CHAPTER FOUR
Virtual Reality

Virtual reality (VR), as a research domain, involves in a number of disciplines including computer science, psychology, planning, architecture and geography. In some of these disciplines, VR is becoming an indispensable tool. The purpose of this Chapter is to review some issues which are related to using VR in this research. In §4.1 the definition and components of VR are presented and different types of commonly used systems are described. In §4.2 issues of realism and presence are discussed. §4.3 presents a review of research on acquiring and learning spatial knowledge through VR in comparison with the real world experiences. The conclusions in §4.4 highlight the applicability of VR as an environment for studying and understanding human spatial cognition in the real world.

4.1 Virtual reality

The definition of virtual reality has been expressed differently by a number of authors. Virtual Reality (VR) or Virtual Environment (VE), in a literal sense, provides three-dimensional representations of computer generated objects projected to two-dimensional displays, within which people view and interact (Slater *et al*., 2002). One common characteristic of VR is that it is not just the flat screen which people look at, but is a three dimensional visual world in which people feel a degree of immersion (Lathrop, 1999). VR is also referred to as virtual environments or virtual worlds (Batty *et al.,* 1998). In this thesis, the term 'virtual reality' (VR) is used. There are three major components that constitute virtual reality, as suggested by Ellis (1991). They are content, geometry and dynamics. The content is a set of objects forming the virtual reality, whilst the geometry comprises dimension and extent. The dynamics of the virtual reality consists of the interaction rules between the objects. VR can also be defined and used according to the emphasis of different research domains. Thus, VR research can be classified according to its emphasis upon different research foci of visualisation and data modelling (Fisher & Unwin, 2000) and upon its substantive domain of application (specifically urban versus rural: see Lovett 2005). Batty *et al.* (2002) provide a time line showing the development of virtual environment with virtual built environments context (Figure 4.1).

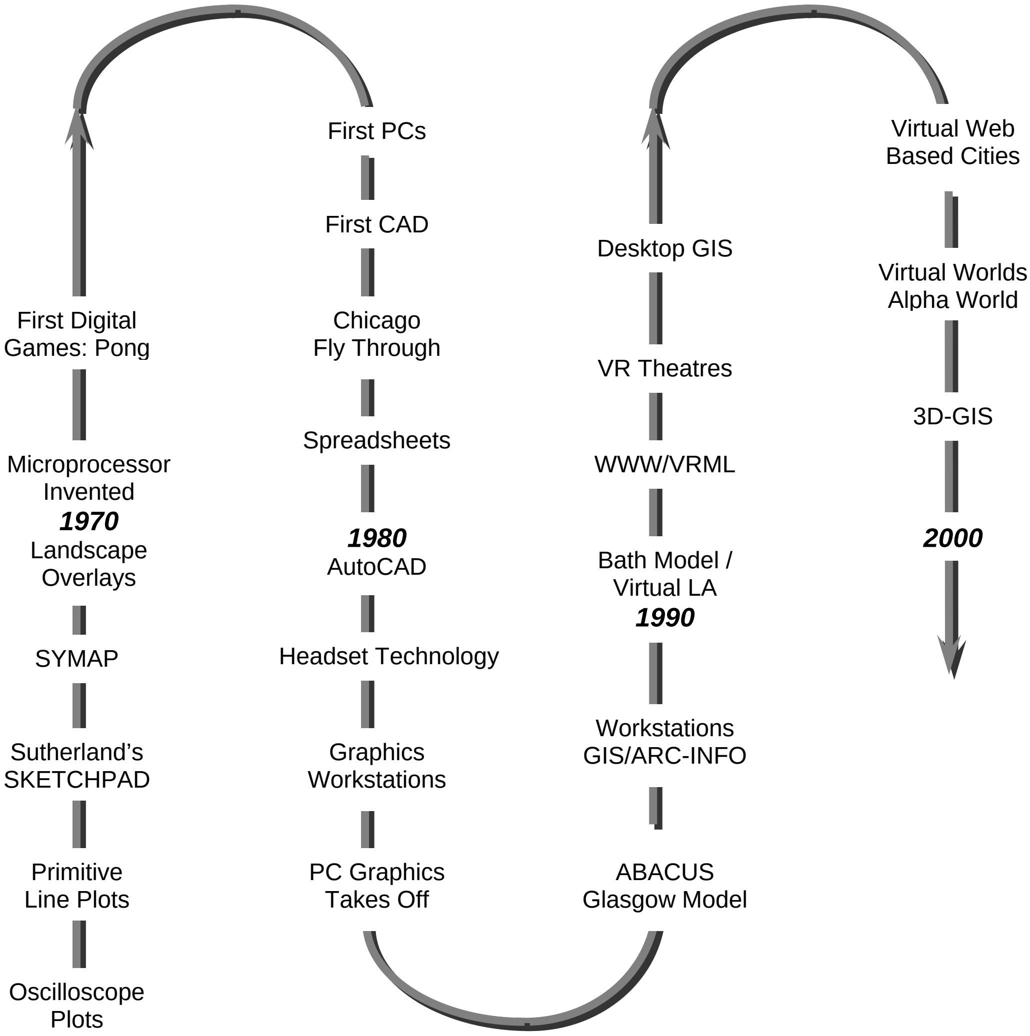

Figure 4.1 The development of virtual built environments: A time line
(From Batty *et al.*, 2002)

There is a range of VR systems employed in various applications, from non-immersive desktop display to immersive CAVE systems. Here some commonly used systems are discussed, which by no means includes all the VR systems. For desktop VR systems, virtual environments are viewed through a standard desktop monitor. Normally mice, joysticks, trackballs and keyboards are used for interacting with the VR environment displayed on the monitor. Such systems are non-immersive and provide only a limited field of view. However they can be implemented on most computers with different levels of graphics performance. Another type of VR system is implemented using a large screen projection system and a relatively high performance graphics computing system. In some of these systems, shutter glasses are used for stereographic images. A range of devices is used for interacting within the VR environments such as joysticks. This type of VR system provides some level of immersion compared with desktop VR systems, but is not regarded as fully immersive. Head Mounted Display (HMD) VR systems can be regarded as immersive. HMDs use a small screen (LCD – Liquid Crystal Display or CRT – Cathode Ray Tubes) in front each eye to provide stereo views. User head movements can be tracked through a device located in the HMD system. The system updates the VR display continuously according to the head movement and constructs views taken from changing perspectives. User views of the real world are partially or completely blocked, and what is seen is the wider field of view provided in the VR environment. Therefore, users feel greater immersion in such VR environments. More powerful computer systems are always needed in order to achieve higher levels of realism with acceptable fields of view. Moreover, HMD equipment is heavy on the head. Similar to HMD, Binocular Omni Orientation Monitor (BOOM) VR systems can be viewed as immersive. In these types of VR systems, there are two lenses in BOOM's viewing box. Users put their foreheads against the box in order to view the display. Handles, control buttons or other devices can be used to interact with the VR environment such as to move around. Cave Automatic Virtual Environment (CAVE) systems are regarded as immersive VR systems (Cruz-Neira *et al.*, 1993). In a CAVE, the images are projected onto the walls and floor. These projected images achieve a stereo effect by rapidly alternation between the two eye images. A person with shutter glasses in the room can see a 3-D effect view. Track devices may be used to feed back changing locations and head movements to the computer system for updating the display continuously. Users can look in different directions and 'move' through the environment by using joysticks, treadmills and other devices. Any real world objects located in the room can also be seen through the user's shutter glasses.

4.2 The realism of VR and the sense of presence

It is extremely difficult to create 'reality' in a computer projection display; VR aims to provide a sufficiently realistic display for people to accept an illusion of being in a form of reality. Slater *et al.* (2002) discuss the realism of VR from several computer graphics meanings: geometric visual realism, illumination realism and behavioural realism. Geometric visual realism concerns the closeness of geometrical resemblances between graphical objects in VR and corresponding objects in the real world. For example, a building needs to have walls, windows and doors in the dimension corresponding to a building in the real world if such a real world building is to be represented in VR. Illumination realism is about correct lighting of objects and scenes, which can be more important in some applications such as representing day- and night-time scenarios. Behavioural realism concerns the behaviour of objects in VR which give observers a sense of realism despite a paucity of geometric and illumination realism. Taking the research results from Pertaub *et al.* (2002) as an example, participants with a phobia of speaking in public were placed in front of a virtual audience. The participants experienced different levels of anxiety when the virtual audience showed different expressions and movements consistent with interest or boredom although it was obvious to the participants that such an audience was not geometrically real. Although realism is often the aim of computer graphics, in fact the results are often highly iconic and impressionistic.

More importantly, real-time performance in VR is essential (Slater, *et al.*, 2002). The real-time performance in VR, in general, means that the correct sequence of many images are displayed with a speed fast enough for people to see a continuous scene. Moreover, in VR, this display must also correspond with the actions and interventions of the people within the VR. Interaction with objects in real-time in VR is one situation requiring real-time performance. Yet another situation, which is particularly related to this research, is real-time walk-through in VR. In a real-time walk-through situation, a person can move about in a VR setting and look around without experiencing noticeable delay of images. For example, when walking down a street, a person might be able to move along the street and look around the buildings on the either sides of the street. When he/she looks left or right, the physical movement of head is tracked with feedback to the computer system. The system continuously updates the image display within an acceptable time delay in order to present the kind of smooth moving view that one would experience when moving one's head around. Likewise, when looking down the street, a view of a row of buildings would be seen, although the more images that need to be rendered by the system, the longer the refresh interval. The ideal image updating rate should be at least 60Hz, i.e. 60 images per second (also called the frame rate) (Slater *et al.*, 2002). Lower frame rates would give a jerky appearance which may cause 'motion sickness'. Therefore, given the computer power, there is a balance (or tension) between degree of realism and real-time performance. The level of detail of objects can be reduced in order to improve the real-time performance. There are also approaches that create different levels of detail for objects from different view locations (Cote, 2005). For instance, near objects will have more realistic displays than those further away. However, there are few studies and guidelines available on the level of acceptable detail with respect to viewing distance, with consideration to realism and real-time performance. Furthermore, the changing of detail is a more of a fuzzy process than a clear cut distance-related variable from a human perspective.

A particular aspect of VR research, which is relevant to this research, has been the notion of 'presence' in a virtual environment. Presence in VR means the concept that participants experience a 'sense of being there' within the environments created by VR systems (Held and Durlach, 1992; Sheridan, 1992). The issue of sense of presence is a common thread in most VR applications because it is believed likely to be associated with behaviour in VR environments and has a close link with the effectiveness of VR usage. There are two different aspects to the sense of presence. One of them considers sense of presence as "a mental state in which a user feels physically present within the computer-mediated environment" (Draper *et al.*, 1998). People experiencing VR have a sense of being in the environment created by the VR technology instead of in the actual environment where they are physically located. Another view on presence considers that it is not just the pure mental state but the actions in the environment that form the reality of the experience (Zahoric and Jenison, 1998). The action one undertakes in the VR is considered more important than just the appearance of the VR. From this perspective, sense of presence is fundamentally about a user's ability to do things. Furthermore, a distinction has been drawn between the concepts of 'presence' and 'immersion' (Draper *et al.*, 1998; Bystrom *et al.*, 1999), and there is a sense in which level of immersion has an effect on the degree of presence in a VR environment (Sheridan, 1992; Witmer and Singer, 1998)

Studies have been carried out on the sense of presence in VR environments. The sense of presence in VR is a multifaceted concept, and therefore has been studied from a number of aspects. The comparison between the experience in VR and the real-world has been studied. For example, in a study by Usoh *et al.* (2000), there were two groups of participants. One group carried out a task in a real site and another group performed the same task in a simulated VR of the same site. The questionnaire results identified the overall similar levels of presence between participants in VR and in real site experiments. Various factors in VR which contribute to the sense of presence have been studied and indicate that the involvement and control in VR contribute to a strong sense of presence (Witmer and Singer, 1998). Involvement in VR concerns focusing one's attention on meaningful activities, events and/or stimuli, and where control concerns the interaction with environments. Studies into the relation between body movement and presence have also been carried out. For example, a positive association between movement and presence was shown for people who actively interacted in the VR. This was shown by using questionnaires and measuring the number of transitions between the reported state in the VR and in the real world (Slater and Steed, 2000). In other studies, level of measurable anxiety is shown in some stressful VR environments through physiological measures to indicate a sense of presence (Rothbaum *et al.*, 1995; Meehan *et al.*, 2002). Moreover, people's responses to virtual motion stimuli in VR environments (e.g. flying objects) have been demonstrated, thus showing a sense of presence in VR situations (Freeman *et al.*, 2000). Sense of presence questionnaires of people's experience in VR do indicate that presence can be measured by these instruments. However, this method has been questioned because of the ethereal nature of 'presence' and the ways in which participants interpret such questions (such as the feeling of 'presence'). Thus Slater (2004) has suggested the use of a combination of methods, rather than heavy reliance upon questionnaires. In general though, studies show a common agreement on the sense of presence in VR and support the view that VR triggers a similar perception and set of behaviours as in reality.

4.3 Spatial learning through VR

VR technology has been used in a number of areas: tools to visualise and interact in situations and structures which cannot be seen or are difficult to manipulate directly by humans; training programmes in different scenarios; augmented reality which combines real world and virtual world; distributed collaboration of people at different geographical locations; entertainment such as computer games. In many VR technology applications, the knowledge gained from VR has been considered to be similar to that learned from the real-world. However, some differences might be expected to exist between knowledge acquired through experiencing the real-world and experiencing the environments created by various VR systems. Research has been carried out from different aspects on the knowledge gained from the experiences in VR environments.

As discussed in Chapter 3, spatial knowledge can be acquired and gained through direct and/or indirect experience. Direct experience refers to the activities in a real environment such as viewing or experiencing an environment by interacting with the real-world, while indirect experience relates to that gained through simplified and symbolised representation without direct contact with the environment – as, for example, when gaining knowledge of a spatial layout through reading maps. VR experience, as a means of environmental exposure, shares many characteristics with direct experience, despite subtle differences. The sense of presence in VR, as discussed in §4.2, also contributes to the experience of being in a real geographically extensive environment. A number of studies give evidence for a connection between direct experience and VR experience. VR environments could be regarded as primary sources for spatial information instead of secondary sources (Liben, 1997; Wilson, 1997). In general, VR environments simulate real environments in an iconic representation instead of using the kinds of abstract symbols used in conventional mapping. As such, VR environments provide a more natural source for acquiring and learning spatial information than learning from a symbolically-presented pace. Therefore, people acquire spatial information in VR environments with less cognitive effort than that required by maps (Hunt and Waller, 1999). In Rohrmann and Bishop's (2002) studies, a VR walk-through urban environment with man-made feature and natural features was created in several variations (such as day/night, sunny/foggy, sound/no sound and shadow/no shadow) for investigating responses on validity of computer simulated environments. The findings from the responses on appraisals of relevant environmental attributes, perceived quality of VR environments, comprehension and retention showed that such simulated environments were generally acceptable as valid representations of environmental features. The potential of using VR environments for studying human behaviour is evident (van Veen, *et al.*, 1998; Bishop, *et al.*, 2001). However, different aspects and forms of VR might not simulate exact direct experience in the real-world.

Another aspect studied is the orientation-specificity of spatial knowledge acquired through direct and VR experience. Orientation-specific spatial knowledge has preference for a particular orientation. Orientation-specificity is one of the main characteristics of map acquired spatial knowledge, whilst knowledge learnt from direct experience shows little such orientation-specificity. For the VR experience, some studies show that spatial knowledge acquired through VR experience has no orientation-specificity, that is, knowledge similar to that acquired through direct experience (May et al. 1995; Tlauka and Wilson, 1996). However, the evidence of orientation-specificity in experiencing computer simulated environments was found in some studies such as the one carried out by Rossano *et. al.* (1999). Nevertheless, it should be noted that the VR environments, in this experiment, were presented to participants in an experimental setting, instead of participants exploring the VR environment. Rossano and Moak (1998) found that when free exploration was allowed, orientation-specificity was weakened.

Studies also point out that people who acquire spatial knowledge in VR often have similar capabilities to those who acquire their knowledge via direct experience and can produce extensive and accurate route knowledge but less well developed configurational knowledge (Witmer *et al.*, 1996; Wilson, 1997; Ruddle *et al.*, 1997). Other studies provide evidence that survey knowledge may be acquired more quickly using computer models. The study by Rossano *et. al.* (1999) with regard to spatial knowledge acquired using computer models, showed some tendency towards a better performance compared with map learning for route knowledge and poorer performance for survey knowledge. The degree to which survey knowledge can be acquired through VR experience is not clear. This could be the fact that surveying knowledge is difficult to acquire through direct experience in the real world. Thus the experiences in simulated VR environments, which similar to direct experiences, have the same effect. Nevertheless, the study suggested that both route and survey knowledge can be acquired through VR experience. It should be noted, however, that some experiments carried out in this study were performed passively rather than with active movement. This could have had an impact on the results of acquisition of spatial knowledge.

That spatial information is acquired through VR and in a similar manner to the real world is further confirmed by a number of studies that have been carried out on specific aspects of wayfinding and spatial learning in VR environments (Darken & Sibert, 1996; Sandstrom *et al.*, 1998; Murray, 2000; Ruddle & Peruch, 2004). For example, Sandstrom *et al.* (1998) studied gender differences in wayfinding using a VR environment. Steck and Mallot (2000) investigated the role of global and local landmarks in completing wayfinding tasks by altering landmarks in VR environments. Furthermore, the use of navigational aids whilst in VR can improve spatial knowledge acquisition and wayfinding performance (Schlender *et al*. 2000; Witmer *et al*. 2002). In general, VR environments can be considered to provide acceptable and valid representations of environments for most participants and can be used as an approach to study human behaviour and human-environment relations.

4.4 Conclusion

In the above Sections, a number of arguments have been put forward concerning the validity of using VR as a simulation environment that allows the study of spatial cognition and learning as if in the real world (Loomis *et al.* 1999; Wilson, 1997; Montello *et al.*, 2004). As discussed, there are several important facets to this issue such as orientation specificity, acquisition of route and survey knowledge and wayfinding performance. The general consensus is that VR experience and direct experience of the real world share many salient characteristics and that VR can be used in studies of human behaviour.

Questions still remain concerning some aspects of VR that might not provide an accurate simulation of direct experience, particularly the issues of whole-body movement, control of locomotion and extent of field of view (Montello *et al.*, 2004) Nevertheless, research has shown that spatial cognition and the acquisition of spatial information can be studied effectively using VR simulated environments. Different types of VR systems used vary, which can affect the experience and learning of spatial knowledge. As discussed in §4.1, different VR systems do give different scales of field of view, different levels of immersion and interaction with environments. Activities and interaction with VR environments provide a more direct experience than passive viewing of the environment. Another important aspect, which is often overlooked, is the type of VR environments created for studies. The types of environments (e.g. inside buildings or rooms, campus, streets) and complexity of environments created (e.g. different spatial layout, buildings and objects in environments) would have an influence the degree of similarity between experience in VR and the real world.

VR has certain advantages from a research perspective. Firstly, the VR environment can be purpose-built to contain all the features that may be relevant to the research. Secondly, it can offer a consistent environment over which there is a high level of control yet allowing an equally high level of user interaction (further discussed in Chapter 5). Thirdly, it is possible to track the movement and monitor overt behaviour within the VR environment so that repeated experiments can be compared.

A CAVE VR system is used for this research. As discussed in §4.1, there are different levels of immersion available through a range of VR systems. Taking into account the level of immersion of the system and the feasibility of using real-world mobile devices in a virtual environment, large screen projection VR systems and CAVE systems were considered initially in this research. In CAVE systems, a wider field of view and a relatively realistic change of view with head movement can be obtained. Moreover, in a CAVE system, the technology can accurately track the movement of the individual within the virtual environment. As will be discussed in Chapter 6 the realism of the images and the geometric fidelity of the objects usually require some level of trade-off in order to achieve a smooth real-time performance. The overall goal is to create a VR environment that provides a high level of presence so that individuals can have a matching experience as if in the real world, particularly their wayfinding strategies.