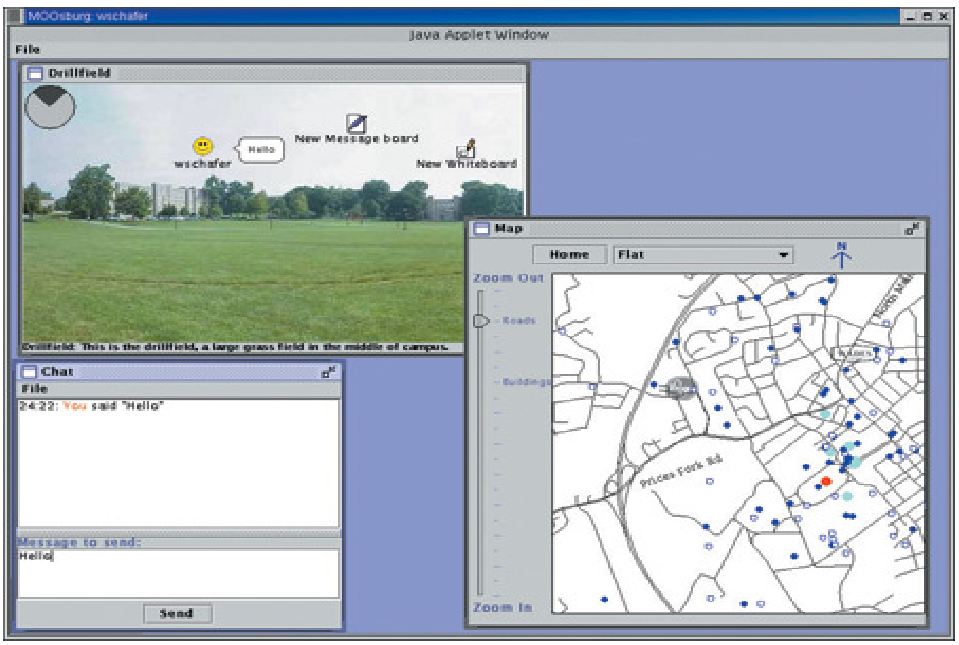



Figure 11. An Example of a Detached Map-MOOsburg Interface (Schafer, Bowman, & Carroll, 2002)

Maps can be presented in two different ways. One is as a separate GUI from a 3D world, referred to in this study as *detached affordance cues (DAC),* and the other is as an inclusive element of the 3D environment referred to here as *embedded affordance cues (EAC).* As detached affordance cues, maps can be rendered separately from internal objects in virtual spaces: that is, maps cues can be presented next to or on top of a 3D world as a separate layer (Bowman et al., 2005).

The design of the map as a detached affordance cue facilitates active seeking of information (Adams, 2006). For example, a guided navigation map, shown in Figure 12, appears on the screen when users start navigation and then directs users toward intended locations (Haik, Barker, Sapsford, & Trains, 2002). Although artificial, this feature allows users to explore the environment more actively (Adams, 2006).

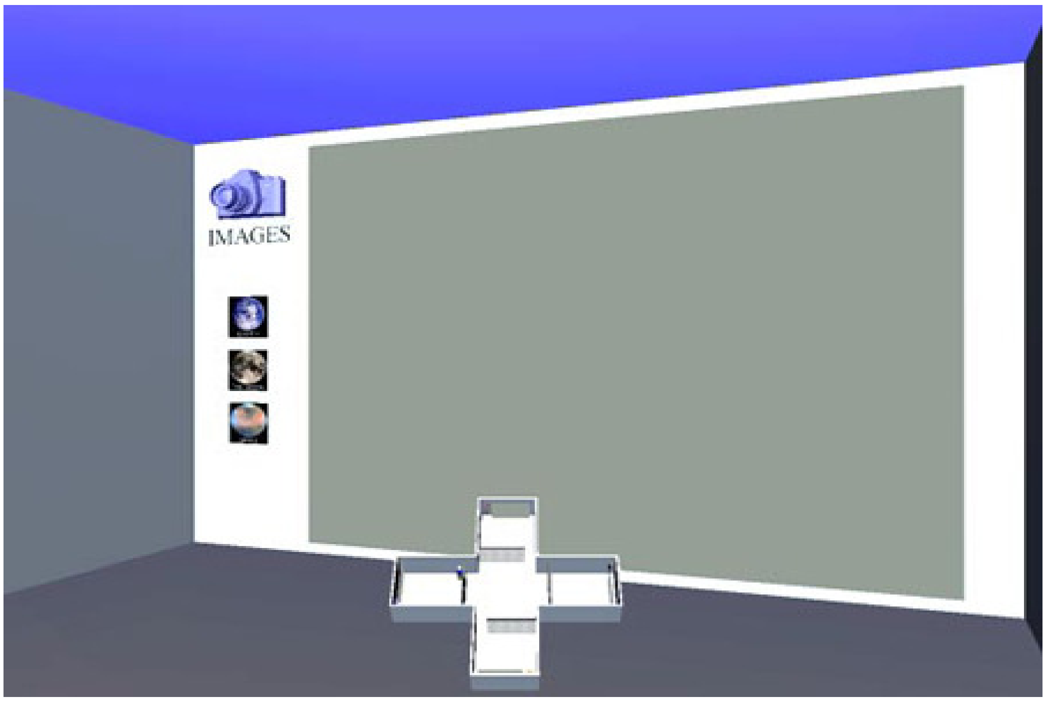



Figure 12. A Navigation Map from Haik et al (2002)

The main shortcoming of this approach is that users need to switch between two different GUI modes (Bowman et al., 2005). Detached maps also fill a large portion of the display and, thus, block other objects and the environment (Bowman et al., 2005; Haik et al., 2002; Stoakley, Conway, & Pausch, 1995). However, on most desktop-based 3D user interfaces, detached affordance cues have become popular because users can take advantage of those cues whenever they need to (Bowman et al., 2005).

An interesting aspect of detached maps is that if detached cues are critical for users to make sense of an interface, it seems likely that users will view maps as a real part of the environment (Adams, 2006). In a sense, affordance cues function as an augmented reality system (Adams, 2006).

As an alternative, maps can be implemented as part of the VE interface as shown in Figure 13. This approach offers the most natural way of presenting maps without blocking or limiting the users' visual fields. The main problem of this approach, however, is that it may affect the effectiveness of maps. In other words, maps as embedded affordance cues are not always visible and, therefore, users must remember the locations of maps and move to them, when necessary.

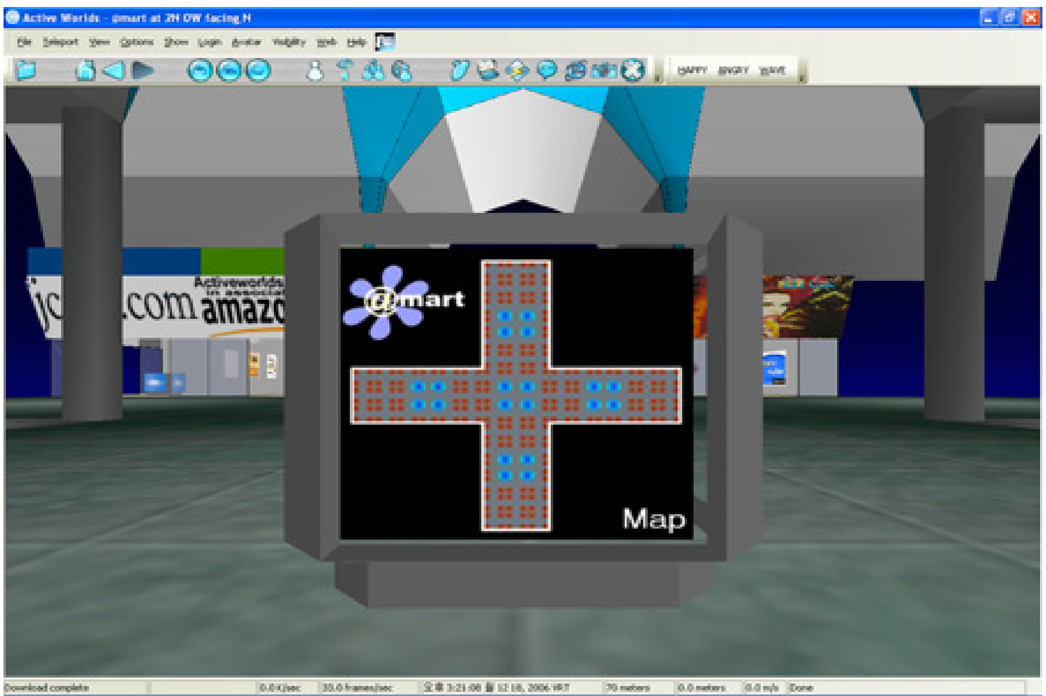



Figure 13. An Example of an Embedded Map from ActiveWorlds

### 3.3. SUMMARY

Chapter 3 has looked at navigation issues in 3D VEs and provided a detailed overview of affordance concept as a theoretical framework to improve wayfinding in 3D spaces. This chapter has also introduced affordance cues as a usability and design solution to resolve navigation problems in 3D environments.

In the following chapter, the focus will shift to the experiences of the users. That is, Chapter 4 describes users' perceptual experience in 3D VEs, particularly focused on presence and playfulness. Then, Chapter 5 gives a specific description of methodology, and Chapters 6 and 7 provide a summary of the results and discussion about the findings.

# Chapter 4 -- User Experience in VEs: Presence and Playfulness

Chapter 4 describes users' perceptual experience in 3D VEs. This chapter focuses mainly on two concepts - presence and playfulness - and each concept is covered in terms of definitions, influencing factors, effects, and empirical measures of each experience.

## 4.1. THE SENSE OF PRESENCE OR SITUATIONAL AWARENESS

One of the possible characteristics of future computer interfaces is compelling illusion[iii] that invites users to feel a sense of embodiment and presence in a computer-simulated environment (Biocca, 1997). There exists a clear distinction between users' perception, on the one hand, that they are either within (or interacting with) a virtually structured environment and their perception, on the other, that the display is a mere projection of a three-dimensional model (Wann & Mon-Williams, 1996). Perceiving oneself to be inside a virtual space is the underpinning of a sense of presence (Wann, & Mon-Williams, 1996) and such an immersive user experience is considered the essence of the VE experience (Riva, 1999). For this reason, the sense of presence has been extensively researched as a key construct in the VE experience.

### 4.1.1. Definition of Presence

Presence is a compelling sense of being in a mediated environment other than where physical body is located (Slater & Usoh, 1993). In the world of media, presence refers to the perceptual illusion of nonmediation that occurs when users react as though a medium is not present (Mania & Chalmers, 2001). The term presence is, however, more widely used to refer to the sensation experienced when users are within virtual environments (Biocca, 1997).

While VEs have brought the issue of presence to the forefront of research in recent years, the illusion of presence is actually a product of all media (Biocca, 1997). Steuer (1995) claims what differentiates VEs from other media is the level of presence that influences the creation of presence as an explicit design goal as well as a leading indicator of VE usability. According to Slater et al. (1996), when users feel presence, they experience VEs as more than mediated reality and consider the experience as places visited rather than as images seen. Biocca (1997) also stated that they no longer view themselves as mere observers but rather see themselves as actual participants in events happening on the computer screen. Simple human-computer interfaces establish a subject-object distinction between users and information environments, thereby creating a boundary around the computer and its information whereas presence in VEs removes this boundary, thus making the interface transparent (Bricken, 1990). The VE brings about a perspective shift, transformation that allows users to move from the feeling of simply viewing a picture to that of being in a place, a transition from observation to experience, from being an external user to an internal participant, from the sense of just interfacing with a display to actually inhabiting an environment (Lauria, 1997).

Presence, which refers to the user's experience, enjoys a functional relationship with (system) immersion, which is the extent to which computer displays are capable of delivering a surrounding environment to the sense of being a human participant within that system (Slater, 1999). Unlike presence, VE system immersion has measurable aspects that include, for example, the finding that a system with more sensory modalities has richer representational capabilities than does one with fewer modalities[iv] (Slater, 1999). Immersion is focused on quantifiable metrics and, therefore, involves a more objective description of technology whereas presence describes the subjective response of participants (Mania & Chalmers, 2001). It is believed that while immersion influences presence, presence is not directly determined by immersion (Mania & Chalmers, 2001).

In other words, the most elaborate technology does not always result in the highest level of presence (Mania & Chalmers, 2001).

Four factors determine the level of immersion: inclusiveness, extensiveness, range of surrounding, and vividness of the system determine the level of immersion (Slater & Wilbur, 1997). Inclusiveness means the degree to which all external sensory stimuli from the real world are excluded from the user. The extensiveness of displays is a function of the number of sensory modalities accommodated by the system. The range of surrounding is the extent to which the displays are panoramic. The vividness of the system is determined by the variety and richness of the sensory information. In the context of visual displays, vividness is concerned with the richness, information content, resolution and quality of the displays.

It has been suggested that users might perceive desktop VEs as less immersive than HMDs. (Romano & Brna, 2001). However, Weiderhold et al. (1998) found that changes in users' heart rates were not significantly different between HMD and PC interfaces in a study where users accessed simulated plane flights. A study by Tichon and Banks (2006) also found that the degree of presence did not lead to differences between a semi-immersive screen and a desktop VE.

#### 4.1.2. Factors That Influence Presence

Several factors – both solely and inter-correlated - contribute to a sense presence. While many factors may be associated with presence, considerable empirical work must be done before a definitive conclusion can be reached. Some of the factors examined in previous research are described as follows.

### *Media Properties and Sensory Information*

Presence can be affected by media properties such as visual display update rate[v] (Barfield & Hendrix, 1995), screen resolutions (Slater & Usoh, 1993) and spatialized sound (Barfield & Hendrix, 1995). Presence may also be influenced by sensory information including environmental richness (Sheridan, 1992), multimodal presentation (Held & Durlach, 1992), consistency of multimodal information (Held & Durlach, 1992) and degree of movement (Witmer & Singer, 1998).

### *Natural Mode of Interaction and Control*

Interaction style and control have been found to exert a strong influence on the sense of presence. First, users feel a greater sense of presence when they have more control over their actions (Witmer & Singer, 1994). Sheridan (1992) suggests that users' control over the relationship between sensors and the environment as well as their ability to modify physical characteristics of VEs serve as two determinants of a sense of presence. Similarly, Fontaine (1992) identifies control over the situation as separate from but closely related to presence. Second, it is believed that the sense of presence is enhanced by immediate and apparent consequences of users' actions (McGreevy, 1992, Held & Durlach, 1992). Third, users are expected to experience a greater sense of presence when they are able to predict consequences (Held & Durlach, 1992). Finally, presence may be diminished if the mode of control is artificial, especially where users need to learn new responses in the environment (Held & Durlach, 1992).

### *Realism*

According to Barfield and colleagues (1997), the sense of presence is dependent upon the degree to which spatial, auditory, and haptic transformations of objects in a VE are similar to those of objects in the real world. Other factors affecting VE realism include objective and physical consistency of information (Witmer & Singer, 1998), realistic visual depth cues (Wilson, Nichols, & Haldane, 1997), and scene realism (Witmer & Signer, 1998). Scene or pictorial realism relates to the connectedness, continuity, consistency and meaningfulness of the perceptual stimuli presented (Witmer & Signer, 1998).

### *Users' Personal Characteristics*

In addition to factors built into the VE system, presence is determined also by users' personal preferences for, knowledge of and prior experience with VEs (Held & Durlach, 1992; Witmer & Singer, 1998)**.** When users are unfamiliar with VE systems – in terms of how they are used and the nature of the experience - this unfamiliarity is likely to discourage their sense of presence whereas when users become more comfortable with manipulating VEs, this effect will likely disappear (Held & Durlach, 1992).

Presence depends also on the degree to which users shift their attention from the physical environment to the VE (Witmer & Singer, 1998). According to an explanation put forth by Witmer and Singer (1998), users experience varying degrees of presence. Presence, however, does not require the total displacement of attention to VEs because, in the real life, users' attention is typically divided between the physical world and the mental world of memories, daydreams, planned activities, books and movies or through involvement in a VE experience.

### *Distraction Factors*

By contrast, users' presence can be displaced or discouraged by certain distractions, such as any type of noise, defined as "information that is irrelevant to the intended communication regardless of the sensory channel through which it is transmitted" (Kim, 1996, p. 10)**.** Examples of noise include stimuli that signal the existence of the medium (Held & Durlach, 1992), artificial (or mediated) nature of the presentation (Heeter, 1992), or, more importantly, malfunctions in the operation of the medium (Lombard & Ditton, 1997).

***Content***

At the other end of the spectrum, presence can be enhanced through use of affective content. A study by Banos et al. (2004) compared three immersive systems (a PC monitor, a rear projected video wall and a HMD) and found that even in less immersive VEs, presence was enhanced through use of emotional content.

### 4.1.3. Influence of Presence

The importance of presence is often realized in the context of its potential relationship with performance. The results of many evaluations show that the greater the level of presence in VE productions, the better the performance (Bailey & Witmer, 1994; Witmer & Singer, 1994).

A strong sense of being there also facilitates learning and increases the efficiency of training in the real world (Carlin, Hoffman & Weghors, 1997). In general, when individuals interact with an environment, they gain personal, direct, tacit, non-reflective and even unconscious types of first-person experience (Winn, 1993). In many cases, VEs can be a valuable substitute for real world experience by providing a first-person perspective and allowing for interactive, engaging activities that include a higher sense of presence (Chittaro & Serra, 2004). Individuals in VEs, therefore, feel as if they have visited the place and that their participation in the VE is as active as what might have occurred in reality (Slater & Wilbur, 1997). In addition, the natural interaction in VEs reduces the unnecessary cognitive load (Wetzel, Radtke, & Stern, 1994). In immersive VEs, interaction with technology becomes very natural and, thus, enables users to focus cognitive resources on learning the content material rather than on attending to the interfaces (Hoffman, Prothero, Wells, & Groen, 1998). In learning situations, the concentration of cognitive resources motivates and enables users to be more deeply involved in the educational materials (Moreno & Mayer, 2002).

Presence not only enhances performance but also where there is a higher degree of presence, there is a greater likelihood that participants will behave in VEs in a manner similar to their behavior in the real world (Slater, Linakis, Usoh, & Kooper, 1996). The observation is particularly important in the transfer or efficiency of training (e.g., fire-fighters or surgeons). For example, trainee Marines are able to learn about the interior and operation of a submarine using a VE system so that they will be familiar with different compartments and their access points as well as how to operate relevant controls when they arrive on real submarines (Vince, 1998). In the same way, it is possible to become familiar with foreign cities, new office structures and chemical refineries even before they are built (Vince, 1998).

Researchers believe that the positive relationship between presence and performance is constructed in certain situations. Held and Durlach (1992) suggest that presence enhances performance when the tasks are wide-ranging, complex and uncertain because those situations ask users to extend their adaptive sensory-motor and problem-solving skills to another physical environment. Future research should, therefore, seek to uncover when, and under what conditions, presence can be a benefit or a detriment to performance and what is contributed by the sense of presence (Barfield, Sheridan, Zeltzer, & Slater, 1995).

#### 4.1.4. Measurements of Presence

While the concept of presence has been widely discussed, only a few studies have attempted to measure presence by empirical means. One of the challenges in researching presence, therefore, is to develop metrics that measure the degree of presence and its operational effectiveness (Brooks, 1999). A variety of methods have been proposed that can be generally classified into two categories: subjective and objective measures. Subjective measures probe personal feelings of presence, often with a rating scale type of report, whereas objective measures examine observable and, thus, physical and behavioral responses during task performance (Zahorik & Jenison, 1998).

Freeman and his colleagues (2000) examined observers' behavioral realism on the premise that, when observers experience presence in a mediated environment, they will respond to stimuli within that environment as they would in the real world. In their experiment, Freeman measured postural responses to a video sequence filmed from the hood of a car traversing a rally track. As a quantitative strategy, Schloerb (1995) developed a method based on a user's inability to discriminate between a real environment and a VE. In this method, researchers added certain types of noises to a real images until those noises were indistinguishable from the virtual images. Freeman and colleagues (1999) also proposed a direct subjective evaluation method in which users were asked to rate their sense of presence using a handheld slider. Using these methods, physiological responses including skin conductance, blood pressure, heart rate, muscle tension, respiration and dysphoria could be assessed during users' interaction with VEs.

The more commonly employed method in measuring presence, however, is the post-experiment self-report. According to this method, questionnaires direct users to rate diverse qualities of VEs ranging from perceptions of *being there* to more detailed features, such as ranking controls, feedback, perception of realism and user engagement (Sutcliffe & Gault, 2004). Witmer and Singer (1998) introduced a Presence Questionnaire (PQ) and an Immersive Tendencies Questionnaire (ITQ). The PQ measures the subjective experience of presence, taking into consideration other contributing factors such as control, sensory, distraction and realism. The ITQ evaluates individual capability of involvement, engagement, or immersion and focuses particularly on individual user's characteristics. Similarly, Slater and colleagues (1998) proposed a questionnaire that is developed to assess three aspects of presence concepts: the sense of being in the VE, the extent to which the VE becomes the dominant reality and the extent to which the VE is remembered as a place.

Future research should continue to explore problems and issues involved in measuring the concept of presence, as assessed through questionnaires (Singer & Witmer, 1999; Slater, 1999). For example, questionnaires may be ineffective due to measurements of users' subjective experiences after the event has occurred (Mania & Chalmers, 2001). Slater (1999) also claims that self-report questionnaires do not function as memories of mental processes because such questionnaires are inexplicably tied to personal aspects of users. According to Nisbett and Wilson (1977), because introspective reports are a subjective process of explaining behavior, it is unlikely that participants will report identical experiences, even though they actually had the same experience. Another challenge in subjective response questionnaires is the difficulty in validating each concept in the questionnaire (Mania & Chalmers, 2001). For this reason, it is widely recommended that presence measures incorporate both subjective and objective measures due to the possibility of different results between the two types of measurement (Zahorik & Jenison, 1998).

### 4.2. PLAYFULNESS AND THE STATE OF FLOW

The most prominent psychological impact of presence is playfulness (Lombard & Ditton, 1997). Playfulness has been used to explain various human activities ranging from sports, games, music, hobbies and recreation to, more recently, human computer interaction (Skadberg & Kimmel, 2004). This section provides an overview of playfulness including its definition, influencing factors, effects and empirical measurements of playfulness and flow.

### 4.2.1. Definition of Playfulness

Playfulness is a subjective experience characterized by perceptions of pleasure and involvement (Webster, Trevino, & Ryan, 1993). It is "the ability to fool around, to spin out 'what if' scenarios" (Laurel, 1991, p.114). In terms of user interactions with computers, playfulness is described as a situation-specific individual characteristic or tendency to interact spontaneously, inventively and imaginatively with computers (Reid, 2004; Webster & Martocchio, 1992).

Traditionally, playfulness has been studied from three main perspectives (Webster & Martocchio, 1992): playfulness as a trait or a relatively-enduring characteristic of an individual (Lieberman, 1997); play as an opposition to work (Kabanoff, 1980) and, thus, a potential social influence during training; and playfulness as a temporary state (Ellis, 1973). One of the key findings of previous studies is that playfulness in computer interaction is a function of both individual trait(s) and psychological states(s) (Woszczynski, Roth, & Segars, 2002).

The term *trait* refers to individual predispositions to behave consistently over time across situations (Kenrick & Funder, 1988) whereas the term *state* is cued by the nature of the situation (Spielberger, 1970). Playfulness as a state can be influenced by a situation, such as the technology being used or the challenge in interacting with the computer (Woszczynski et al., 2002). The state of playfulness is specifically conceptualized as *flow*.

The term *flow* is a psychological state of consciousness in which an individual feels happy, motivated and cognitively efficient and, therefore, totally satisfied beyond a sense of having fun, when actively engaged in an intrinsically rewarding activity (Csikszentmihalyi, 1990; Moneta & Csikszentmihalyi, 1996; Clarke & Haworth, 1995). Flow, therefore, has an important emotional component that denotes an intrinsic enjoyment of the task or activity in and of itself (Woszczynski, Roth, & Segars, 2002). Flow is often called an *optimal experience* or *autotelic enjoyment,* as self-reinforcing and the highest level of well-being (Csikszentmihalyi & Wong, 1991; Webster & Martocchio, 1992).

Flow is different from the more passive concept of pleasure. Whereas pleasure is based on genetically encoded drives for survival that do not require much conscious effort (e.g., eating behavior), flow involves an active use of skills that entails enjoyment and growth (Massimini, Csikszentmihalyi, & Delle Fave, 1988). Flow is also associated with situational interaction (Skadberg & Kimmel, 2004). Situating conditions for computer interaction facilitates users' engagement and participation and is more likely to be achieved in spontaneous, informal and non-sequential characteristics of context-based presentation (Skadberg & Kimmel, 2004).

Flow is a multi-dimensional concept that incorporates diverse features of individual experience. The central properties of flow include a sense of pleasure, enjoyment, curiosity[vi], complete involvement or engagement in an activity, attention focus[vii], intrinsic interest,[viii] and volition (Webster, Trevino, & Ryan, 1993, Ghani & Deshpande, 1994, Trevino & Webster, 1992; Webster & Ho, 1997). In related research, Trevino and Webster (1992) identified four dimensions of flow during human-computer interactions: control over technology, focused attention, arousal of curiosity and intrinsic interest. Glynn and Webster (1992) proposed a set of 25 items explaining major flow characteristics, including creativity, imagination, enjoyment, spontaneity and free-spiritness. Ghani and Deshpande (1994) further described flow as intense concentration and enjoyment, suggesting two key characteristics of flow: total concentration in an activity and the enjoyment gained from that activity. Finally, Hoffman and Novak (1996) highlighted the distinction of a) the flow state, b) the potential antecedents such as a perceived congruence of skills and challenges, focused attention, interactivity, and telepresence, and c) consequences of flow such as increased learning, perceived behavioral control and exploratory and positive subjective experience.

#### 4.2.2. Factors Influencing Playfulness

There has been a great deal of prior work exploring the influence of certain factors on playfulness and flow**.** Individual characteristics (Webster & Martocchio, 1995), perceived and objective technology (Trevino & Webster, 1992), organization (Godfrey, 1989), and the task (Ghani, Supnick, & Rooney, 1991) are a few of them.

According to Neumann (1971) and Bateson (1971), playfulness can be determined by intrinsic motivation, internal control, freedom to suspend reality and framing. Intrinsic motivation refers to a certain aspect of the activity that gives an impetus to the individual's involvement. Internal control describes the extent to which users perceive a sense of control over their actions or activity outcomes when interacting with the system. Freedom to suspend reality suggests that users choose how similar to objective reality the interaction will be. Finally, framing describes the ability to give and take social cues to maintain the play frame. Miller & Reid (2003), from a similar perspective, suggest that users experience the optimal level of flow when a) activities involve clear goals and immediate feedback, b) an individual perceives a sense of control and loss of self-consciousness, c) the overall experience is enjoyable and d) an individual's skill levels are challenged[ix]. Finally, Trevino and Webster (1992) propose that the flow experience is a function of a) the types of computer-mediated communication technology, 2) a perceived technological characteristic (ease of use), and 3) an individual's characteristics (computer skill).

With regard to individual characteristics, Csikszentmihalyi (1975) claimed that individuals experience flow when they are offered a level of challenges comparable to their skill level - that is, when skills and challenges are simultaneously low, medium, or high. In a later work, Csikszentmihalyi and LeFevre (1989) further elaborated this idea and noted that the optimal flow experience occurs with high level of challenges and skills. Csikszentmihalyi (1990, p. 3) stated that "the best moments usually occur when a person's body or mind is stretched to its limits in a voluntary effort to accomplish something difficult or worthwhile." These works are based upon Csikszentmihalyi's theory of flow (1975), which illustrates individual tendency to challenge situations as rewarding; if challenges are comparatively low relative to skills, the individuals will become bored but if challenges are high, the individual may become frustrated and discontinue the activity. More recently, Skadberg and Kimmel (2004) reconfirmed the previous work, arguing that the congruence of skills and challenges, referred as *the flow channel* determines flow, boredom or anxiety.

Apart from the individual skill level, playfulness is associated also with motivation toward the accomplishment of self-imposed goals, tendencies towards active involvement, tendencies to attribute to objects or behaviors their own meaning as well as tendencies to disregard externally imposed rules (Rubin, Fein & Vandenberg, 1983; Glynn & Webster, 1992).

#### 4.2.3. Influence of Playfulness

The impact of playfulness is extensive, including increased user satisfaction (Woszczynski, et al., 2002; Ghani, 1991), increased learning (Csikszentmihalyi & LeFevre, 1989; Hoffman & Novak, 1996; Webster, Trevino, & Ryan, 1993), time distortion (Csikszentmihalyi, 1990; Skadberg & Kimmel, 2004), changes in attitudes and behavior (Ghani & Deshpande, 1994; Hoffman & Novak, 1996; Webster, Trevino, & Ryan, 1993), increased curiosity (Webster, Trevino, & Ryan, 1993), intrinsic interest (Webster, Trevino, & Ryan, 1993), positive subjective experience (Hoffman & Novak, 1996), enhanced creativity as well as more openness to possibilities offered by information technologies (Trevino & Webster, 1992).

First of all, several notable studies (Csikszentmihalyi & LeFevre, 1989; Hoffman & Novak, 1996; and Webster, Trevino, and Ryan, 1993) found that the flow experience positively affects learning. In terms of changes in attitudes and behavior, Ghani and Deshpande (1994) showed that the flow experience has a positive relationship with exploratory behaviors in their study of computer users' experimenting with different commands. Users' sense of time distortion is another related consequence of the flow experience (Csikszentmihalyi, 1990). Flow causes users to become completely focused and involved in a situation-specific activity, resulting in users' loss of time (Skadberg & Kimmel, 2004).

Finally, enhanced creativity in VEs can be explained with a construct called *entexturement*, that refers to an individual's regulation of activity and sensory media through various sensory textures, including visual imagery, activity, content ambiance, color, light, space and sound to produce a finely articulated and satisfying whole (Rubinstein, 1989). Enxtexturement allows users to control an activity by sensory media (e.g., aural and visual stimuli) to VEs in order to facilitate creative activities (Reid, 2002).

#### 4.2.4. Measurement of Playfulness

Playfulness is usually measured with a set of Likert-type scales that are composed of a number of adjectives such as spontaneous, flexible, creative, and playful (Woszczynski et al., 2002). Playfulness scales are administered primarily through self-reports of behavior when using a particular software product or technology (Woszczynski et al., 2002). However, this type of scale has several limitations (Woszczynski et al., 2002). First, trait measure may be confounded with a predisposition of an individual and subsequent self-report behavior. Second, the source and the nature of trait variance are not clear.

Webster and Martocchio (1992) suggest that playfulness should be measured as a state variable. The state portion of playfulness is called flow state and is usually measured with an instrument developed by Webster, Trevino, and Ryan (1993). This measurement instrument asks respondents how they would characterize themselves when interacting with computers. As an example, Trevino and Webseter (1992) asked users to rate their sense of control when using the voice mail system.

### 4.3. SUMMARY

Chapter 4 has provided a review of the literature on users' perceptual experience, particularly as it relates to presence and playfulness. Each concept has been investigated in terms of its original meaning, factors that define each experience, effects on users' performance and other subjective experience as well as empirical measures of each experience.

Chapter 5 presents the methodology used in this study, including participants, experimental design, measurement, equipment, procedures and data analysis. Then, Chapters 6 and 7 describe the most important findings and provide insights into issues raised by research questions.

# Chapter 5 -- Methodology

This section explains research methodology that includes participants, experimental design, measurement, equipment, procedures and data analysis.

## 5.1. EXPERIMENT 1

In this study, two experiments were conducted to answer the four research questions: one in simple environments and the other in complex environments. This section describes Experiment 1.

### 5.1.1. Participants

Thirty-two participants were recruited at the University of Texas at Austin and from online community websites. Participants received a compensation for $15.

### 5.1.2. Experimental Design

The study employed a controlled experiment with within-participant factorial design. It is generally thought that the within-subject repeated measure is more appropriate to examine VE interaction because this method minimizes participants' individual differences such as personality, ability and experience in using computers and VEs (Bowman, 2002; Ruddle, Payne & Jones, 1998).

The participants were asked to accomplish four sets of comparable tasks in two sessions of trials with four different conditions. The experimental conditions were manipulated by the display of maps and signs that showed participants' locations and orientations on virtual university campuses.

As mentioned in Chapter 3, affordance cues can be presented in one of two ways. One is as a separate GUI from the 3D world and the other is as an inclusive element of 3D VEs. Besides location of affordance cues, this study considers the visibility of cues resulting in four different affordance conditions as shown in Table 5. The four conditions are the Switchable Detached Affrodance Cues (SDAC) condition, the Fixed Detached Affordance Cues (FDAC) condition, the Portable Embedded Affordance Cues (PEAC) condition, and the Fixed Embedded Affordance Cues (FEAC) condition as shown in Figures 15-18.

| Location of Cues \ Visibility of Cues | Fixed | Movable |
|---|---|---|
| **Detached** | FDAC (Fixed Detached Affordance Cues) | SDAC (Switchable Detached Affordance Cues) |
| **Embedded** | FEAC (Fixed Embedded Affordance Cues) | PEAC (Portable Embedded Affordance Cues) |

Table 5. Experimental Conditions Defined by Visibility and Location of Cues

In the FDAC condition, participants completed their tasks with a map and signs that were independent from the 3D virtual environment and fixed on the top left corner of the screen. In the SDAC condition, participants performed their tasks using a detached map. The SDAC condition used a map separate from the 3D VE, similar to that in the FDAC condition except that in the SDAC condition, users were able to control visibility and location of the map and signs. In other words, users could toggle maps on and off and move on a screen as desired. In contrast, in the FEAC condition, participants carried out their tasks with maps and signs that were created as objects in the VE and that were fixed

**Fixed** **Movable**

**Detached**

Figure 15. Fixed Detached Affordance Cues (FDAC)

Figure 16. Switchable Detached Affordance Cues (SDAC)

**Embedded**

Figure 17. Fixed Embedded Affordance Cues (FEAC)

Figure 18. Portable Embedded Affordance Cues (PEAC)

in certain locations. In the PEAC condition, participants accomplished their tasks with a built-in map and signs that moved as participants changed their location. Table 5 shows four experimental conditions defined by visibility and location of cues. For two sets of sessions, two virtual university campuses (University 1 and University 2) were constructed with ActiveWorlds (http://www.activeworlds.com) as shown in Appendix A.

The combinations of experimental conditions and university models for the two sets of sessions resulted in 48 different treatment cases (Appendix B). The order of universities and experimental conditions were counterbalanced to minimize participants' learning effects and reduce fatigue. Thirty-two participants were randomly assigned to one of 48 cases, systematically skipping 16 cases. As shown in Appendix B, every twelve cases started with a different condition and in each cluster of 12 cases, four experimental cases were skipped.

### 5.1.3. Measurement

The experiment was conducted using a within-participant design with the type of wayfinding affordance cues as the main independent variable. The dependent variables were presence, playfulness and task performance.

#### *Independent Variables*

The major independent variable in experiment 1 was a type of wayfinding affordance cues implemented with maps and signs that informed participants of their location and orientation on the virtual university campuses. As stated earlier, these were from levels of these variables: FDAC, SDAC, PEAC and FEAC.

***Dependent Variables***

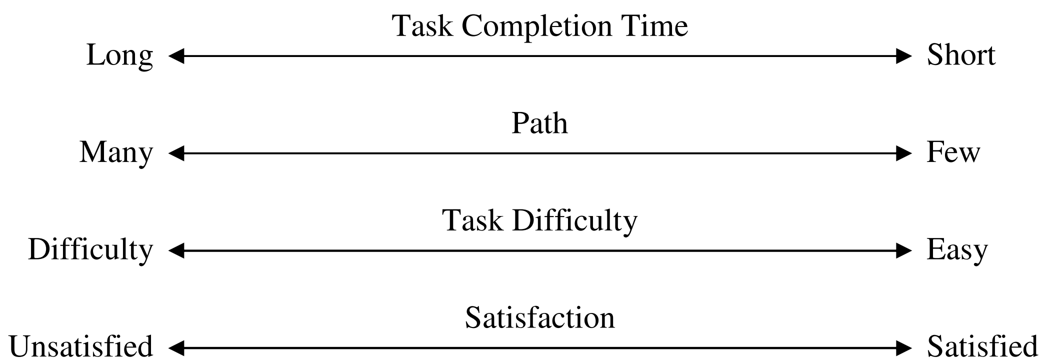
Responses to a presence and playfulness questionnaire were recorded on a 1-to-7 Likert-type scale for which the higher score indicated higher reported presence and playfulness (Appendix C). The presence questionnaire was developed for this research based on Slater and colleagues (1998), and Witmer and Singer (1998). The playfulness scores were evaluated with a questionnaire based on Skadberg and Kimmel (2004).

To complement the Likert-type scale, an open-ended questionnaire was given to participants at the end of the procedure. The topics covered in the open-ended questionnaire included the impact of the wayfinding affordance design on the users' sense of presence, playfulness and task performance, the advantages and disadvantages of each interface, the users' personal preferences and their reasons for those preferences.

Finally, the task performance was evaluated by the following criteria. Illustration 1 shows all the variables examined.

- Task completion time: Task completion time directly reflects effectiveness of navigation (Haik et al., 2002). It increases by the inefficiency in performing tasks (Haik et al., 2002). In this study, task completion time was measured only for wayfinding tasks, not including the time for manipulation tasks. In each condition, participants completed 3 sets of wayfinding and manipulation tasks as will be explained in the procedures. In each set of tasks, the time started when participants began a wayfinding task by moving to a new destination, and then the time stopped when participants ceased moving in order to read instructions for the subsequent manipulation task. The time from these three sets of wayfinding tasks were totaled to calculate the overall task completion time for each condition.
- Path: The term path describes the number of steps that participants took in order to perform their tasks: that is, the actual number of navigation steps taken by the participants.

- Perceived Task difficulty: Task difficulty refers to the overall difficulty in performing wayfinding tasks. Participants were subjectively rated on a 7-point Likert scale.
- User satisfaction with task performance: Participants were subjectively rated on their satisfaction with task performance on a 7-point Likert scale.




Variables for Examining Task Completion

**5.1.4. Equipment**

The experimental system was developed as shown in Figures 15-18. The main window displayed the university campus on the wayfinding VRML browser. In the FDAC and SDAC conditions, maps of an entire university campus were given in separate two-dimensional windows next to a virtual world whereas in the PEAC and FEAC conditions, the maps were embedded in the virtual universities.

Participants used keyboard arrow keys to move forward and backward a fixed distance on each key press and to turn left and right by a fixed angle on each key press. The viewpoint was fixed to “third-person,” view to “look-up” and visibility to 200 meters. The experiment was performed using a personal PC with a Pentium 3 processor and a 17-inch monitor with 1042×768 displayed pixels and 24 bits color depth.

### 5.1.5. Procedure

There were six discrete steps in this experiment as shown in Table 7. Each participant was asked to complete all of the following procedures.

Step 1: Participants were given a consent form and background questionnaire that gathered basic demographic and other information, such as prior experience with computers and VEs (Appendix D).

After participants completed a consent form and background questionnaire, they received general experiment instructions. The instructions included a description of the experiment, its purposes and instructions regarding the use of the wayfinding aid.

Finally, participants entered exploration phases. They were allowed to spend 15 to 20 minutes in a virtual town constructed of four blocks by two blocks in order to become familiar with the application. Each participant was then asked to find his or her way to two destinations.

Step 2: The participants were assigned randomly into one of the 4 experimental conditions. Participants received 3 sets of tasks (Appendix E). The tasks were basically a search for and manipulate an object in the 3D environment.

After participants completed the tasks to their satisfaction, they were asked to complete a post-test questionnaire on their experience, including their perceived sense of presence and state of playfulness.

Step 3: For this step, participants repeated Step 2 with different conditions on different university campuses. After Step 3, participants took a 5-minute break.

Steps 4 and 5: For these steps, participants repeated Steps 2 and 3 with different sets of tasks.

Step 6: Participants completed the post-test questionnaire that covered their personal opinions and thoughts.

| **Procedures** | **Pretest (step 1)** | **Session 1.2 (step 2)** | | **Session 1.2 (step 3)** | |
|---|---|---|---|---|---|
| **Collected Data** | Personal Characteristics | Task Performance | Presence & Playfulness | Task Performance | Presence & Playfulness |
| **Procedures** | **Session 2.1 (step 4)** | | **Session 2.2 (step 5)** | | **Posttest (step 6)** |
| **Collected Data** | Task Performance | Presence & Playfulness | Task Performance | Presence & Playfulness | Personal Opnion |

Table 6. Procedures and Data Collected from Each Procedure

### 5.1.6. Data Analysis

This study produced both quantitative performance data for each type of interface and qualitative data that reflected participants' experience while performing their tasks. Quantitative data was collected from the performance-based tasks to determine if there were differences in using each interface with regard to the sense of presence, the state of playfulness and task performance.

Analysis of Variance (ANOVA) repeated measure was performed for each of the dependent variables to identify the differences between SDAC, FDAC, PEAC and FEAC. Two-tailed correlation analysis was also conducted to examine the relationship among presence, playfulness and task performance. The total number of the participants was 32. Table 7 (p.61) summarizes the statistical analysis conducted for investigating proposed research questions. In order to identify the differences in performance and experience related to gender and VE expertise as well as computer literacy, independent sample t-tests were employed.

Qualitative data were also collected from both the exploratory tasks and the open-ended questionnaires to determine what subjective preferences for the four conditions and what specific thoughts and ideas participants had in comparing the four conditions. For the analysis of qualitative data, HyperResearch was used to identify commonalities and variances among participants.

| | Research Questions | Variable 1 | Variable 2 | Statistics |
|---|---|---|---|---|
| 1 | The influence of wayfinding affordances design on wayfinding task performance | Wayfinding affordance cues | Task Performance** | ANOVA repeated measure tests<br>Independent Sample t-tests |
| 2 | The influence of wayfinding affordances design on users' perceptual experience | Wayfinding affordance cues | Presence*<br>Playfulness* | ANOVA repeated measure tests<br>Independent Sample t-tests |
| 3 | The relationship between users' perceptual experience and task performance | Presence<br>Playfulness<br>Task Performance** | | (Pearson) Correlation Analysis |
| 4 | The relationship between presence and playfulness | Presence<br>Playfulness | | (Pearson) Correlation Analysis |

Table 7 Statistical analyses for three dependent variables to answer four research questions

* Based on 7-point Likert scale questionnaire and interview

** Task completion time, path, task difficulty, user satisfaction with task performance

## 5.2. EXPERIMENT 2

In order to investigate the effects of wayfinding task complexity, a new experiment was conducted. Several researchers suggest that tasks have significant influence on participants' performance and perceptual experience through task difficulty (Sheridan, 1992), attentional resources (Draper et al., 1998), and the length of the task (Stanney et al., 1998). While the effects of task characteristics are often cited, the specific impact of each factor and necessary condition for making particular effects is unknown.

In this study, the task difficulty was manipulated by the complexity of environments. More specifically, two more virtual universities (University Model 3, University Model 4) were created by expanding University Models 1 and 2 as shown in Appendix A. Twelve new tasks (three for each experimental condition) were set up (Appendix E) in accordance with new environments and these tasks asked participants to perform navigation and manipulation tasks in larger and more complex environments.

For the Experiment 2, another 30 participants were recruited at the University of Texas at Austin and from online community websites. The experimental design and procedure were the same as the Experiment 1. Data were also analyzed with the same quantitative and qualitative methods.

Chapter 5 has described specifics of the methodology that include participants, experimental design, measurement, equipment, procedures and data analysis. The following chapter presents the descriptive findings regarding participants' task performance, presence, playfulness and the relationships among them. Chapter 7 provides further insights on the important findings of this research in 3D VEs and suggestions for future research.

# Chapter 6 -- Results

Two experiments were conducted in order to examine the four research questions. In each experiment, participants performed three sets of tasks in four different conditions: the Fixed Embedded Affordance Cues (FEAC) condition, the Portable Embedded Affordance Cues (PEAC) condition, the Switchable Detached Affordance Cues (SDAC) condition, and the Fixed Detached Affordance Cues (FDAC) condition.

## 6.1. EXPERIMENT 1

In Experiment 1, thirty-two participants completed three sets of navigation and manipulation tasks in 3×2 (University Model 1) and 4×4 (University Model 2) block university environments.

### 6.1.1. Participants

Table 8 shows the characteristics of the 32 participants based on gender and years of computer use. Nineteen (59.4%) were male and 13 (40.6%) were female. Of the 32 participants, 4 (12.5%) had two-to-five years' experience with computers; 12 (37.5%) had five-to-ten years' experience; 5 (15.6%) had ten-to-fifteen years; and 11 (34.4%) had 15 years or more, yielding a median of five-to-ten years' experience.

All participants except two reported using computers on a daily basis. Regarding the hours of computer use, the participants were classified into five groups: 2 (6.3%) used a computer for less than an hour a day; 8 (25.0%) for 1-to-2 years; 9 (28.1%) for 2-to-4 hours; 8 (25.0%) for 4-to-7 hours; and 5 (15.6%) for 7 hours or more, yielding a median of 2-4 hours.

| Characteristics | Measurement | Number of Participants | % |
|---|---|---|---|
| Gender | Male | 19 | 59.4 |
| | Female | 13 | 40.6 |
| Years of Computer Use | 2-5 years | 4 | 12.5 |
| | 5-10 years | 12 | 37.5 |
| | 10-15 years | 5 | 15.6 |
| | More than 15 years | 11 | 34.4 |
| Hours of Computer Use (per day) | Less than an Hour | 2 | 6.3 |
| | 1-2 hours | 8 | 25.0 |
| | 2-4 hours | 9 | 28.1 |
| | 4-7 hours | 8 | 25.0 |
| | 7 hours or more | 5 | 15.6 |

Table 8. Participants' Characteristics in Experiment 1 (n = 32)

Of the 32 participants, 23 (71.9%) had experience with 3D VEs whereas 9 (28.1%) did not have any prior experience. With regard to years of 3D VE use, 11 (47.8%) had less than 2 years of experience; 4 (17.4%) had two-to-five years; 4 (17.4%) for five-to-ten years; 2 (8.7%) for ten-to-fifteen years; and 2 (8.7%) for 15 years or more.

Concerning frequency of 3D VE use, participants were categorized into three groups. Six (26.1%) used 3D VEs for one-to-two days a week; 4 (17.4%) for three-to-four days; and 13 (56.5%) for very rarely.

When looked at the hours of 3D VE use, 16 (69.6%) used VEs for less than an hour per week; 2 (8.7%) used for one-to-two hours; 1 (4.3%) for two-to-four hours; 3 (13.0%) for four-to-seven hours; and only one participant had (4.3%) for seven hours or more. Table 9 shows the characteristics of participants who had prior experience with three-dimensional virtual environments.

When participants' reasons for using VEs were considered, the participants' purposes generally fell into one of the four categories: playing games, socializing online chatting), doing e-business and creating 3D models for games and websites.

| Characteristics | Measurement | Number of Participants | % |
|---|---|---|---|
| Years of 3D VE Use | Less than 2 years | 11 | 47.8 |
| | 2-5 years | 4 | 17.4 |
| | 5-10 years | 4 | 17.4 |
| | 10-15 years | 2 | 8.7 |
| | More than 15 years | 2 | 8.7 |
| Frequency of 3D VE | 1-2 days a week | 6 | 26.1 |
| Use | 3-4 days a week | 4 | 17.4 |
| | Very Rarely | 13 | 56.5 |
| Hours of 3D VE Use | Less than an hour | 16 | 69. |
| (per week) | 1-2 hours | 2 | 6 |
| | 2-4 hours | 1 | 8.7 |
| | 4-7 hours | 3 | 4.3 |
| | 7 hours or more | 1 | 13. |
| | | | 0 |
| | | | 4.3 |

Table 9. The Characteristics of Participants with VE Experience in Experiment 1(n = 23)

### 6.1.2. Task Performance

Task Performance was measured by task completion time, path, task difficulty and participants' satisfaction with task performance. Then, ANOVA repeated measure test was conducted to examine the effects of wayfinding affordance design on participants' task performance. Additionally, independent t-tests were used to identify the differences resulting from participants' characteristics, such as gender, VE experience, and task completion time.

***Task Completion Time***

The mean wayfinding task completion time was 509.66 (SD = 249.28). As presented in Table 10, the mean difference between the detached conditions and the embedded conditions was significant F (1, 63) = 16.67, p < .001, showing that the participants completed their tasks faster using the detached conditions (FDAC, SDAC) whereas they were slower using the embedded conditions (PEAC, FEAC).

| Condition | | Minimum | Maximum | Mean (sec.) | | SD (sec.) | |
|---|---|---|---|---|---|---|---|
| DAC | FDAC | 169 | 830 | 393.09 | 446.28 | 120.08 | 195.91 |
| | SDAC | 186 | 1089 | 499.47 | | 240.29 | |
| EAC | PEAC | 116 | 1345 | 512.41 | 573.03 | 273.92 | 280.57 |
| | FEAC | 281 | 1207 | 633.66 | | 278.14 | |

Table 10. Descriptive Statistics for the Effects of Four Wayfinding Affordance Conditions on Task Completion Time

The mean completion time was greatest in the FEAC condition with 633.66 (SD = 278.14) whereas it was smallest in the FDAC condition with 393.09 (SD = 120.08), indicating that the difference was more than 240 seconds.

The descriptive statistics also indicated that standard deviations in the detached conditions were not as great as those in the embedded conditions, suggesting that the difference between the fast participants and the slow participants was much smaller in the detached conditions (FDAC, SDAC) than in the embedded conditions (PEAC, FEAC).

In order to examine the effects of wayfinding affordance design on task completion time, ANOVA repeated measure test was performed and the results revealed there were significant differences among the four conditions, $F(3, 93) = 12.77$, $p < .001$ as shown in Table 11.

| Within Subject Effect | F | df | Error df | P | $\eta^2$ | Power |
|---|---|---|---|---|---|---|
| **The Effect of Wayfinding Affordance Design on Task Completion Time** | 12.77 | 3 | 93 | .00 | .29 | 1.00 |

Table 11. ANOVA Repeated-Measure Test for the Effect of Wayfinding Affordance Design on Task Completion Time

| Paired Comparisons | FEAC | PEAC | SDAC | FDAC |
|---|---|---|---|---|
| **FEAC** | . | ** | ** | ** |
| **PEAC** | | . | N.S. | * |
| **SDAC** | | | . | * |
| **FDAC** | | | | . |

Table 12. Pairwise Comparison of Four Wayfinding Affordance Conditions on Task Completion Time (*: p <.05, **: p <.01)

The pairwise comparisons yielded 121.25 (SD=.39.00), 134.19 (SD=30.80) and 240.56 (SD=44.10) mean differences for FEAC-PEAC, FEAC-SDAC and FEAC-FDAC that were all significant at the .01 level. The results suggest that participants were significantly slower in the FEAC condition than in other conditions. There were also significant mean differences of 119.31 (SD=44.86) and 106.38 (SD=39.30) for the FDAC-PEAC and the FDAC-SDAC at the .01 level and .05 level, indicating that participants in the FDAC condition were faster than other three conditions. The results of pairwise comparisons are presented in Table 12.

As part of my study, the 32 participants were divided into 2 groups of 16 each for the purpose of identifying difference among those who completed their tasks faster and those who were slower. The 16 participants who finished the tasks faster were designated as the fast participants and the other 16 participants who completed their tasks slower were designated as the slow participants.

| **Condition** | **Participant Type** | **N** | **Mean** | **SD** | **Mean Diff** | **t** | **P** |
|---|---|---|---|---|---|---|---|
| **FEAC** | Fast | 16 | 452.94 | 186.07 | 361.44 | 4.81 | <.001 |
| | Slow | 16 | 814.38 | 235.76 | | | |
| **PEAC** | Fast | 16 | 343.94 | 99.89 | 336.94 | 4.38 | <.001 |
| | Slow | 16 | 680.88 | 290.76 | | | |
| **SDAC** | Fast | 16 | 318.69 | 107.85 | 361.56 | 6.49 | <.001 |
| | Slow | 16 | 680.25 | 194.88 | | | |
| **FDAC** | Fast | 16 | 330.81 | 101.21 | 124.56 | 3.39 | <.01 |
| | Slow | 16 | 455.38 | 106.20 | | | |

Table 13. Descriptive Statistics and t-test Results for the "Fast" and the "Slow" Participants in Four Wayfinding Conditions Relative to Task Completion Time

In order to identify the difference between the "fast" and the "slow" participants, an independent sample t-test was conducted. Overall, there was a significant difference between the "fast" participants and the "slow" participants for all four conditions at the .01 level. Participants in the SDAC and FEAC showed almost the same difference between the "fast" and the "slow" participants with 361.44 and 361.56: those were the greatest differences among the four conditions. The difference was least in the FDAC condition with 169.94. This indicates that the performance of the "slow" participants was comparable to the "fast" participants in the FDAC condition, implying that the FDAC condition was more favorable to the "slow" participants. Table 13 shows the difference between the "fast" participants and the "slow" participants in each condition.

| Condition | Participant Type | N | Mean | SD | Mean Diff | T | P |
|---|---|---|---|---|---|---|---|
| **FEAC** | Experienced | 23 | 541.91 | 217.48 | 327.00 | 3.48 | <.01 |
| | Non-Experienced | 9 | 868.11 | 289.26 | | | |
| **PEAC** | Experienced | 23 | 434.39 | 208.23 | 277.39 | 2.34 | <.05 |
| | Non-Experienced | 9 | 711.78 | 330.60 | | | |
| **SDAC** | Experienced | 23 | 396.78 | 158.54 | 365.11 | 5.28 | <.001 |
| | Non-Experienced | 9 | 761.89 | 216.42 | | | |
| **FDAC** | Experienced | 23 | 384.96 | 136.87 | 28.93 | .60 | |
| | Non-Experienced | 9 | 413.89 | 60.66 | | | |

Table 14. Descriptive Statistics and t-test Results between "Experienced" and "Non-Experienced" Participants in Four Wayfinding Affordance Conditions Relative to Task Completion Time

Regarding the difference between the "experienced" and "non-experienced" participants, those participants who had previous experience with 3D virtual environments did significantly better than those participants who had no prior VE experience in all conditions, except in the FDAC condition, as shown in the Table 14. The difference was greatest with 365.11 in the SDAC condition and least with 28.93 in the FDAC condition. This indicates that the performance of "non-experienced" participants was not that different from that of the “experienced” participants in the FDAC condition.

Table 14 also shows that the differences among the “non-experience” participants were much greater than among the “experienced” participants across the four different conditions and that the “non-experienced” participants in the FDAC condition completed their tasks in a comparatively shorter time than in other conditions, suggesting that the FDAC condition was more favorable to “non-experienced” participants. Finally, there was not significant relationship between task completion time and experience.

***Path***

Path refers to the number of steps that participants took in order to perform their tasks. As summarized in Table 15, the mean difference between the detached conditions and the embedded conditions was significant $F (1, 63) = 12.40$, $p < .01$, showing that the participants took significantly more steps in the embedded conditions (PEAC, SDAC) than in the detached conditions (FDAC, SDAC).

| **Condition** | | **Minimum** | **Maximum** | **Mean (sec.)** | | **SD (sec.)** | |
|---|---|---|---|---|---|---|---|
| **DAC** | **FDAC** | 12 | 22 | 16.03 | 16.63 | 2.79 | 3.75 |
| | **SDAC** | 12 | 33 | 17.22 | | 4.49 | |
| **EAC** | **PEAC** | 12 | 31 | 17.31 | 19.11 | 5.16 | 5.78 |
| | **FEAC** | 12 | 34 | 20.91 | | 5.89 | |

Table 15. Descriptive Statistics for Four Wayfinding Affordance Conditions on Path

The mean was highest in the FEAC condition with 20.91 (SD = 5.89) whereas it was lowest in the FDAC condition with 16.03 (SD = 2.79). The descriptive statistics also indicated that standard deviations in the fixed conditions, in particular, in the FDAC condition were much smaller than those of the embedded conditions. This means that the differences among participants were comparatively smaller in the fixed affordance conditions than in the embedded conditions.

ANOVA repeated measure test was performed in order to examine the differences among the four wayfinding affordance conditions and the results revealed a significant effect of wayfinding affordance design on the number of steps taken by participants, $F(3, 93) = 9.99$, $p < .001$ as presented in Table 16.

| **Within Subject Effect** | **F** | **df** | **Error df** | **p** | **$\eta^2$** | **power** |
|---|---|---|---|---|---|---|
| **The Effect of Wayfinding Affordance Design on Path** | 9.99 | 3 | 93 | .00 | .24 | 1.00 |

Table 16. ANOVA Repeated Measure Test for the Effect of Wayfinding Affordance Design on Path

| **Paired Comparisons** | **FEAC** | **SDAC** | **PEAC** | **FDAC** |
|---|---|---|---|---|
| **FEAC** | . | *** | ** | ** |
| **SDAC** | | . | N.S. | N.S. |
| **PEAC** | | | . | N.S. |
| **FDAC** | | | | . |

Table 17. Pairwise Comparison of Four Wayfinding Affordance Conditions on Path (**: p <.01, ***: p<.001)

As shown in Table 17, the subsequent pairwise comparisons indicated significant differences among the following conditions: FEAC-PEAC, FEAC-SDAC, and FEAC-FDAC. The results suggested that participants in the FEAC took significantly more steps than those in other conditions. Unlike task completion time, there were no significant differences between the FDAC-PEAC and the FDAC-SDAC conditions with regard to the number of steps taken.

| Condition | Participant Type | Mean | SD | Mean Diff | t | P |
|---|---|---|---|---|---|---|
| **FEAC** | Fast | 19.38 | 5.30 | 3.06 | 1.50 | |
| | Slow | 22.44 | 6.21 | | | |
| **PEAC** | Fast | 15.25 | 2.57 | 4.13 | 2.44 | <.05 |
| | Slow | 19.38 | 6.27 | | | |
| **SDAC** | Fast | 15.25 | 2.27 | 3.94 | 2.73 | <.05 |
| | Slow | 19.19 | 5.31 | | | |
| **FDAC** | Fast | 16.06 | 3.13 | .06 | .06 | |
| | Slow | 16.00 | 2.50 | | | |

Table 18. Descriptive Statistics and t-test Results between the "Fast" and the "Slow" Participants in the Four Wayfinding Affordance Conditions Relative to Path

In terms of task-speed, the difference between the "fast" and the "slow" participants were significant in the SDAC and PEAC at the .05 level. The results suggest that the "fast" participants took a significantly smaller number of steps to complete their tasks in the SDAC and the PEAC.

However, there was no significant difference in the FDAC and FEAC conditions, indicating that the performance of the "slow" participants was not very different from that of the "fast" participants. Table 18 presents the descriptive statistics and t-test results between the "fast" and the "slow" participants in the four different conditions relative to path. Unlike task completion time, there were no significant differences between "experienced" and "non-experienced" participants in all four conditions.

***Satisfaction with Task Performance***

As presented in Table 19, the mean satisfaction score was 5.02 (SD = 1.59) on a 7-point scale, indicating that participants were satisfied with their overall task performance. When the difference between the detached and the embedded conditions were considered, significant mean difference $F(1, 63) = 6.16$, $p < .05$ was found, suggesting that the participants were more satisfied with their task performance in the detached conditions (FDAC, SDAC) rather than in the embedded conditions (PEAC, FEAC).

| Condition | | Minimum | Maximum | Mean (sec.) | | SD (sec.) | |
|---|---|---|---|---|---|---|---|
| DAC | FDAC | 2 | 7 | 5.41 | 5.28 | 1.62 | 1.39 |
| | SDAC | 3 | 7 | 5.16 | | 1.11 | |
| EAC | PEAC | 2 | 7 | 5.22 | 4.77 | 1.58 | 1.74 |
| | FEAC | 1 | 7 | 4.31 | | 1.80 | |

Table 19. Descriptive Statistics for Four Wayfinding Affordance Conditions on Participants' Satisfaction with Task Performance

When each of the scores was considered, the mean satisfaction score was highest in the FDAC condition with 5.41 (SD =1.62) whereas it was lowest in the FEAC condition with 4.31 (SD =1.80).

| Within Subject Effect | F | df | Error df | P | $\eta^2$ | Power |
|---|---|---|---|---|---|---|
| **The Effect of Wayfinding Affordance Design on Task Satisfaction** | 5.95 | 3 | 93 | .00 | .16 | .95 |

Table 20. ANOVA Repeated Measure Test for the Effect of Wayfinding Affordance Design on Participants' Satisfaction with Task Performance

The results of the repeated measure revealed a significant effect of wayfinding affordance design on participants' satisfaction with their task performance, $F(3, 93) = 5.95$, $p < .01$ as shown in Table 20.

The subsequent pairwise comparisons indicated significant differences between the following conditions at the .01 level, as shown in Table 21: FEAC-PEAC, FEAC-SDAC, and FEAC-FDAC. The results suggest that participants in the FEAC condition reported significantly lower satisfaction score than those in the other conditions.

| Paired Comparisons | FEAC | SDAC | PEAC | FDAC |
|---|---|---|---|---|
| **FEAC** | · | ** | ** | ** |
| **SDAC** | | · | N.S. | N.S. |
| **PEAC** | | | · | N.S. |
| **FDAC** | | | | · |

Table 21. Pairwise Comparison of Four Wayfinding Affordance Conditions Regarding Participants' Satisfaction with Task Performance (**: $p < .01$)

Finally, unlike task completion time and path, there were no significant effects of gender, VE experience and task-speed on participants' satisfaction with their task performance.

### *Task Difficulty*

As shown in Table 22, the overall mean difficulty score was 3.38 (SD = 1.47) on a 7-point scale, slightly lower than the mid-point. When the difference between detached and embedded conditions was considered, there were significant mean difference, $F(1, 63) = 17.58$, $p < .01$, demonstrating that the participants felt more difficulty in the embedded conditions (PEAC, FEAC) than in the detached conditions (FDAC, SDAC).

| Condition | | Minimum | Maximum | Mean (sec.) | | SD (sec.) | |
|---|---|---|---|---|---|---|---|
| DAC | FDAC | 1 | 6 | 2.78 | 2.98 | 1.26 | 1.24 |
| | SDAC | 1 | 6 | 3.19 | | 1.20 | |
| EAC | PEAC | 1 | 6 | 3.31 | 3.77 | 1.45 | 1.58 |
| | FEAC | 2 | 7 | 4.22 | | 1.60 | |

Table 22. Descriptive Statistics for Four Wayfinding Affordance Conditions on Task Difficulty

When each of the scores was viewed, the mean difficulty score was highest in the FEAC condition with 4.22 (SD = 1.60) whereas it was lowest in the FDAC condition with 2.78 (SD =1.26).

The results of the ANOVA repeated measure test revealed significant differences in difficulty scores among the four conditions: specifically, as shown in Table 23, the results indicated a significant effect of wayfinding affordance design on task difficulty $F(3, 93) = 13.57$, $p < .001$.

| Within Subject Effect | F | df | Error df | P | $\eta_2$ | Power |
|---|---|---|---|---|---|---|
| **The Effect of Wayfinding Affordance Design on Task Difficulty** | 13.57 | 3 | 93 | .00 | .30 | 1.00 |

Table 23. ANOVA Repeated-Measure test for the Effect of Wayfinding Affordance Design on Task Difficulty

The subsequent pairwise comparisons indicated significant differences among the following conditions at the .01 level, as indicated in Table 24: FEAC-PEAC, FEAC-SDAC, and FEAC-FDAC. The results suggest that participants in the FEAC condition reported significantly higher difficulty score than those in other conditions.

| Paired Comparisons | FEAC | SDAC | PEAC | FDAC |
|---|---|---|---|---|
| **FEAC** | · | ** | ** | ** |
| **SDAC** | | · | N.S. | N.S. |
| **PEAC** | | | · | * |
| **FDAC** | | | | · |

Table 24. Pairwise Comparison of Four Wayfinding Affordance Conditions on Task Difficulty (*: p<.05, **: p <.01)

There was also a significant difference between the PEAC and the FDAC at the .05 level, suggesting that participants had more difficulties in completing their tasks in the PEAC condition than the FDAC.

| Condition | Participant Type | N | Mean | SD | Mean Diff | t | P |
|---|---|---|---|---|---|---|---|
| **FEAC** | Experienced | 23 | 3.83 | 1.50 | 1.40 | 2.38 | <.05 |
| | Non-Experienced | 9 | 5.22 | 1.48 | | | |
| **PEAC** | Experienced | 23 | 3.00 | 1.24 | 1.11 | 2.05 | <.05 |
| | Non-Experienced | 9 | 4.11 | 1.69 | | | |
| **SDAC** | Experienced | 23 | 2.87 | .87 | 1.13 | 1.60 | |
| | Non-Experienced | 9 | 4.00 | 1.59 | | | |
| **FDAC** | Experienced | 23 | 2.54 | 1.12 | .61 | 1.25 | |
| | Non-Experienced | 9 | 3.27 | 1.56 | | | |

Table 25. Descriptive Statistics and t-test Results between "Experienced" and "Non-Experienced" Participants in Four Wayfinding Affordance Conditions Relative to Task Difficulty

Regarding the difference between the “experienced” and “non-experienced” participants, those who did not have previous experience with 3D virtual environments reported significantly higher difficulty score in the two embedded conditions (that is, in the FEAC and PEAC) and the results were significant at the .05 level. However, there was no difference found in the difficulty scores between the “experienced” and “non-experienced” participants in the two detached conditions, SDAC and FDAC. This means that the “non-experienced” participants felt comparatively more difficulty in the embedded conditions than in the detached conditions. Table 25 shows descriptive statistics and t-test results between the “experienced” and “non-experienced” participants in four wayfinding affordance conditions relative to difficulty. With regard to gender and VE experience, t-test results did not show statistically significant difference.

### 6.1.3. Perceptual Experience

Perceptual experience was measured by two concepts: presence and playfulness. This research found that the design of wayfinding affordance had statistically significant effects on participants’ perceptual experiences, although they were not as great as those of task performance.

#### ***Presence***

As presented in Table 26, the overall average of presence score was 4.58 (SD = 1.10) on a 7-point Likert-type scale and there were significantly more participants who felt presence than those who did not ($X^2 = 6.13$ $p < .05$). This means that desktop virtual environments provided some degree of presence to the participants.

When looked at from the perspective of overall average, the participants in the fixed conditions had presence scores that were slightly higher than those for the movable conditions and the mean difference was fairly close to significant, $F(1, 63) = .52$, $p = .065$, showing that the participants tended to more presence in the fixed conditions (FDAC, FEAC) than in the movable conditions (SDAC, PEAC).

| Condition | | Minimum | Maximum | Mean (sec.) | | SD (sec.) | |
|---|---|---|---|---|---|---|---|
| FAC | FDAC | 2 | 7 | 4.91 | 4.70 | 1.17 | 1.15 |
| | FEAC | 3 | 6 | 4.53 | | .98 | |
| MAC | SDAC | 3 | 7 | 4.50 | 4.46 | 1.11 | 1.04 |
| | PEAC | 2 | 6 | 4.39 | | 1.10 | |

Table 26. Descriptive Statistics for Four Wayfinding Affordance Conditions with Regard to Presence

When each condition of the presence scores was compared, the mean presence score was highest in the FDAC with 4.91 (SD = 1.17) whereas it was lowest in the PEAC with 4.39 (SD = 1.10). In order to identify the differences in presence scores among the four wayfinding conditions, ANOVA repeated measure test was performed and the results yielded the significant effects regarding wayfinding affordance design on presence, $F(3, 93) = .2.97$, $p < .05$.

| Paired Comparisons | FEAC | SDAC | PEAC | FDAC |
|---|---|---|---|---|
| FEAC | · | N.S. | N.S. | * |
| SDAC | | · | N.S. | * |
| PEAC | | | · | * |
| FDAC | | | | . |

Table 27. Pairwise Comparison of Four Wayfinding Affordance Conditions with Regard to Presence (*: $p < .05$)

The pariwise comparisons yielded differences for the FDAC-PEAC and the FDAC-FEAC at the .05 level and for FDAC-PEAC at the .01 level. The results suggest that the FDAC condition provided a significantly higher presence experience for the participants, and the difference was especially significant between the FDAC and the PEAC. The results of pairwise comparisons are presented in Table 27.

Regarding the difference between the "experienced" and the "non-experienced" participants, those who had previous experience with 3D virtual environments reported higher presence scores in the detached conditions (FDAC, SDAC). In contrast, participants without prior experience reported that they felt more presence in the embedded conditions (PEAC, FEAC). However, an independent sample t-test did not reveal any statistical difference between the "experience" and the "non-experienced" participants.

In terms of task-speed, the "fast" participants reported higher presence scores in the moveable conditions (PEAC, SDAC) whereas the "slow" participants felt more presence in the fixed conditions (FEAC, FDAC). However, the difference between the movable conditions and the fixed conditions were not significant. Finally, there was no significant difference with regard to presence score between male and female participants.

### *Playfulness*

Playfulness is a subjective experience characterized by perceptions of pleasure and involvement (Webster, Trevino, & Ryan, 1993). As presented in Table 28, the overall average of playfulness score was 4.66 (SD = 1.04) on a 7-point Likert-type scale and there were significantly more participants who felt playfulness than those who did not ($X^2$

= 6.13 p < .05). This suggests that participants reported feeling some degree of flow while they were involved in their tasks.

| **Condition** | | **Minimum** | **Maximum** | **Mean (sec.)** | | **SD (sec.)** | |
|---|---|---|---|---|---|---|---|
| **DAC** | **FDAC** | 3 | 7 | 4.89 | 4.81 | 1.06 | 1.05 |
| | **SDAC** | 3 | 7 | 4.72 | | 1.05 | |
| **EAC** | **PEAC** | 3 | 6 | 4.59 | 4.52 | .88 | 1.02 |
| | **FEAC** | 2 | 7 | 4.44 | | 1.15 | |

Table 28. Descriptive Statistics for Four Wayfinding Affordance Conditions with Regard to Playfulness

When viewed from the perspective of an overall average, the participants in the detached conditions reported playfulness scores that were slightly higher than those for the embedded conditions with difference approaching statistical significance, $F (1, 63) = 6.58$, $p < .05$, showing that the desktop virtual environments provided more playfulness to participants in the detached conditions (FDAC, SDAC) than in the embedded conditions (FEAC, PEAC).

When each condition of the playfulness scores was compared, the mean playfulness score was highest in the FDAC with 4.89 (SD = 1.06) whereas it was lowest in the FEAC with 4.44 (SD = 1.15). In order to identify the difference in playfulness scores between fixed conditions and embedded conditions, ANOVA repeated measure test was performed and the results showed that the effect of wayfinding affordance design on playfulness approached statistical significance, $F (3, 93) = .2.60$, $p = .057$.

The subsequent pariwise comparisons yielded differences for the FDAC-PEAC and the FDAC-FEAC at the .05 level. The results suggest that the FDAC condition provided significantly higher flow experience than the two embedded conditions (PEAC, FEAC). The results of pairwise comparisons are presented in Table 29.

| Paired Comparisons | FEAC | SDAC | PEAC | FDAC |
|---|---|---|---|---|
| **FEAC** | · | N.S. | N.S. | * |
| **SDAC** | | · | N.S. | N.S. |
| **PEAC** | | | · | * |
| **FDAC** | | | | . |

Table 29. Pairwise Comparison of Four Wayfinding Affordance Conditions with Regard to Playfulness (*: $p < .05$)

In terms of the difference between the "experienced" and "non-experienced" participants, those who had previous experience with 3D virtual environments reported higher playfulness score in the detached conditions (FDAC, SDAC) but those without prior experience felt more presence in the embedded conditions (PEAC, FEAC). However, an independent t-test revealed that this difference were not statistically significant. In terms of task-speed, the "fast" participants showed higher playfulness score in moveable conditions (PEAC, SDAC) whereas the "slow" participants felt more playfulness in the fixed conditions (FEAC, FDAC). However, the difference between the movable conditions and the fixed conditions were not significant and there was no significant difference between male and female participants.

### 6.1.4. Correlation among Presence, Playfulness and Task Performance

Tables 30 through 33 show correlations among task performance, presence and playfulness in each condition. Pearson correlation coefficients indicate that presence and playfulness scores were significantly correlated with each other, across all four conditions

($r$ = .797, p < .01 in FEAC, $r$ = .734, p < .01 in PEAC, $r$ = .732, p < .01 in SDAC, $r$ = .796, and p < .01 in FDAC). This means that participants who reported feeling a greater sense of presence also reported feeling more playfulness. However, the results of correlation analysis revealed that task performance was not directly related to presence or playfulness.

| | **Time** | **Path** | **Satisfaction** | **Difficulty** | **Presence** | **Playfulness** |
|---|---|---|---|---|---|---|
| **Time** | 1.000 | | | | | |
| **Path** | .679** | 1.000 | | | | |
| **Satisfaction** | -.535** | -.635** | 1.000 | | | |
| **Difficulty** | .498** | .519** | -.728** | 1.000 | | |
| **Presence** | .255 | -.002 | .285 | .129 | 1.000 | |
| **Playfulness** | .189 | -.080 | .433* | -.077 | .797** | 1.000 |

Table 30. Correlations among Task Performance, Presence and Playfulness in the FEAC Condition (* p < .05, ** p < .01)

When each condition was examined separately, all task performance-related measures including time, path, satisfaction with task performance, and task difficulty were significantly correlated with each other in the FEAC condition as shown in Table 30. There were also significant correlations between participants' satisfaction with their tasks performance and playfulness scores in the FEAC condition ($r$ = .433, p < .05). In the PEAC condition, the presence scores were significantly correlated with task difficulty ($r$ = .395, p < .05). In both of the embedded conditions (FEAC, PEAC), all four task performance-related measures (time, path, participants' satisfaction with their task performance and task difficulty) were significantly correlated at the level of .01.

|  | Time | Path | Satisfaction | Difficulty | Presence | Playfulness |
|---|---|---|---|---|---|---|
| **Time** | 1.000 |  |  |  |  |  |
| **Path** | .789** | 1.000 |  |  |  |  |
| **Satisfaction** | -.446* | -.424* | 1.000 |  |  |  |
| **Difficulty** | .496** | .596** | -.581** | 1.000 |  |  |
| **Presence** | .129 | -.041 | -.155 | .395* | 1.000 |  |
| **Playfulness** | .141 | -.014 | -.050 | .180 | .734** | 1.000 |

Table 31. Correlation among Task Performance, Presence and Playfulness in the PEAC Condition (* p < .05, ** p < .01)

In the SDAC, not all performance-related measures were correlated with each other; Pearson correlations showed that time were related to path and satisfaction scores at the .01 level but not directly related to time; path were related to time and satisfaction scores at the .01 level but not to time; satisfaction were related to path and task difficulty at the .01 level but not to path; and task difficulty were related to time and satisfaction scores at the .01 level but not to path. In contrast, in the FDAC condition, none of these task performance-related measures was related to one another.

|  | Time | Path | Satisfaction | Difficulty | Presence | Playfulness |
|---|---|---|---|---|---|---|
| **Time** | 1.000 |  |  |  |  |  |
| **Path** | .572** | 1.000 |  |  |  |  |
| **Satisfaction** | -.296 | -.532** | 1.000 |  |  |  |
| **Difficulty** | .470** | .303 | -.457** | 1.000 |  |  |
| **Presence** | -.052 | -.075 | .171 | .145 | 1.000 |  |
| **Playfulness** | -.244 | -.280 | .287 | -.008 | .732** | 1.000 |

Table 32. Correlation among Task Performance, Presence and Playfulness in the SDAC Condition (** p < .01)

| | Time | Path | Satisfaction | Difficulty | Presence | Playfulness |
|---|---|---|---|---|---|---|
| **Time** | 1.000 | | | | | |
| **Path** | .166 | 1.000 | | | | |
| **Satisfaction** | -.031 | -.174 | 1.000 | | | |
| **Difficulty** | .212 | .313 | -.238 | 1.000 | | |
| **Presence** | -.087 | -.285 | .054 | .182 | 1.000 | |
| **Playfulness** | -.016 | -.062 | .049 | .148 | .796** | 1.000 |

Table 33. Correlation among Task Performance, Presence and Playfulness in the FDAC Condition (** $p < .01$)

## 6.2. EXPERIMENT 2

In Experiment 2, thirty participants completed three sets of navigation and manipulation tasks in 6×5 and 6×4 block university environments.

### 6.2.1. Participants

Twenty-one (70.0%) were male and 9 (30.0%) were female. Of the 30 participants, 4 (13.3%) had two-to-five years of experience with computers; 8 (26.7%) had five-to-ten years of experience; 11 (36.7%) had ten-to-fifteen years of experience; and 7 (23.3%) had 15 years or more, yielding a median of ten-to-fifteen years' experience. Table 34 shows the characteristics of the 30 participants.

| **Characteristics** | **Measurement** | **Number of Participants** | **%** |
|---|---|---|---|
| Gender | Male | 21 | 70.0 |
| | Female | 9 | 30.0 |
| Years of Computer Use | 2-5 years | 4 | 13.3 |
| | 5-10 years | 8 | 26.7 |
| | 10-15 years | 11 | 36.7 |
| | More than 15 years | 7 | 23.3 |
| Hours of Computer Use (per day) | Less than an Hour | 2 | 6.7 |
| | 1-2 hours | 7 | 23.3 |
| | 2-4 hours | 8 | 26.7 |
| | 4-7 hours | 10 | 33.3 |
| | 7 hours or more | 3 | 10.0 |

Table 34. Participants' Characteristics in Experiment 2 (n = 30)

As in Experiment 1, all participants except two reported using computers on a daily basis. Regarding the hours of computer use, the participants were classified into five groups: 2 (6.7%) used a computer for less than an hour a day; 7 (23.3%) for 1-to-2 years; 8 (26.7%) for 2-to-4 hours; 10 (33.3%) for 4-to-7 hours; and 3 (10.0%) for 7 hours or more, yielding a media of 2-4 hours.

| **Characteristics** | **Measurement** | **Number of Participants** | **%** |
|---|---|---|---|
| Years of 3D VE Use | Less than 2 years | 16 | 59.3 |
| | 2-5 years | 4 | 14.8 |
| | 5-10 years | 3 | 11.1 |
| | 10-15 years | 4 | 14.8 |
| Frequency of 3D VE Use | Daily | 1 | 3.7 |
| | 1-2 days a week | 3 | 11.1 |
| | 3-4 days a week | 7 | 25.9 |
| | Very Rarely | 15 | 55.6 |
| | Other | 1 | 3.7 |
| Hours of 3D VE Use (per week) | Less than an hour | 17 | 63.0 |
| | 1-2 hours | 3 | 11.1 |
| | 2-4 hours | 2 | 7.4 |
| | 4-7 hours | 4 | 14.8 |
| | 7 hours or more | 1 | 3.7 |

Table 35. The Characteristics of Participants with VE Experience in Experiment 2 (n = 27)

Of the 30 participants, 27 (90.0%) had experience with 3D VEs whereas 3 (10.0%) did not have any prior experience. With regard to years of 3D VE use, 16

(59.3%) had less than 2 years of experience; 4 (14.8%) had two-to-five years; 3 (11.1%) for five-to-ten years and 4 (14.8%) for ten-to-fifteen years.

Concerning frequency of 3D VE use, participants were categorized into five groups. One (3.7%) used 3D VEs everyday; 3 (11.1%) for one-to-two days a week; 7 (25.9%) for three-to-four days; 15 (55.6%) for very rarely; and one (3.7%) participant did not fall into any of these categories.

When the hours of 3D VE use were considered, 17 (63.0%) used VEs for less than an hour per week; 3 (11.1%) used them for one-to-two hours; 2 (7.4%) for two-to- four hours; 4 (14.8%) for four-to-seven hours; and one participant had (3.7%) for seven hours or more. Table 35 shows the characteristics of participants who had prior experience with three-dimensional virtual environments. The participants' purposes for use of VE were the same as those in Experiment 1.

### 6.2.2. Task Performance

Task Performance was measured by task completion time, path, task difficulty and participants' satisfaction with task performance. Then, ANOVA repeated measure test was conducted to examine the effects of wayfinding affordance design on participants' task performance. Additionally, independent t-tests were used to identify the difference resulting from participants' characteristics, such as gender, VE experience, and task completion time.

#### *Task Completion Time*

The mean wayfinding task completion time was 493.20 (SD = 234.74) which was not that different from the mean task completion time in Experiment 1. As presented in Table 36, the mean difference between the detached conditions and the embedded conditions was significant F (1, 59) = 7.11, p < .01, showing that the participants completed their tasks faster using the detached conditions (FDAC, SDAC) whereas they were slower using the embedded conditions (PEAC, FEAC).

| Condition | | Minimum | Maximum | Mean (sec.) | | SD (sec.) | |
|---|---|---|---|---|---|---|---|
| **DAC** | **FDAC** | 214 | 967 | 453.87 | 454.80 | 204.86 | 211.46 |
| | **SDAC** | 211 | 1144 | 455.73 | | 221.37 | |
| **EAC** | **PEAC** | 238 | 1202 | 499.63 | 531.62 | 245.40 | 253.82 |
| | **FEAC** | 251 | 1282 | 563.60 | | 262.17 | |

Table 36. Descriptive Statistics for the Effects of Four Wayfinding Affordance Conditions on Task Completion Time

The mean completion time was greatest in the FEAC condition with 563.60 (SD = 262.17) whereas it was smallest in the FDAC condition with 453.87 (SD = 204.86), indicating that the difference was more than 109 seconds.

The descriptive statistics also indicated that standard deviations in the detached conditions were not as great as those in the embedded conditions, suggesting that the difference between the fast participants and the slow participants was much smaller in the detached conditions (FDAC, SDAC) than in the embedded conditions (PEAC, FEAC).

| Within Subject Effect | F | Df | Error df | P | $\eta^2$ | power |
|---|---|---|---|---|---|---|
| **The Effect of Wayfinding Affordance Design on Task Completion Time** | 4.00 | 3 | 87 | .00 | .12 | .82 |

Table 37. ANOVA Repeated Measure Test for the Effect of Wayfinding Affordance Design on Task Completion Time

In order to examine the effects of affordance design on task completion time, ANOVA repeated measure test was performed and the results revealed that there were significant differences among the four conditions, $F(3, 93) = 12.77$, $p < .001$ as shown in Table 37.

The pairwise comparisons yielded 63.97 (SD = 30.83), 107.87 (SD = 46.46) and 109.73 (SD = 33.58) mean differences for FEAC-PEAC, FEAC-SDAC and FEAC-FDAC that were all significant at the .05 level. The results suggest that participants were significantly slower in the FEAC condition than in other conditions. The results of pairwise comparisons are presented in Table 38.

| **Paired Comparisons** | **FEAC** | **PEAC** | **SDAC** | **FDAC** |
|---|---|---|---|---|
| **FEAC** | · | * | * | * |
| **PEAC** | | · | N.S. | N.S. |
| **SDAC** | | | · | N.S. |
| **FDAC** | | | | . |

Table 38. Pairwise Comparison of Four Wayfinding Affordance Conditions on Task Completion Time (*: $p < .05$)

Overall, there was a significant difference between the "fast" participants and the "slow" participants for all four conditions at the .001 level and the .01 level. The difference was greatest in the FEAC condition with 383.47 whereas the difference was least in the SDAC with 262.00. This indicates that the performance of the "slow" participants was comparable to the "fast" participants in the SDAC condition, demonstrating that the SDAC condition was more favorable to the "slow" participants. In Experiment 1, the difference was the least in the FDAC condition. Table 39 shows the difference between the "fast" participants and the "slow" participants in each condition.

| Condition | Participant Type | N | Mean | SD | Mean Diff | T | P |
|---|---|---|---|---|---|---|---|
| **FEAC** | Fast | 15 | 371.87 | 77.82 | 383.47 | 5.89 | <.001 |
| | Slow | 15 | 755.33 | 239.89 | | | |
| **PEAC** | Fast | 15 | 323.93 | 60.45 | 351.40 | 5.62 | <.001 |
| | Slow | 15 | 675.33 | 234.40 | | | |
| **SDAC** | Fast | 15 | 324.73 | 94.31 | 262.00 | 3.98 | <.01 |
| | Slow | 15 | 586.73 | 236.31 | | | |
| **FDAC** | Fast | 15 | 311.53 | 70.10 | 284.67 | 5.29 | <.001 |
| | Slow | 15 | 596.20 | 196.48 | | | |

Table 39. Descriptive Statistics and t-test Results for the “Fast” and the “Slow” Participants in Four Wayfinding Conditions Relative to Task Completion Time

| Condition | Participant Type | N | Mean | SD | Mean Diff | T | P |
|---|---|---|---|---|---|---|---|
| **FEAC** | Male | 21 | 466.62 | 192.58 | 323.27 | 3.72 | <.01 |
| | Female | 9 | 789.89 | 272.30 | | | |
| **PEAC** | Male | 21 | 419.10 | 180.49 | 268.46 | 2.62 | <.01 |
| | Female | 9 | 687.56 | 283.04 | | | |
| **SDAC** | Male | 21 | 394.81 | 205.17 | 203.08 | 2.50 | <.05 |
| | Female | 9 | 597.89 | 199.80 | | | |
| **FDAC** | Male | 21 | 311.53 | 70.10 | 206.06 | 2.81 | <.01 |
| | Female | 9 | 596.20 | 196.48 | | | |

Table 40. Descriptive Statistics and t-test Results between “Male” and “Female” Participants in Four Wayfinding Affordance Conditions Relative to Task Completion Time

As indicated in Table 40, male participants did significantly better than female participants in all four conditions. The difference was the greatest with 323.27 in the FEAC condition and the least with 203.08 in the SDAC condition. This indicates that the performance of female participants was not that different from that of male participants in the SDAC condition.

With regard to VE experience, statistical analyses were not performed because there were only three participants who did not have prior experience with 3D virtual environments.

***Path***

As summarized in Table 41, participants took 4.02 more steps to complete their tasks in the second experiment. As in Experiment 1, the mean difference between the detached conditions and the embedded conditions was significant $F(1, 59) = 8.42$, $p < .01$, showing that the participants took significantly more steps in the embedded conditions (PEAC, SDAC) than in the detached conditions (FDAC, SDAC).

<table>
<tr><th colspan="2">Condition</th><th>Minimum</th><th>Maximum</th><th colspan="2">Mean (sec.)</th><th colspan="2">SD (sec.)</th></tr>
<tr><td rowspan="2">DAC</td><td>FDAC</td><td>16</td><td>28</td><td>20.37</td><td rowspan="2">20.65</td><td>3.68</td><td rowspan="2">4.47</td></tr>
<tr><td>SDAC</td><td>15</td><td>38</td><td>20.93</td><td>5.19</td></tr>
<tr><td rowspan="2">EAC</td><td>PEAC</td><td>15</td><td>35</td><td>21.50</td><td rowspan="2">23.14</td><td>5.78</td><td rowspan="2">6.20</td></tr>
<tr><td>FEAC</td><td>23</td><td>67</td><td>24.77</td><td>6.16</td></tr>
</table>

Table 41. Descriptive Statistics for Four Wayfinding Affordance Conditions on Path

The mean was highest in the FEAC condition with 24.77 (SD = 6.16) whereas it was lowest in the FDAC condition with 20.37 (SD = 3.68). However, the differences among FDAC (M = 20.37, SD = 3.68), SDAC (M = 20.93, SD = 5.19) and PEAC (M = 21.50, SD = 5.78) were minor.

As presented in Table 42, ANOVA repeated measure test was performed in order to examine the differences among the four wayfinding affordance conditions and the results revealed a significant effect of wayfinding affordance design on the number of steps taken by participants, $F(2.25, 65.37) = 5.98$, $p < .01$.

| Within Subject Effect | F | Df | Error df | p | $\eta^2$ | power |
|---|---|---|---|---|---|---|
| **The Effect of Wayfinding Affordance Design on Path** | 5.98 | 2.25 | 65.37 | .00 | .17 | .89 |

Table 42. ANOVA Repeated Measure Test for the Effect of Wayfinding Affordance Design on Path

| Paired Comparisons | FEAC | SDAC | PEAC | FDAC |
|---|---|---|---|---|
| **FEAC** | . | * | * | * |
| **SDAC** | | . | N.S. | N.S. |
| **PEAC** | | | . | N.S. |
| **FDAC** | | | | . |

Table 43. Pairwise Comparison of Four Wayfinding Affordance Conditions on Path (*: $p < .05$)

As shown in Table 43, the subsequent pairwise comparisons indicated significant differences among the following conditions: FEAC-PEAC, FEAC-SDAC, and FEAC-FDAC at the .05 level. The results suggested that participants in the FEAC condition took significantly more steps than those in other conditions.

| Condition | Participant Type | Mean | SD | Mean Diff | t | P |
|---|---|---|---|---|---|---|
| **FEAC** | Fast | 21.33 | 4.61 | 6.87 | 3.55 | <.01 |
| | Slow | 28.20 | 5.91 | | | |
| **PEAC** | Fast | 18.73 | 4.10 | 5.53 | 2.95 | <.01 |
| | Slow | 24.27 | 5.99 | | | |
| **SDAC** | Fast | 19.53 | 4.00 | 2.80 | 1.51 | |
| | Slow | 22.33 | 5.97 | | | |
| **FDAC** | Fast | 18.67 | 2.16 | 3.40 | 2.82 | <.01 |
| | Slow | 22.07 | 4.15 | | | |

Table 44. Descriptive Statistics and t-test Results between the Fast and the "Slow" Participants in the Four Wayfinding Affordance Conditions Relative to Path

The difference between the "fast" and the "slow" participants are presented in Table 44. An independent sample t-test indicated that the difference between the "fast" and the "slow" participants were significant in the FDAC, PEAC and FEAC conditions at the .01 level. The results suggest that the "fast" participants took a significantly smaller number of steps to complete their tasks, except in the FEAC condition. However, there was no significant difference in the SDAC condition, indicating that the performance of the "slow" participants was not much different from that of the "fast" participants. Table 44 presents the descriptive statistics and t-test results between the "fast" and the "slow" participants in the four different conditions relative to path.

In terms of gender, there were statistically significant difference between male and female participants only in the PEAC condition at the .05 level while t-test results did not show any difference between the "experienced" and the "non-experienced" participants in all four conditions.

***Satisfaction with Task Performance***

As presented in Table 45, the mean satisfaction score was 5.21 (SD = 1.46) on a 7-point scale, indicating that participants were satisfied with their overall task performance. The mean satisfaction score of 5.21 was slightly higher than the mean satisfaction score of 5.02 (SD = 1.59) in Experiment 1.

When the difference between the detached and the embedded conditions was considered, a significant mean difference $F(1, 59) = 7.10$, $p < .05$ was found, indicating that the participants were more satisfied with their task performance in the detached conditions (FDAC, SDAC) than in the embedded conditions (PEAC, FEAC).

| **Condition** | | **Minimum** | **Maximum** | **Mean (sec.)** | | **SD (sec.)** | |
|---|---|---|---|---|---|---|---|
| **DAC** | **FDAC** | 2 | 7 | 5.41 | 5.28 | 1.62 | 1.39 |
| | **SDAC** | 3 | 7 | 5.16 | | 1.11 | |
| **EAC** | **PEAC** | 2 | 7 | 5.22 | 4.77 | 1.58 | 1.74 |
| | **FEAC** | 1 | 7 | 4.31 | | 1.80 | |

Table 45. Descriptive Statistics for Four Wayfinding Affordance Conditions on Participants' Satisfaction with Task Performance

When each of the scores was considered, the mean satisfaction score was highest in the FDAC condition with 5.43 (SD = 1.46) which is slightly higher than the mean satisfaction score, 5.41 (SD = 1.62), in Experiment 1. In contrast, the mean satisfaction score was lowest in the FEAC condition with 4.93 (SD = 1.50) which was also higher than the mean satisfaction score, 4.31 (SD = 1.80), in Experiment 1.

As shown in Table 46, the results of the ANOVA repeated measure test revealed that the effects of wayfinding affordance design on participants' satisfaction approached statistical significance, $F(3, 87) = 2.44$, $p = .078$.

| Within Subject Effect | F | df | Error df | P | $\eta_2$ | Power |
|---|---|---|---|---|---|---|
| **The Effect of Wayfinding Affordance Design on Task Satisfaction** | 2.44 | 3 | 87 | .08 | .08 | .59 |

Table 46. ANOVA Repeated Measure Test for the Effect of Wayfinding Affordance Design on Participants' Satisfaction with Task Performance

The subsequent pairwise comparisons indicated significant differences between the following conditions at the .05 level, as shown in Table 47: FEAC-SDAC, and FEAC-FDAC. The results suggest that participants in the FEAC condition reported significantly lower satisfaction score than those in the two detached conditions (FDAC, SDAC).

| Paired Comparisons | FEAC | SDAC | PEAC | FDAC |
|---|---|---|---|---|
| **FEAC** | · | * | N.S. | * |
| **SDAC** | | · | N.S. | N.S. |
| **PEAC** | | | · | N.S. |
| **FDAC** | | | | · |

Table 47. Pairwise Comparison of Four Wayfinding Affordance Conditions Regarding Participants' Satisfaction with Task Performance (*: $p < .05$)

In terms of task-speed, the differences between the "fast" and the "slow" participants were significant in the FEAC condition at the .01 level and in the FDAC and SDAC at the .05 level. The results suggest that the "fast" participants were more satisfied with their task performance in the FEAC, FDAC and PEAC conditions. However, there was no significant difference in the SDAC condition, indicating that the satisfaction of the "slow" participants was not much different from that of the "fast" participants. Table

48 presents the descriptive statistics and t-test results between the “fast” and the “slow” participants in the four different conditions relative to participants’ satisfaction of task performance. In terms of gender and VE experience, t-tests did not show statistically significant differences.

| Condition | Participant Type | Mean | SD | Mean Diff | t | P |
|---|---|---|---|---|---|---|
| **FEAC** | Fast | 5.73 | 1.10 | 1.60 | 3.40 | <.01 |
| | Slow | 4.13 | 1.48 | | | |
| **PEAC** | Fast | 5.67 | 1.54 | 1.20 | 2.23 | <.05 |
| | Slow | 4.47 | 1.41 | | | |
| **SDAC** | Fast | 5.80 | 1.27 | .80 | 1.60 | |
| | Slow | 5.00 | 1.46 | | | |
| **FDAC** | Fast | 6.00 | 1.13 | 1.13 | 2.28 | <.05 |
| | Slow | 4.87 | 1.55 | | | |

Table 48. Descriptive Statistics and t-test Results between the “Fast” and the “Slow” Participants in the Four Wayfinding Affordance Conditions Relative to Participants’ Satisfaction with Task Performance

***Task Difficulty***

As shown in Table 49 the overall mean difficulty score was 3.09 (SD = 1.48) on a 7-point scale. The mean difficulty score of 3.09 was slightly lower than the mid-point and the mean score of 3.38 (SD = 1.47) in Experiment 1.

When the difference between the detached and embedded conditions were considered, there was significant mean difference, $F(1, 59) = 19.45$, $p < .001$, showing that the participants felt more difficulty in the embedded conditions (PEAC, FEAC) than in the detached conditions (FDAC, SDAC). When each of the scores was viewed, the mean difficulty score was highest in the FEAC condition with 3.77 (SD = 1.74) whereas it was lowest in the SDAC condition with 2.67 (SD = 1.29).

| Condition | | Minimum | Maximum | Mean (sec.) | | SD (sec.) | |
|---|---|---|---|---|---|---|---|
| DAC | FDAC | 1 | 6 | 2.83 | 2.75 | 1.34 | 1.31 |
| | SDAC | 1 | 5 | 2.67 | | 1.30 | |
| EAC | PEAC | 1 | 6 | 3.10 | 3.43 | 1.32 | 1.57 |
| | FEAC | 1 | 7 | 3.77 | | 1.74 | |

Table 49. Descriptive Statistics for Four Wayfinding Affordance Conditions on Task Difficulty

The results of the ANOVA repeated measure test revealed significant differences in difficulty with regard to scores among the four conditions: specifically, as shown in Table 50, the results indicated a significant effect of wayfinding affordance design on task difficulty $F(3, 87) = 8.78$, $p < .001$.

| Within Subject Effect | F | df | Error df | P | $\eta^2$ | Power |
|---|---|---|---|---|---|---|
| **The Effect of Wayfinding Affordance Design on Task Difficulty** | 8.78 | 3 | 87 | .00 | .23 | 0.99 |

Table 50. ANOVA Repeated Measure Test for the Effect of Wayfinding Affordance Design on Task Difficulty

The subsequent pairwise comparisons indicated significant differences among the following conditions at the .05 level, as indicated in Table 51: FEAC-PEAC, FEAC-SDAC, and FEAC-FDAC. The results suggest that participants in the FEAC condition reported significantly higher difficulty score than those in other conditions. There were also significant differences between the PEAC and the SDAC at the .05 level, suggesting that participants had more difficulties in completing their tasks in the PEAC condition than in the SDAC.

| Paired Comparisons | FEAC | SDAC | PEAC | FDAC |
|---|---|---|---|---|
| **FEAC** | · | * | * | * |
| **SDAC** | | · | * | N.S. |
| **PEAC** | | | · | N.S. |
| **FDAC** | | | | · |

Table 51. Pairwise Comparison of Four Wayfinding Affordance Conditions on Task Difficulty (*: $p < .05$)

| Condition | Participant Type | Mean | SD | Mean Diff | T | P |
|---|---|---|---|---|---|---|
| **FEAC** | Fast | 2.73 | 1.58 | 2.07 | 4.03 | <.001 |
| | Slow | 4.80 | 1.21 | | | |
| **PEAC** | Fast | 2.40 | .74 | 1.40 | 3.38 | <.01 |
| | Slow | 3.80 | 1.42 | | | |
| **SDAC** | Fast | 2.13 | .99 | 1.07 | 2.44 | <.05 |
| | Slow | 3.20 | 1.37 | | | |
| **FDAC** | Fast | 2.27 | 1.22 | 1.13 | 2.51 | <.05 |
| | Slow | 3.40 | 1.24 | | | |

Table 52. Descriptive Statistics and t-test Results between the "Fast" and the "Slow" Participants in the Four Wayfinding Affordance Conditions Relative to Task Difficulty

In terms of task-speed, the differences between the "fast" and the "slow" participants were significant in FEAC at the .001 level, FDAC at the .01 level, and PEAC and SDAC at the .05 level. The results suggest that the "slow" participants felt more difficulties in completing their tasks in all conditions. Table 52 presents the descriptive statistics and t-test results between the "fast" and the "slow" participants in the four different conditions relative to participants' satisfaction of task performance. In terms of gender and VE experience, t-test results did not show statistically significant differences.

### 6.2.3. Perceptual Experience

Unlike Experiment 1, the results of the ANOVA repeated measure test did not show statistically significant effects of wayfinding affordance design on participants' perceptual experiences in terms of both presence and playfulness.

#### *Presence*

As presented in Table 53, the overall average of presence score was 4.26 (SD = 1.01) on a 7-point Likert-type scale, slightly lower than the mean presence score of 4.58 (SD = 1.10) in Experiment 1. Like Experiment1, there were significantly more participants who felt presence than those who did not ($X^2 = 4.80$ $p < .05$), showing that participants felt some degree of presence in desktop virtual environments.

| **Condition** | | **Minimum** | **Maximum** | **Mean (sec.)** | | **SD (sec.)** | |
|---|---|---|---|---|---|---|---|
| **FAC** | **FDAC** | 2 | 6 | 4.33 | 4.32 | .95 | 1.09 |
| | **FEAC** | 3 | 6 | 4.32 | | 1.19 | |
| **MAC** | **SDAC** | 3 | 7 | 4.24 | 4.19 | .96 | .94 |
| | **PEAC** | 2 | 6 | 4.14 | | .91 | |

Table 53. Descriptive Statistics for Four Wayfinding Affordance Conditions with Regard to Presence

When looked at from the perspective of overall average, the participants in the fixed conditions had presence score that were slightly higher than those for the movable conditions but the mean difference was not significant and that was different from Experiment 1.

When each condition of the presence scores was compared, the mean presence score was highest in the FDAC with 4.33 (SD = .95) whereas it was lowest in the PEAC with 4.14 (SD = .91). However, the differences across four conditions were minor.

***Playfulness***

The overall average of playfulness score was 4.30 (SD = 1.04) on a 7-point Likert-type scale and there were significantly more participants who felt playfulness than those who did not ($X^2 = 6.53$, $p < .05$).

| Condition | Minimum | Maximum | Mean (sec.) | SD (sec.) |
|---|---|---|---|---|
| **FDAC** | 2 | 6 | 4.00 | 1.04 |
| **SDAC** | 3 | 6 | 4.36 | .95 |
| **PEAC** | 2 | 6 | 4.00 | 1.07 |
| **FEAC** | 2 | 6 | 4.23 | 1.17 |

Table 54. Descriptive Statistics for Four Wayfinding Affordance Conditions with Regard to Playfulness

This suggests that participants reported feeling some degree of flow while they were involved in their tasks. In order to identify the differences in playfulness scores among four wayfinding conditions, ANOVA repeated measure test was performed but the results did not show any statistical differences across the four conditions. Table 54 presents a summary of descriptive statistics for the four wayfinding affordance conditions with regard to playfulness.

### 6.2.4. Correlation among Presence, Playfulness and Task Performance

Tables 55 through 58 show correlations among task performance, presence and playfulness in each condition. As in Experiment 1, Pearson correlation coefficients indicate that presence and playfulness scores were significantly correlated with each other across all four conditions ($r$ = .816, p < .01 in FEAC, $r$ = .779, p < .01 in PEAC, $r$ = .781, p < .01 in SDAC, $r$ = .838, and p < .01 in FDAC). This means that participants who reported feeling a greater sense of presence also reported feeling more playfulness. However, the results of correlation analysis revealed that task performance was not directly related to presence or playfulness.

| | Time | Path | Satisfaction | Difficulty | Presence | Playfulness |
|---|---|---|---|---|---|---|
| **Time** | 1.000 | | | | | |
| **Path** | .682** | 1.000 | | | | |
| **Satisfaction** | -.553** | -.531** | 1.000 | | | |
| **Difficulty** | .527** | .521** | -.560** | 1.000 | | |
| **Presence** | -.116 | -.089 | .148 | - .013 | 1.000 | |
| **Playfulness** | -.188 | -.088 | .243 | -.150 | .816** | 1.000 |

Table 55. Correlations among Task Performance, Presence and Playfulness in the FEAC Condition (** p < .01)

When each condition was examined separately, the results of the FEAC condition were consistent with the results for Experiment 1, as shown in Table 55: all task performance-related measures including time, path, satisfaction with task performance, and task difficulty were significantly correlated with each other. There were also significant correlations between participants' satisfaction with their tasks performance and playfulness score in the FEAC condition ($r$ = .816, p < .01).

| | Time | Path | Satisfaction | Difficulty | Presence | Playfulness |
|---|---|---|---|---|---|---|
| **Time** | 1.000 | | | | | |
| **Path** | .614** | 1.000 | | | | |
| **Satisfaction** | -.586* | -.338 | 1.000 | | | |
| **Difficulty** | .561** | .273 | -.616** | 1.000 | | |
| **Presence** | -.107 | -.043 | .198 | .162 | 1.000 | |
| **Playfulness** | -.269 | -.210 | .358 | .043 | .779** | 1.000 |

Table 56. Correlation among Task Performance, Presence and Playfulness in the PEAC Condition (* p < .05, ** p < .01)

| | Time | Path | Satisfaction | Difficulty | Presence | Playfulness |
|---|---|---|---|---|---|---|
| **Time** | 1.000 | | | | | |
| **Path** | .489** | 1.000 | | | | |
| **Satisfaction** | -.448* | -.228 | 1.000 | | | |
| **Difficulty** | .460** | -.147 | -.493** | 1.000 | | |
| **Presence** | -.116 | -.083 | .330 | .117 | 1.000 | |
| **Playfulness** | -.023 | -.101 | .410* | -.143 | .781** | 1.000 |

Table 57. Correlation among Task Performance, Presence and Playfulness in the SDAC Condition (* p < .05, ** p < .01)

In the PEAC and SDAC conditions, three task performance-related measures - time, satisfaction with task performance and task difficulty - were correlated at the level of .01 and .05 but path did not have a statistically significant relationship with other measures. In the SDAC condition, there was also a significant correlation between satisfaction with task performance and playfulness at the .05 level.

Finally, in the FDAC condition, three task performance-related measures - time, satisfaction with task performance and task difficulty - were correlated at the level of .01 but path did not have a statistically significant relationship with participants' satisfaction with task performance.

| | Time | Path | Satisfaction | Difficulty | Presence | Playfulness |
|---|---|---|---|---|---|---|
| **Time** | 1.000 | | | | | |
| **Path** | .521** | 1.000 | | | | |
| **Satisfaction** | -.704** | -.174 | 1.000 | | | |
| **Difficulty** | .651** | .404* | -.722** | 1.000 | | |
| **Presence** | -.045 | -.047 | .156 | .172 | 1.000 | |
| **Playfulness** | -.085 | -.010 | .218 | .046 | .838** | 1.000 |

Table 58. Correlation among Task Performance, Presence and Playfulness in the FDAC Condition (* p < .05, ** p < .01)

### 6.3. PARTICIPANTS' SUBJECTIVE PREFERENCES

In order to capture participants' subjective preferences for and thoughts about the four experimental conditions, post-test questionnaires were completed. The reasons participants identified for positive experiences in each condition are the following.

First, participants mentioned that the Fixed Embedded Affordance Cues (FEAC) condition offered them more chances to explore and appreciate the worlds and objects, such as sculptures, buildings and trees, rather than to focus only on tasks that led to their next destination. Participants also stated that, unlike other conditions, the FEAC condition did not interfere with their views of artificially located maps and signs. In other words, the FEAC condition provided environments that were visually more appealing and offered participants a more compelling and engaging experience. Finally, participants pointed out that the FEAC condition was most similar to the real world and such a realistic environment allowed participants to perform exciting and challenging tasks. On the other hand, participants pointed out that it was more difficult to accomplish wayfinding tasks in the FEAC condition because they felt easily disoriented and oftentimes became lost without necessary affordance cues at hand. Participants also stated that they attempted to memorize next destinations and routes while performing their tasks, and sometimes it was essential for them to guess their current location and orientation.

In contrast to the FEAC condition, the participants reported that the advantages of the Portable Embedded Affordance Cues (PEAC) condition were its ability to support wayfinding task performance. Participants stated that wayfinding cues in the PEAC condition were more convenient to reference because those cues were always with them. The participants also pointed out that the location and visibility of affordance cues enabled them to complete their tasks easily by helping them to focus on their physical movements and destinations. However, participants who did not like this condition claimed that affordance cues in the PEAC condition blocked and limited their visual field and eventually interfered with their attention and perceptual experience. The majority of participants described such experiences as follows:

- The PEAC condition made it more difficult to “get into” the virtual world.
- I didn't feel like navigating a virtual world, it was simply like map finding.
- Having the graphic in front of me irritated me and my eyes. It was an annoying experience.
- It was difficult for me to try to pay full attention.

Third, participants stated that detached conditions, that is, the Fixed Detached Affordance Cues (FDAC) and the Switchable Detached Affordance Cues (SDAC) conditions, were more efficient and easier to use than the embedded conditions because the orientation and location information was immediately available by way of affordance cues and, therefore, participants did not have to remember environmental settings. Participants mentioned that these conditions were like having a map in their pockets to refer to when necessary. Another interesting finding about detached conditions is that even though few participants actually used the switching and moving functions in the SDAC condition, the majority of participants reported that the SDAC condition was more preferable than the FDAC condition and more user-friendly because it was more flexible and customizable in terms of visibility and location of affordance cues. Unlike the embedded conditions, not many participants mentioned problems with the FDAC and SDAC conditions. Because affordance cues were fixed on the top left corner of the screen, only a few participants pointed out that the SDAC condition blocked the visual area.

This chapter has described specifics of research findings drawn from two experiments. The data have shown the effects of affordance design on participants' wayfinding task performance, presence and playfulness. The data have also revealed the relationship among task performance, presence and playfulness. The final chapter provides further details on implications of research findings, limitations of the study and suggestions for future research.

# Chapter 7 -- Discussion

The purpose of this study has been to examine the effects of wayfinding affordance design that is implemented with maps and signs on users' task performance and perceptual experience, specifically in terms of presence and playfulness. For the purpose of this study, four different wayfinding affordance conditions were set up**:** Fixed Detached Affordance Cues (FDAC), Switchable Detached Affordance Cues (SDAC), Portable Embedded Affordance Cues (PEAC), and Fixed Embedded Affordance Cues (FEAC).

In this chapter, the results of this study are discussed based on the four research questions: the effects of wayfinding affordance design on task performance; the effects of wayfinding affordance design on users' perceptual experience, particularly in terms of presence and playfulness; and the relationships between users' task performance, presence and playfulness. The last two sections consider the implications for practice as well as the limitations of this study.

## 7.1. THE EFFECTS OF WAYFINDING AFFORDANCE DESIGN ON TASK PERFORMANCE

Task Performance was measured by task completion time, path, task difficulty and participants' satisfaction with task performance. The overall results of this study provide evidence that the design of wayfinding affordance has significant effects on participants' task performance.

### 7.1.1. Task Completion Time

The mean wayfinding task completion time was 509.66 (SD = 249.28) seconds in Experiment 1 and 493.20 (SD = 234.74) seconds in Experiment 2. The participants took less time by 16.46 seconds in completing their tasks in Experiment 2 although the environments in Experiment 2 were larger and more complex. One possible reason for this finding is that there were only three non-experienced participants in Experiment 2 as opposed to 9 non-experienced participants in Experiment 1. Another possible explanation is that the total distance that participants moved from one wayfinding task to another was not that different in both Experiments 1 and 2. These findings together suggest that there was no task complexity effect on task completion time. However, findings regarding path show that task complexity did have some effect on steps that participants took to complete their tasks, as will be discussed later.

The overall research findings indicate that the participants performed their tasks faster using the detached conditions where the wayfinding affordance cues were provided separately from the 3D environments. On the other hand, the participants were slower in completing their tasks using the embedded conditions, especially the FEAC condition. In that condition, the wayfinding cues were fixed and embedded inside the 3D virtual environments so that the participants had to remember the layout until they reached the next wayfinding cue. The results of task completion time were consistent in both Experiments 1 and 2, indicating that those findings can be applied to simple as well as complex environments.

When the specific statistical findings were considered, the ANOVA results revealed that the design of wayfinding affordance had significant effects on task completion time, favoring the detached affordance cues (FDAC, SDAC) at a .001 alpha level in Experiment 1 and at a .01 alpha level in Experiment 2. The subsequent pairwise comparison showed that the participants' task performance was significantly slower in the FEAC condition at a .01 alpha level in Experiment 1 and at a .05 alpha level in Experiment 2, compared to the other three conditions. In addition, the participants' performance using the FDAC condition was also considerably faster than the other three conditions (FDAC, SDAC, and PEAC) in Experiment 1. However the participants' performance in the other three conditions was relatively similar in Experiment 2.

| | **FEAC** | **SDAC** | **PEAC** | **FDAC** |
|---|---|---|---|---|
| **Experiment 1** | - | · | · | + |
| **Experiment2** | - | · | · | · |

Table 59. The Effects of the Wayfinding Affordance Design on Participants' Task Performance

A comparison of the "fast" and "slow" participants showed, in general, that participants in both groups were able to do their tasks quickly and without problems if they had wayfinding cues available at all times, as in the FDAC, SDAC, and PEAC conditions. However, when performance of the "fast" and "slow" participants was compared relative to each condition, the results varied. The difference in their performance was greatest in the FEAC condition in both experiments whereas the difference was least in the FDAC condition in Experiment1 and in the SDAC condition in Experiment 2. These results indicate that the performance of the "slow" participants was much slower than that of the "fast" participants where the participants saw the wayfinding cues as objects that were constructed inside the virtual environment and, therefore, were not always visible.

Expert-versus-novice distinctions are one of the primary user characteristics that explain participants' behavior and experience (Dix et al., 1993). Eberts (1994) indicated that experts and novices have different capabilities and, therefore, computer systems need to accommodate diverse needs and requirements. In this study, participants were divided into two groups in order to identify differences between expert participants and novice participants. In general, fast participants showed better abilities in encoding environmental information and focusing attention on unlearned information. The difference between expert and novice participants was especially significant when maps were not always visible to users.

In the FEAC condition, the “fast” participants appear to have had more experience in map-reading and better strategies to move through virtual space so that they were better able to remember all the necessary details, although they did not have access to the wayfinding cues. By contrast, the “slow” participants appear to have become confused about the orientation and frequently unable to know which way to turn, once the wayfinding cues were not available. As a result, the “slow” participants required a longer time to complete their tasks in the FEAC condition, in contrast to other conditions.

On the other hand, the performance of the “fast” and “slow” participants was not significantly different where the wayfinding affordance cues remained available so that the participants could reference the cues whenever necessary. This finding suggests that the performance of the “slow” participants was comparable to that of the “fast” participants in the detached conditions (FDAC, SDAC), thus implying that those two conditions were more favorable to the “slow” participants than were the two embedded conditions (FEAC, SDAC).

Now turning to the difference between the “experienced” and “non-experienced” participants, those participants who had previous experience with 3D virtual environments performed significantly better than those participants who had no prior VE experience in all conditions, except in the FDAC condition. In the FDAC condition, the difference between the “experienced” and “non-experienced” participants was only 28.93 seconds, in contrast to the differences in the FEAC (327.00 sec.), PEAC (277.39 sec.) and SDAC (365.11 sec.) conditions in the Experiment 1. Another interesting point is that in all four conditions, the performance of “experienced” participants was comparatively stable whereas the performance of the “non-experienced” participants changed substantially from condition to condition. This finding implies that the wayfinding affordance design has more significant effects on "non-experienced" participants than on "experienced" participants, thus leading to the conclusion that the detached conditions are more favorable to the "non-experienced" participants.

### 7.1.2. Path

With regard to the influence of wayfinding affordance, the overall study results provided strong evidence that the design of wayfinding cues significantly affected path. The mean number of steps that participants needed to complete the wayfinding tasks was 17.87 (SD = 5.01) in Experiment 1 and 21.89 (SD = 5.51) in Experiment 2, indicating that participants took 4.02 more steps to complete their tasks in Experiment 2. Even though the results of the study did not reveal the effects of task complexity on task completion time, as mentioned in Section 7.1.1, there was significant path difference between Experiments 1 and 2, suggesting complexity of wayfinding tasks had significant effects on the number of steps participants took to finish their tasks.

When the findings were examined in detail, the research demonstrated that the participants took considerably more steps in the embedded conditions, especially in the FEAC condition where the wayfinding affordance cues were provided as part of the VE interfaces and, for that reason, were not always visible to the participants. As in the analysis of task completion time, the results of path were consistently applied to simple as well as complex environments.

More specifically, the overall results of ANOVA were in favor of the detached affordance cues (FDAC, SDAC) at a .01 alpha level in both Experiments 1 and 2. The follow-up pairwise comparison indicated that the participants took considerably more steps in the FEAC condition than in the other three conditions in both Experiments 1 and

2. However, the differences among the other three conditions (FDAC, PEAC and SDAC) were not great in both Experiments 1 and 2, suggesting that the location or visibility of wayfinding cues did not make significant differences to path as long as those cues were available to the participants whenever necessary.

When the path of the "fast" and "slow" participants was compared, the PEAC condition showed a difference between the "fast" and "slow" participants and this finding remained consistent in both Experiments 1 ($t = 2.44$, $p < .05$) and 2 ($t = 2.95$, $p < .01$). These results suggest that the "slow" participants had a relatively more difficult time in accomplishing their tasks when wayfinding cues were located in the center of the screen and, for that reason, interfered with their interaction with the 3D virtual environments. This finding indicates that the PEAC condition was less favorable for the "slow" participants.

### 7.1.3. Satisfaction with Task Performance

The mean satisfaction score was 5.01 (SD = 1.59) in Experiment 1 and 5.21 (SD = 1.46) in Experiment 2 on a 7-point scale, showing that participants' satisfaction score was slightly higher than mid-point in both Experiments 1 and 2.

The overall study results provided evidence that the design of wayfinding cues affected participants' satisfaction with their task performance, in favor of the detached affordance cues (FDAC, SDAC) conditions. As expected from the results regarding task completion time and path, ANOVA revealed that participants' satisfaction scores were slightly lower in the embedded conditions compared to the other three conditions.

To verify and further explore this finding, subsequent pairwise comparisons were conducted and the results indicated that the satisfaction score for the FEAC condition was significantly different from those of the fixed conditions (FDAC, SDAC) but not that different from the other embedded condition (PEAC) in both Experiments 1 and 2. As in the analysis of other task performance related measures, these findings were consistent in both Experiments 1 and 2, indicating that the results can be applied to simple as well as complex environments.

When the satisfaction score of the "fast" and "slow" participants was compared, only Experiment 2 showed differences between these two groups in the FEAC, PEAC, and FDAC conditions, but not in the SDAC condition. One possible explanation for these findings is that the "slow" participants were more sensitive to task complexity. In other words, because task environments in Experiment 2 were more complicated than in Experiment 1, the "slow" participants experienced comparatively greater difficulty when they were carrying out their tasks, thus leading to lower satisfaction scores. Meanwhile, the satisfaction scores of "fast" participants were fairly consistent across all four conditions.

#### 7.1.4. Task Difficulty

The mean task difficulty score was 3.38 (SD = 1.47) in Experiment 1 and 3.09 (SD = 1.48) in Experiment 2 on a 7-point scale, slightly lower than mid-point. Unexpectedly, the task difficulty scores were higher in Experiment 1 where the environment was smaller and, for that reason, the participants' tasks were comparatively simpler than those in Experiment 2. A possible explanation for this finding is that for task difficulty, there were more participants in Experiment 2 who had had previous experience with 3D environments and, as a result, may have found the tasks to be simpler when compared to those of other 3D environments.

The overall study results showed that the design of wayfinding cues had significant effects on task difficulty in favor of the detached affordance cues (FDAC, SDAC) conditions. ANOVA demonstrated that task difficulty scores were significantly lower in the embedded conditions, especially in the FEAC condition, in both Experiments 1 and 2. As observed with other task performance related measures, these findings were consistent in both Experiments 1 and 2, indicating that these results can be applied to simple as well as complex environments. When the task difficulty scores of the "fast" and the "slow" participants were compared, only the results from Experiment 2 showed there were significant differences between these two groups across all four conditions.

Another point to be noted with regard to task difficulty is that there were two participants - one in Experiment 1 and another in Experiment 2 – who, in the middle of the experiment, gave up trying to perform the tasks and thus failed to finish the whole set of tasks. Both participants had had limited experience with 3D environments and both reported they have difficulty with a sense of direction in real life. Interestingly, both participants started with the FEAC condition. Based on this observation, it is possible that the FEAC condition is significantly unfavorable to certain types of participants.

## 7.2. THE EFFECTS OF WAYFINDING AFFORDANCE DESIGN ON PERCEPTUAL EXPERIENCE

Perceptual experience was measured in terms of two concepts: presence and playfulness. This research found that the design of wayfinding affordance had statistically significant effects on participants' perceptual experience in simple environments although the effects were not as great as those related to task performance.

### 7.2.1. Presence

As described in Section 4, presence is the compelling illusion that invites users to feel a sense of embodiment in a computer-simulated environment (Biocca, 1997).

Perceiving oneself to be inside a virtual space is the underpinning of a sense of presence and such an immersive user experience is considered to be the essence of the VE experience (Wann, & Mon-Williams, 1996, Riva, 1999).

In this study, the mean presence score was 4.58 (SD = 1.10) in Experiment 1 and 4.26 (SD = 1.01) in Experiment 2 on a 7-point scale, slightly higher than mid-point, indicating that desktop virtual environments provided some degree of presence to the participants. This finding is important because a controversy exists about whether users feel presence in desktop virtual environments. This research supports the argument that participants do, in fact, feel a sense of presence in non-immersive desktop virtual environments.

Interestingly, the "non-experienced" participants reported slightly higher presence scores than the "experienced" participants although the difference was not statistically significant. Previous studies indicate that when users are unfamiliar with VE systems, their lack of familiarity is likely to discourage their sense of presence (Held & Durlach, 1992). However, in this study, the findings seem to indicate that once the "non-experienced" participants felt comfortable manipulating VEs, they felt more presence perhaps due to heightened curiosity and inquisitiveness about using new technology.

When viewed from the perspective of overall presence average, participants in the fixed conditions had slightly higher presence scores than those in the movable conditions in both Experiments 1 and 2. The results from ANOVA showed that, in Experiment 1, the mean difference was fairly close to significant, $F(1, 63) = 3.52$, $p = .065$, showing that the participants tended to feel more presence in the fixed conditions (FDAC, FEAC) than in the movable conditions (SDAC, PEAC). The follow-up pairwise comparisons indicated that the FDAC condition provided a significantly higher sense of presence than did the other three conditions, and the difference was especially greater between the FDAC and the PEAC conditions.

It is noteworthy that the difference regarding presence scores appeared between the fixed (FDAC, FEAC) and movable (SDAC, PEAC) conditions rather than between the detached (FDAC, SDAC) and embedded (FEAC, PEAC) conditions. In the movable (SDAC, PEAC) conditions, the wayfinding cues were always available and, it is assumed, positively affected participants' wayfinding task performance. However, these movable wayfinding cues were obviously artificial and may have interfered with the participants' perceptual experience. A number of participants in the PEAC condition reported that they could not "get into" the 3D environments because the wayfinding cues limited their visual field in every direction and, therefore, distracted them from their experience. With regard to the movable SDAC condition, the low presence scores may be due to the participants' awareness that the cues could be switched on and off. In fact, several participants mentioned that they liked the freedom and flexibility of the SDAC condition even though they did not actually use this option for their tasks.

In contrast to the movable SDAC and PEAC conditions, the wayfinding cues in the fixed FEAC condition were created as an object in the environment and, therefore, may have appeared to be more natural. Even though the wayfinding cues in this FEAC condition provided a poor environment for wayfinding task performance, this condition may have seemed to be more similar to real-world environments for the participants. An interesting aspect of this issue is that if affordance cues are critical for users to make sense of an interface, it seems likely that users may perceive wayfinding cues as a real part of the environment (Adams, 2006).

Another interesting point of these findings is that the participants' sense of presence was greater in the FEAC condition than in the SDAC and PEAC conditions even though the participants' task performance was not as great as that in the FEAC condition, with regard to all four task performance-related measures. In other words, participants in the FEAC condition had a significantly more difficult time completing their wayfinding tasks but their presence scores were surprisingly high, thus implying that users' task performance was not directly related to their perceptual experience.

Unexpectedly, the results in Experiment 2, however, did not yield a statistical difference between the fixed and movable conditions. It appears that in the simple environments, the subtle interface design differences created greater effects on participants' perceptual experience whereas in the more complex environments, the complicated task requirements diminished the effects that arose as the result of minor interface design differences.

### 7.2.2. Playfulness

As discussed in Section 4, the most prominent psychological impact of presence is playfulness (Lombard & Ditton, 1997). Playfulness is a subjective experience characterized by perceptions of pleasure and involvement (Webster, Trevino, & Ryan, 1993). In terms of user interactions with computers, playfulness is described as a situation-specific individual characteristic or tendency to interact spontaneously, inventively and imaginatively with computers (Reid, 2004; Webster & Martocchio, 1992).

In this study, the mean playfulness score was 4.66 (SD = 1.04) in Experiment 1 and 4.30 (SD = 1.04) in Experiment 2 on a 7-point scale, slightly higher than mid-point and higher also than the presence scores. This means that desktop virtual environments provided some degree of playfulness, as well as presence, for the participants.

With regard to the influence of wayfinding affordance, the overall results of this study revealed that the design of wayfinding cues had significant effects on playfulness in Experiment 1 in favor of the detached condition, especially the FDAC condition. The follow-up pairwise comparisons showed that the FDAC condition scored significantly higher than did the two embedded conditions (FEAC, PEAC), indicating that the FDAC condition provided a significantly higher state of playfulness than did the FDAC and PEAC conditions. However, this difference was not significant in Experiment 2.

As the research findings relative to perceptual experience indicated, it seems that the concepts of presence and playfulness measure slightly different aspects of users' experience in virtual environments. For presence, the fixed conditions (FEAC, PEAC) provided a more favorable environment. However, for playfulness, the detached conditions (FDAC, SDAC) were preferable. This suggests that participants felt a greater sense of emotional pleasure and freedom in the detached conditions but that they felt a greater sense of cognitive presence or immersion in the fixed conditions.

## 7.3. The Relationship among Task Performance, Presence and Playfulness

The importance of perceptual experience is often highlighted in the context of its potential relationship with performance. The results of this study, however, did not explicitly show a relationship between any of the perceptual experiences and wayfinding task performance, thus indicating that wayfinding task performance was not significantly related to the participants' sense of presence or playfulness.

The overall presence scores were higher in the fixed conditions whereas the participants' task performance was better in the detached conditions. These findings suggest that participants might feel a higher degree of presence even though they did not perform their wayfinding tasks well in certain environments. Actually, participants reported higher presence scores in the FEAC condition even though they took a substantially longer amount of time and were required to take more steps to finish their tasks. In contrast, the participants reported higher playfulness scores in the detached conditions where they accomplished their tasks in a significantly shorter amount of time that required fewer steps.

In looking at the relationship between presence and playfulness, the Pearson correlation analysis revealed that those two concepts were significantly related to each other, across all four conditions in both Experiments 1 and 2. However, it is noteworthy that participants reported higher presence scores in the fixed conditions (FDAC, FEAC) than in the movable conditions (PEAC, SDAC) whereas they reported higher playfulness scores in the detached conditions (FDAC, SDAC) than in the embedded conditions (FEAC, PEAC). These findings imply that although playfulness and presence are closely related, these concepts measure two different aspects of users' experience in virtual environments, as mentioned previously.

### 7.4. IMPLICATIONS OF THIS STUDY

One of the most important aspects of user interaction in virtual environments is wayfinding. Users experience difficulties in keeping track of their current locations and orientation while they are traversing virtual environments and, as a result, users spend considerable time and effort in figuring out spatial information (Chen & Stanney, 1999; Stanney et al., 2003). Therefore, the design of VEs should include appropriate wayfinding affordance cues, and those cues should be carefully presented to users to minimize wayfinding complexity (Stanney, Mourant & Kennedy, 1998).

Among various types of wayfinding affordance cues, maps are among the most frequently used affordance cues in VEs and, thus, a number of design methods have been developed for map applications. The purpose of this study was, therefore, to examine the effects of four different wayfinding design approaches that are based on maps and to provide practical implications for designers of virtual environments.

Regarding task performance, the detached conditions (FDAC, SDAC) were more favorable for all users – but the FDAC condition was especially preferable for novices. Therefore, when designers of virtual environments need to support users' wayfinding task performance, it may be advisable to provide affordance cues that are independent of the 3D environment – as in the FDAC condition. The reason seems to be that in the FDAC condition, cues are more stable and immediately available so that users can move about quickly without giving much thought to their next destination.

| | | Type of Wayfinding Affordance | | | |
|---|---|---|---|---|---|
| | | **FDAC** | **SDAC** | **FEAC** | **PEAC** |
| **Task Performance** | | + | · | - | · |
| **Perceptual Experience** | **Presence** | + | - | + | - |
| | **Playfulness** | + | + | - | - |

Table 60. The Summary of Overall Study Results

With regard to perceptual experience, even though playfulness and presence are related, it is assumed that those concepts measure two slightly different aspects of users' experience in virtual environments. Therefore, when designers of virtual environments want to support users' sense of presence, the fixed conditions (FDAC, FEAC) appear to be preferable. Especially for "expert" users who have more experience and better strategies to manipulate VE interfaces, the FEAC condition would be a better option in complex environments that require challenging tasks. By contrast, when playfulness or entertainment aspects are the goal of the design, the detached conditions (FDAC, SDAC) may be preferable. In those conditions, the wayfinding cues are always visible, easy to access and, therefore, may offer users more mental energy to explore the environment and enjoy their tasks. Table 60 shows overall study results.

As indicated in this study, the FEAC condition significantly lowered the efficiency of participants' wayfinding performance in terms of task completion time, path, satisfaction with task performance and the sense of task difficulties. However, today's most popular Desktop 3D Virtual Environments, including Second Life, Active Worlds, IMVU, There, and Red Light Center, rely upon wayfinding affordance cues that are presented only as fixed embedded forms. According to Second Life Statistic Report (http://secondlife.com/whatis/economy_stats.php), approximately 14 million uniquely named avatars were registered in 2008 and users spent 28,274,505 hours in these VEs during January 2008. If Second Life is an example of future VEs, and in order to realize the great potential that exists for these types of VE software, it is recommended that better strategies be developed for wayfinding cues in recognition of the importance of the ways that these cues affect users' overall task performance and experience.

In this study, the focus was centered on wayfinding affordance cues that are based on maps. Only limited attention has been devoted to a comparison of different types of wayfinding cues as well as relationships between wayfinding cues and users' particular characteristics. According to Ruddle, Payne & Jones (1997), there was a significant wayfinding cue type effect when users move through VEs but only little empirical data have been reported about the effects of wayfinding cues on users' performance and experience in VEs. Further research is, therefore, required to investigate the effectiveness of various affordance cues and to optimize the designs of VEs.

## 7.5. LIMITATIONS OF THE STUDY

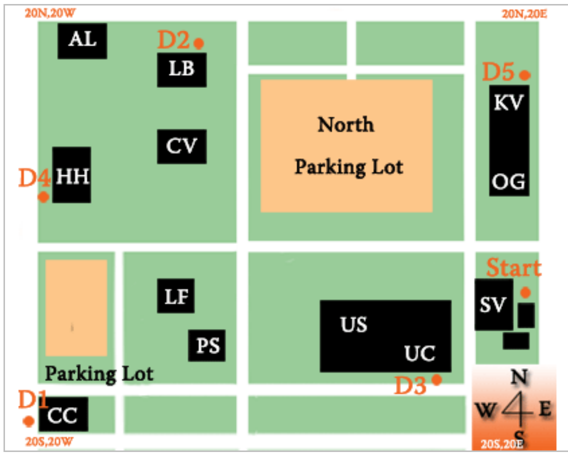
Several limitations and concerns apply to this study. First, in recruiting and assigning participants to different experimental cases, this study did not consider characteristics such as gender, previous experience with 3D virtual environments and computer skills. As a result, a relatively small number of female participants were included in both Experiments 1 and 2. Also, a substantially small number of participants who had no prior experience with 3D environments were included. Especially in Experiment 2, all but three participants had previous experience with 3D virtual environments so that comparisons could not be made between “experienced” and “non-experienced” participants. Because users’ experiences are determined also by their personal preferences and subjectivity of perceptual experience (Held & Durlach, 1992; Witmer & Singer, 1998), future research may expand the findings of this study by giving greater consideration to personal characteristics of participants in the recruitment process.

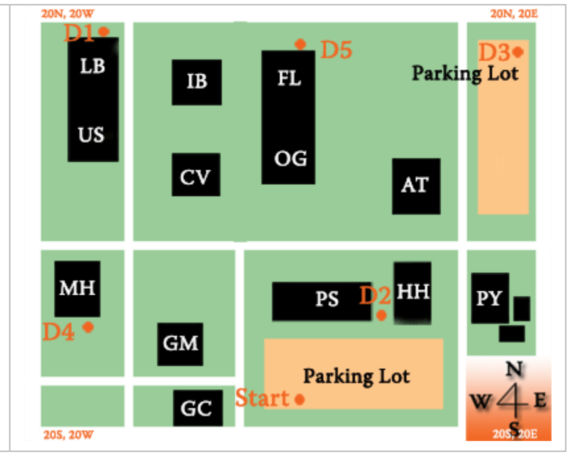
Second, in each experiment, two university models and four experimental conditions resulted in 48 possible experimental cases. However, this study tested only 32 participants in Experiment 1 and 30 participants in Experiment 2, randomly skipping 16 and 18 cases. Future studies may clarify the present findings with a larger sample size of participants.

Finally, another limitation of this study was due to the manipulation of environmental complexity and task difficulty. Four university models were created for this study: two models (University Models 1 and 2) for Experiment 1 and two models (University Models 3 and 4) for Experiment 2. The two University Models for Experiment 2 were built by expanding the University Models 1 and 2, adding one or two blocks on each side in order to examine the effects of task complexity in a larger environment.

Based on the results of this study, it may be suggested that the wayfinding tasks used in Experiment 2 may have been more complicated for the participants than the tasks in Experiment 1, thus leading to greater effects of task difficulty and complexity. Future studies may need to examine the effects of more complicated tasks in even larger environments, including more diversified tasks to be undertaken by participants in a number of different ways.

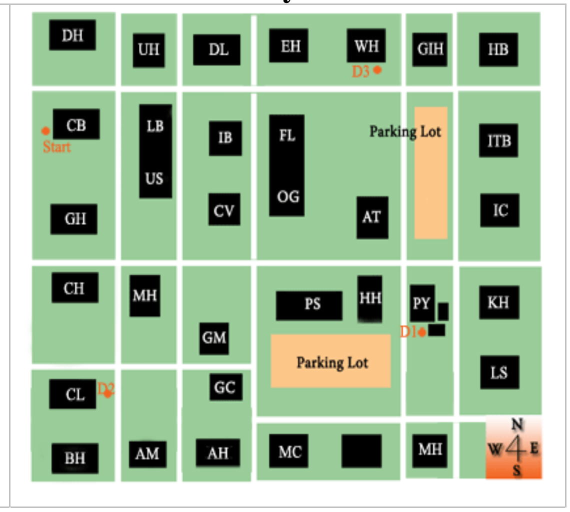
## Appendix A: University Models




University Model 1

University Model 2


University Model 3

University Model 4

## Appendix B: The 48 Experimental Cases

| Case | Session1 | Session2 | Session3 | Session4 |
|---|---|---|---|---|
| Case 1 | SDAC, U1(3) | PEAC, U2 (4)* | FDAC, U1 (3) | FEAC, U2 (4) |
| Case 2 | SDAC, U2(4) | PEAC, U1(3)* | FDAC, U2(4) | FEAC, U1(3) |
| Case 3 | SDAC, U1(3) | PEAC, U2(4) | FEAC, U1(3) | FDAC, U2(4) |
| Case 4 | SDAC, U2(4) | PEAC, U1(3) | FEAC, U2(4) | FDAC, U1(3) |
| Case 5 | SDAC, U1(3) | FEAC, U2(4) | PEAC, U1(3) | FDAC, U2(4) |
| Case 6 | SDAC, U2(4) | FEAC, U1(3) | PEAC, U2(4) | FDAC, U1(3) |
| Case 7 | SDAC, U1(3) | FEAC, U2(4) | FDAC, U1(3) | PEAC, U2(4) |
| Case 8 | SDAC, U2(4) | FEAC, U1(3) | FDAC, U2(4) | PEAC, U1(3) |
| Case 9 | SDAC, U1(3) | FDAC, U2(4) | PEAC, U1(3) | FEAC, U2(4) |
| Case 10 | SDAC, U2(4) | FDAC, U1(3) | PEAC, U2(4) | FEAC, U1(3) |
| Case 11 | SDAC, U1(3) | FDAC, U2(4) | FEAC, U1(3) | PEAC, U2(4) |
| Case 12 | SDAC, U2(4) | FDAC, U1(3) | FEAC, U2(4) | PEAC, U1(3) |
| Case 13 | PEAC, U1(3) | SDAC, U2(4) | FDAC, U1(3) | FEAC, U2(4) |
| Case 14 | PEAC, U2(4) | SDAC, U1(3) | FDAC, U2(4) | FEAC, U1(3) |
| Case 15 | PEAC, U1(3) | SDAC, U2(4) | FEAC, U1(3) | FDAC, U2(4) |
| Case 16 | PEAC, U2(4) | SDAC, U1(3) | FEAC, U2(4) | FDAC, U1(3) |
| Case 17 | PEAC, U1(3) | FEAC, U2(4) | SDAC, U1(3) | FDAC, U2(4) |
| Case 18 | PEAC, U2(4) | FEAC, U1(3) | SDAC, U2(4) | FDAC, U1(3) |
| Case 19 | PEAC, U1(3) | FEAC, U2(4) | FDAC, U1(3) | SDAC, U2(4) |
| Case 20 | PEAC, U2(4) | FEAC, U1(3) | FDAC, U2(4) | SDAC, U1(3) |
| Case 21 | PEAC, U1(3) | FDAC, U2(4) | FEAC, U1(3) | SDAC, U2(4) |
| Case 22 | PEAC, U2(4) | FDAC, U1(3) | FEAC, U2(4) | SDAC, U1(3) |

| | | | | |
|---|---|---|---|---|
| Case 23 | PEAC, U1(3) | FDAC, U2(4) | SDAC, U1(3) | FEAC, U2(4) |
| Case 24 | PEAC, U2(4) | FDAC, U1(3) | SDAC, U2(4) | FEAC, U1(3) |
| Case 25 | FDAC, U1(3) | SDAC, U2(4) | FEAC, U1(3) | PEAC, U2(4) |
| Case 26 | FDAC, U2(4) | SDAC, U1(3) | FEAC, U2(4) | PEAC, U1(3) |
| Case 27 | FDAC, U1(3) | SDAC, U2(4) | PEAC, U1(3) | FEAC, U2(4) |
| Case 28 | FDAC, U2(4) | SDAC, U1(3) | PEAC, U2(4) | FEAC, U1(3) |
| Case 29 | FDAC, U1(3) | FEAC, U2(4) | SDAC, U1(3) | PEAC, U2(4) |
| Case 30 | FDAC, U2(4) | FEAC, U1(3) | SDAC, U2(4) | PEAC, U1(3) |
| Case 31 | FDAC, U1(3) | FEAC, U2(4) | PEAC, U1(3) | SDAC, U2(4) |
| Case 32 | FDAC, U2(4) | FEAC, U1(3) | PEAC, U2(4) | SDAC, U1(3) |
| Case 33 | FDAC, U1(3) | PEAC, U2(4) | SDAC, U1(3) | FEAC, U2(4) |
| Case 34 | FDAC, U2(4) | PEAC, U1(3) | SDAC, U2(4) | FEAC, U1(3) |
| Case 35 | FDAC, U1(3) | PEAC, U2(4) | FEAC, U1(3) | SDAC, U2(4) |
| Case 36 | FDAC, U2(4) | PEAC, U1(3) | FEAC, U2(4) | SDAC, U1(3) |
| Case 37 | FEAC, U1(3) | PEAC, U2(4) | FDAC, U1(3) | SDAC, U2(4) |
| Case 38 | FEAC, U2(4) | PEAC, U1(3) | FDAC, U2(4) | SDAC, U1(3) |
| Case 39 | FEAC, U1(3) | PEAC, U2(4) | SDAC, U1(3) | FDAC, U2(4) |
| Case 40 | FEAC, U2(4) | PEAC, U1(3) | SDAC, U2(4) | FDAC, U1(3) |
| Case 41 | FEAC, U1(3) | SDAC, U2(4) | PEAC, U1(3) | FDAC, U2(4) |
| Case 42 | FEAC, U2(4) | SDAC, U1(3) | PEAC, U2(4) | FDAC, U1(3) |
| Case 43 | FEAC, U1(3) | SDAC, U2(4) | FDAC, U1(3) | PEAC, U2(4) |
| Case 44 | FEAC, U2(4) | SDAC, U1(3) | FDAC, U2(4) | PEAC, U1(3) |
| Case 45 | FEAC, U1(3) | FDAC, U2(4) | SDAC, U1(3) | PEAC, U2(4) |
| Case 46 | FEAC, U2(4) | FDAC, U1(3) | SDAC, U2(4) | PEAC, U1(3) |
| Case 47 | FEAC, U1(3) | FDAC, U2(4) | PEAC, U1(3) | SDAC, U2(4) |

| | | | | |
|---|---|---|---|---|
| Case 48 | FEAC, U2(4) | FDAC, U1(3) | PEAC, U2(4) | SDAC, U1(3) |

* U1; Virtual University Model 1

* U2: Virtual University Model 2

* U3; Virtual University Model 3

* U4: Virtual University Model 4

## Appendix C-1: The Measure of Presence

Please, rate your experience on the following scale from 1 to 7.

**1. I had a sense of "being there" in the virtual world**

(not at all) 1---- 2----3----4----5----6----7 (very much)

**2. There were times during the experience when the virtual world was the reality for me**

(at no time) 1---- 2----3----4----5----6----7 (almost all the time)

**3. The virtual world seems to me to be more like**

(something I saw) 1---- 2----3----4----5----6----7 (some place I visited)

**4. I had a stronger sense of**

(being elsewhere) 1---- 2----3----4----5----6----7 (being in the virtual world)

**5. During the experience I often thought that I was really standing in the virtual world**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**6. How completely were all of your senses engaged?**

(not at all) 1---- 2----3----4----5----6----7 (very much)

**7. How compelling was your sense of moving around inside the virtual environment?**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**8. How aware were you of events occurring in the real world around you?**

(at no time) 1---- 2----3----4----5----6----7 (almost all the time)

**9. How much did your experiences in the virtual environment seem consistent with your real world experiences?**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**10. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**11. How quickly did you adjust to the virtual environment experience?**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**12. How involved were you in the virtual environment experience?**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**13. Were you involved in the experimental task to the extent that you lost track of time?**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

## Appendix C-2: The Measure of Playfulness

Please, rate your experience on the following scale from 1 to 7.

**1. Overall, I enjoyed the virtual tour.**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**2. The tour was interesting.**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**3. The design of the virtual world is attractive.**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**4. I had no problem finding what I wanted.**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**5. I felt that I had the freedom to go anywhere in the virtual world.**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**6. Interacting with the virtual world was easy.**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**7. While I was navigating the virtual world, time seemed to go by very quickly.**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**8. While navigating the virtual world, I was able to be aware of my immediate surroundings.**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

**9. I felt that I was in the world created by the virtual world.**

(not at all) 1---- 2----3----4----5----6----7 (very much so)

## Appendix C-3: The Measure of Subjective Task Performance

Please, rate your experience on the following scale from 1 to 7.

**1. Rate the task difficulty**

(very easy) 1---- 2----3----4----5----6----7 (very difficult)

**2. I achieved my task….**

(not very well at all) 1---- 2----3----4----5----6----7 (very well)

# Appendix D: Background Information

**I. Demographic Information**

1. ID:

2. Name:

3. Gender: Male_____ Female_____

4. Email address: ____________________

**II. Computer Experience**

5. What kind of computer do you use?

PC_____ Mac_____ Both PC and Mac_____ Other_____

6. How often do you use the computer?

daily_____ 1-2 days a week_____ 3-4days a week_____

very rarely_____ other_____

7. How much do you use the computer per day?

____ less than an hour ____ 1-2 hours ____ 2-4 hours

____4-7 hours ____ 8 hours or more

8. For what specific purpose do you use computer?

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9. How long have you been using a computer? years

less than 2 years _____ 2-5 years_____ 5-10 years_____

10-15 years_____ more than 15 years_____

10. Please rate your level of computer experience

novice I-----------I-----------1-----------1-----------1 -----------1-----------1 very experienced

1 2 3 4 5 6 7

**III. Desktop VE Experience**

11. How long have you been using 3D VEs?

less than 2 years _____ 2-5 years_____ 5-10 years_____

10-15 years_____ more than 15 years

12. How often do you use 3D VEs?

daily_____ 1-2 days a week_____ 3-4 days a week_____

very rarely_____ other_____

13. How much do you use 3D VEs per week?

____ less than an hour ____ 1-2 hours ____ 2-4 hours

____4-7 hours ____ 8 hours or more

14. Why are you using 3D VEs?

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15. For what purposes are you using 2D and 3D environments? Please, differentiate the use of purposes for two different environments.

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## Appendix E-1: User Scenario and Tasks 1 for Model 1

You are a graduate student at this university. You have two children and they go to a campus preschool. Today, you have three classes and one appointment with your friend. You are now in the front of the Service (SV) building.

**Task 1**

Everyday you have to drop off your two children at the campus preschool before you start your routine at the university. Your first task is to go to the preschool, which is named CC (Children's Center).

**Task 2.1**

Find a flower below this board and, plant (make) two more flowers around the CC.

**Task 2.2**

Now, you need to move to the backside of the CC in order to find a small message board which will show your next task.

**Task 2.3**

Your first class is math and the classroom is located in the Library (LB) building. Your second navigation task is to go to LB.

**Task 3.1**

Find a place to buy a newspaper on the south side of the LB building.

**Task 3.2**

Find a street light next to the newsstand. When you find it, change the street light into a sign (sign1.rwx) and you will find your next task.

**Task 3.3**

Your second class is physics and the classroom is in the University Center (UC). Your third navigation task is to go to UC.

You have completed your tasks. Thank you.

## Appendix E-2: User Scenario and Tasks 2 for Model 1

You are an undergraduate student at this university. Today, you have two classes, one project meeting and one appointment with your friend. You are now in front of the Academic Learning Center (AL).

**Task 1**

Your first class is math and the classroom is in the Physical Science (PS) building. Your first navigation task is to move to the PS building.

**Task 2.1**

Find two street lights near the PS building and, move them next to this board.

**Task 2.2**

Now, you need to move to the north side of the PS building in order to find a small message board that will show your next task.

**Task 2.3**

You have a project meeting for your programming class and the meeting is in Knobview Hall (KV). Your second navigation task is to go to KV.

**Task 3.1**

Find a chess board on the southwest side of KV. Next to the board, you will see your next task with a map.

**Task 3.2**

Make (copy) two more queens on the board.

**Task 3.3**

Your second class is about physics and the classroom is in the Coliseum Victory (CV). Your third navigation task is to go to CV.

You have completed your tasks. Thank you.

## Appendix E-3: User Scenario and Tasks 1 for Model 2

You are an undergraduate student at this university. Today, you have two classes and one project meeting. You are now in the parking garage.

**Task 1**

You have a little time before your first class starts. You have decided to go to the library and find some books for your research. Your first task is to move to the Willis Library (LB).

**Task 2.1**

Make (copy) two more trees around this building.

**Task 2.2**

Find a bus station in the east side of this building. You will get your next task there.

**Task 2.3**

Your first class is history and the classroom is in Highland Hall (HH). Your second navigation task is to go to HH.

**Task 3.1**

Now, move to the northwest side of HH and find a university picture that is located near to the pond. You will see your next task on the picture.

**Task 3.2**

Find a street lamp next to the map and change it into a sign1.rwx.

**Task 3.3**

You forgot to bring a book from your car. Your third navigation task is to go to the east parking lot and find your car.

You have completed your tasks. Thank you.

# Appendix E-4: User Scenario and Tasks 2 for Model 2

You are a graduate student at this university. Today, you have three classes and one project meeting. You are now in font of the west map.

**Task 1**

Your first class is computer science and the classroom is in the Physics Building (PY). Your first navigation task is to go to the PY building.

**Task 2.1**

Make (copy) two more flowers around this building

**Task 2.2**

Move to the northeast side of the PY building and find a university picture. You will see your next task next to the picture.

**Task 2.3**

Your second class is multimedia production and the classroom is in the Information Sciences Building (IB). Your second navigation task is to go to the IB building.

**Task 3.1**

Find a flagpole next to the deck which is in the right (south) side of this building. You will see your next task next to the flagpole.

**Task 3.2**

Change the flagpole into a sign (sign1.rwx) and it will show your final task.

**Task 3.3**

You have an appointment with your roommate next to the Gateway Center (GC). Your third navigation task is to move to the GC.

You have completed your tasks. Thank you.

## Appendix E-5: User Scenario and Tasks 1 for Model 3

You are a graduate student at this university. You have two children and they go to a campus preschool. Today, you have three classes and one appointment with your friend. You are now in the front of the Service (SV) building.

**Task 1**

Everyday you have to drop off your two children at the campus preschool before you start your routine at the university. Your first task is to go to the preschool, which is named CC (Children's Center).

**Task 2.1**

Find a flower below this board and, plant (make) two more flowers around the CC.

**Task 2.2**

Now, you need to move to the backside of the CC in order to find a small message board which will show your next task.

**Task 2.3**

Your first class is math and the classroom is located in Durdine Hall (DH). Your second navigation task is to go to DH.

**Task 3.1**

Find a newspaper stand next to a map that is located on the northwest side of Durdine Hall.

**Task 3.2**

Find a street light next to the newsstand. When you find it, change the street light into a sign (sign1.rwx) and you will find your next task.

**Task 3.3**

Your second class is physics and the classroom is in the Physical Sciences (PS). Your third navigation task is to go to PS.

You have completed your tasks. Thank you.

## Appendix E-6: User Scenario and Tasks 2 for Model 3

You are an undergraduate student at this university. Today, you have classes and a project meeting at school. You are now in front of Blanton Hall (BH).

**Task 1**

Your first class is philosophy and the classroom is in Couzen Hall (CH). Your first navigation task is to move to Couzen Hall.

**Task 2.1**

Find a street lights near CH and, move it next to this board.

**Task 2.2**

Now, you need to move to the west side of CH in order to find a small message board that will show your next task.

**Task 2.3**

You have a project meeting for your programming class and the meeting is in Knobview

**Task 3.1**

Find a chess board on the southwest side of KV. Next to the board, you will see your next task with a map.

**Task 3.2**

Make (copy) two more queens on the board.

**Task 3.3**

Your second class is about physics and the classroom is in the Coliseum Victory (CV). Your third navigation task is to go to CV.

You have completed your tasks. Thank you.

## Appendix E-7: User Scenario and Tasks 1 for Model 4

You are an undergraduate student at this university. Today, you have two classes and one project meeting. You are now in the parking garage.

**Task 1**

You have a little time before your first class starts. You have decided to go to the library and find some books for your research. Your first task is to move to the Willis Library (LB).

**Task 2.1**

Make (copy) two more trees around this building.

**Task 2.2**

Find a bus station in the east side of this building. There are two pictures of the universities. You will get your next task when you click the picture that is in the east side.

**Task 2.3**

Your first class is history and the classroom is in Kroeber Hall (KH). Your second navigation task is to go to KH.

**Task 3.1**

Now, move to the northeast side of KH and find a picture. You will see your next picture.

**Task 3.2**

Find a street lamp next to the picture and change it into a sign1

**Task 3.3**

Your second class is about computer science and the classroom is in the Calvin Laboratory (CL). Your sixth task is to go to CL building.

You have completed your tasks. Thank you.

## Appendix E-8: User Scenario and Tasks 2 for Model 4

You are a graduate student at this university. Today, you have three classes and one project meeting. You are now in font of Cory Building (CB).

**Task 1**

Your first class is computer science and the classroom is in the Physics Building (PY). Your first navigation task is to go to the PY building.

**Task 2.1**

Make (copy) two more flowers around this building

**Task 2.2**

Move to the northwest side of the PY building and find a picture. You will see your next task next to the picture.

**Task 2.3**

Your second class is chemistry and the classroom is in Calvin Laboratory (CL). Your second navigation task is to go to the CL building.

**Task 3.1**

Find a flagpole in the left (south) side of this building. You will see your next task next to the flagpole.

**Task 3.2**

Change the flagpole into a sign (sign1.rwx) and it will show your final task.

**Task 3.3**

You have an appointment with your roommate next to Wurster Hall (WH). Your third navigation task is to move to the WH.

You have completed your tasks. Thank you.

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