THE ARCHITECTURAL ASPECT OF DESIGNING SPACE IN VIRTUAL ENVIRONMENTS

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Declaration

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Abstract

This thesis deals with the architectural aspect of virtual environment design. It aims at proposing a framework which could inform the design of three-dimensional content for defining space in virtual environments, in order to aid navigation and wayfinding. The use of such a framework in the design of certain virtual environments is considered necessary for imposing a certain form and structure to our spatial experience in there.

Firstly, this thesis looks into literature from the fields of architectural and urban design theory, philosophy, environmental cognition, perceptual psychology and geography for the purpose of identifying a taxonomy of spatial elements and their structure in the real world, on the basis of the way that humans think about and remember real environments. Consequently, the taxonomy, proposed for space in the real world is adapted to the intrinsic characteristics of space in virtual environments, on the basis of human factors aspects of virtual reality technology. As a result, the thesis proposes a hypothetical framework consisting of a taxonomy of spatial and space-establishing elements that a virtual environment may comprise and of the possible structure of these elements.

Following this framework, several pilot virtual environments are designed, for the purpose of identifying key design issues for evaluation. As it was impossible to evaluate the whole framework, six specific design issues, which have important implications for the design of space in virtual environments, are investigated by experimental methods of research. Apart from providing answers to these specific design issues, the experimental phase leads to a better understanding of the nature of space in virtual environments and to several hypotheses for future empirical research.

1. CHAPTER (1)

1.1 Introduction

Recent advances in hardware and software aspects of information technology have made the medium of virtual reality (VR[1]) affordable and thus accessible to a variety of disciplines which can utilise it for different purposes. Despite these advances and the likelihood that the use of VR technology will become widely available in the following decade, research directed towards the way that this technology is used has been limited. Most current VR research focuses on advancing the technological aspects of the domain and is rarely occupied with the design implications of virtual environments (VEs[2]).

With respect to the specific problem of designing space in virtual environments (VEs), there is very little literature available. This literature has focused on the design of space in VEs from

- a theoretical perspective (Benedikt, 1991, Davis, Lansdown & Huxor, 1996, Novak, 1991, 1994, 1995)
- a human factors perspective (Smets, Stappers, Overbeeke, & van der Mast, 1995, Carr & England, 1995) or
- an information visualisation perspective (Shum, 1990, Dierberger, 1994, 1997, Ingram & Benford, 1995).

The research which has focused specifically on the design of space in VEs from an architectural perspective (Campbell, 1996, Graham[3]) is not systematic enough to provide any framework for this issue. Acknowledging this gap in VR related literature, this thesis deals with the architectural aspect of virtual environment design in a more systematic way.

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[1] The term 'VR' will be used as an abbreviation for 'virtual reality' in this thesis.
[2] The term 'VE' will be used as an abbreviation for 'virtual environment' in this thesis.
[3] This is an on-line publication; the URL of this site is included in the list of references.

1.2 Defining virtual environments

Before presenting the aim and the objective of this thesis, it is necessary to present a definition for the concept of virtual environments. According to Kalawsky (1993, p.4) a virtual environment is a synthetic sensory experience that communicates physical and abstract components to a human operator or participant. This sensory experience is generated by a computer system through the presentation to the human sensory systems of an interface which approximates several attributes of the real world. Through this presentation, the human is being immersed in a simulation, which imparts visual, auditory and force sensations. The VE system is seen as comprising the hardware and software components of this computer system along with the human operator, who interacts with it. In fact, a VE is the result of this interaction as it is being experienced by the operator of a VE system. Ultimately this interface may one day be indistinguishable from the real physical world.

A VE is an intuitive human-computer interface to a computer-based application, where environments, comprising objects and phenomena, are represented in different sensory modalities. Therefore, the design of a VE requires the dynamic composition of several three-dimensional spatial entities, which takes into account their interrelations, the constraints imposed on their behaviour and of the phenomena that can potentially take place among them, for the purpose of accommodating the overall process of interaction with the user.

1.3 Aim of the thesis

The aim of this thesis is to approach the problem of designing space in VEs from an architectural perspective. The thesis will first attempt to develop an architectural framework for approaching this problem. The need for developing such a framework, as a system of meaningful places which give form and structure to our experiences in the real world is clearly understood (Relph, 1976, p.1). Architects and planners are responsible for the development of such systems in real environments. Similarly, this thesis argues that there is a need for developing an architectural framework, as a system of meaningful spatial elements in VEs, which may impose a certain form and structure onto the space, for the purpose of making our interaction and navigation within VEs a structured and meaningful experience.

This architectural framework may then inform a designer of how to design form in order to formulate space in a VE and convey spatial meaning, for implicitly enhancing the spatial awareness of users and consequently helping them orientate and find their way in the VE. As in the case of architectural or urban design, a VE may be designed so that the conveyed spatial meaning allows users to anticipate forthcoming events and directs them towards spaces significant for the goals of an application.

This thesis suggests architectural and urban design as appropriate precedents for designing space in VEs. It is also necessary to integrate knowledge from the domains of environmental cognition, psychology of perception and human factors aspects of VR technology in the development of the architectural framework for VE design. This theoretical framework will formulate the hypothesis that this thesis will propose as a way of thinking about designing space in a VE. Since the core of this thesis deals with a design problem, the investigation will not only be conducted at a theoretical level. It is essential to implement the framework, proposed by the thesis, by designing several VEs and to investigate specific issues relating to this design as well as aspects of this framework by empirical methods of research. This empirical aspect of the thesis is seen as a response to the existing gap in the literature which deals with the design of space in VEs.

It is necessary to clarify the perspective from which the investigation presented in this thesis has approached the issue of VE design:

- This thesis focuses on the design of space in VEs, with the intention of aiding navigation and wayfinding behaviour; in other words it will focus on the dynamic activity of moving within a VE and not on the static activity of interacting with an object, somewhere within the VE. The issue of interacting with objects in a VE was not seen as directly related to the design of spaces where these activities are located.
- The thesis only deals with the visual and the kinesthetic aspect of VEs, which are the most significant for establishing a sense of space; consideration of auditory or tactile sensory input would be beyond the scope of this thesis. As Kalawsky (1993, p.44) has suggested: *"the visual channel is the most important interface in a VE system. The relative bandwidth of the visual channel is many orders of magnitude greater than of any of the other senses."*
- The thesis has studied the design of single-user desktop VE systems, as opposed to multi-user systems; as a result the social dimension of designing space in VEs has not be dealt with.

1.4 In support of the relation of architecture and human-computer interfaces

Recent technological advances have enabled us to use computers for representing real-world phenomena in a symbolic, schematic or realistic, multisensory way. We interact with such representations via human-computer interfaces (HCIs[4]). Laurel (1991, p.126) defines HCIs as *"the outward and visible signs of computer-based representations - that is the way in which they are available to humans"* Jean-Louis Gasee (1990, p.226) has identified the spatial significance of an interface by defining it as: *"the cognitive locus of human-computer interaction".* It is suggested in this sub-section that new technologies,

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[4] The term 'HCI' will be used as an abbreviation for 'human-computer interface' in this thesis.

and in specific VR technology, have given a predominant spatial character to the experience of interacting with an HCI.

Since the emergence of computer networks, the computer has become a medium for communication. MUDs - multi-user dungeons - and MUSEs - multi-user simulated environments - which supported on-line communication among large numbers of users through a text-based or a graphics user interface (Figure 1.1), have significantly altered the way that humans think about their interaction with the computer. Participants of such systems are thinking in terms of three-dimensional spaces and are creating their subjective mental representations of certain environments in which certain events take place, while interacting with the interface (Morningstar & Farmer, 1991). *"The tele-electronic world of the computer should be entered to participate in a MUSE...Once inside this world, it becomes possible to roam through a space that one has never before experienced. At this point the computer ceases being a tool...and becomes an environment that can be shaped and reshaped"* (Taylor, 1993, p.16). It is however understood that such interfaces were either text-based or two-dimensional Graphical User Interfaces - GUIs - as in the case of Habitat.

Figure 1.1: An example of the Habitat interface (Morningstar & Farmer,1991, p.275).

In GUIs, the display screen can be seen as the barrier between the users and the 'world' of the computer which they are trying to explore. VR technology, according to Walker

(1990, p.444), brings us to the threshold of the next generation of human-computer interfaces, where the user can surpass the display screen and metaphorically 'enter' the space of the human-computer interface. *"I define a cyberspace system as one that provides users a three-dimensional interaction experience that includes the illusion they are inside a world rather than observing an image"* (Walker, 1990, p.444).

Figure 1.2: Two examples of three-dimensional, on-line multi-user worlds: 'WorldsChat' and 'AlphaWorld'. Both VEs present settings of a realistic character (Damer, B., 1996).

Today interactive, three-dimensional, on-line, multi-user worlds, such as 'WorldsChat' (Damer, 1996), 'Excite Talk', 'The Palace', 'Worlds Away' or 'OnLive' are a reality[5] (Figure 1.2). It is also possible that in the near future many people will be spending a considerable amount of time 'inside' such worlds, for the purpose of:

- communicating with others,
- educating themselves,
- performing certain tasks, which may benefit from taking place in a three-dimensional environment, or simply
- entertaining themselves.

If we are to live at least partly, 'inside' these worlds, then we must consider their architecture. This novel kind of architecture will require a new theory and practice.

[5] A useful reference for a list of such on-line communities is: http://www.webdog.com/html/virtual_world_chat.html

On the other hand, the theory and practice of architecture, in the traditional sense of the word, are being largely influenced by electronic media, which are currently used by many architects in the process of design. Taylor (1993, p.15) argues that *"As pen and paper give way to computer-aided design and virtual spaces whose reality is thoroughly simulated, the very methods, tools and techniques of architectural design are undergoing a thorough transformation. The very conditions of architectural theory and practice are irreversibly altered by electronic (computer-based) telecommunications technology".* Novel and unique architectural forms, which would probably never have been designed by traditional media, are being designed by computer-based systems; a good example is the Guggenheim museum in Bilbao, which was designed by Frank O. Gehry.

The effects of using new media and technologies in architectural design and construction, are also manifested in certain built environments where multiple simulations may be integrated. Elements such as

- transparent or reflecting surfaces,
- video walls,
- projections,
- structures of light

in conjunction with the complex, fluid and mobile character of several urban environments, may blur the boundaries between what is simulated - i.e. wall photographs, video or film projections, paintings, mirrors, holograms - and what is real. Such environments may, to an extent, be seen as visually similar to some three-dimensional HCIs. Eventually it may become difficult to tell how 'real' the experience of being in a real environment is, and how simulated the experience of being in a virtual environment is. It may therefore be argued that the way we perceive and interact with our environment, as designers and as users, is being significantly affected by new media and in specific computer related technologies.

1.5 Architecture and VR technology

This thesis argues that the disciplines of architectural design and virtual reality technology may be related in two ways:

- architectural design may employ virtual reality techniques for aiding the design process and
- virtual reality may employ architectural design knowledge, for informing the design of virtual environments.

1.5.1 Architecture utilizing VR technology

Figure 1.3: View from an interactive walkthrough within Murlington Mall (Grinstein & Southard, 1996, p.155)

One of the most important areas where VR technology is currently being applied is architecture (Figure 1.3). With the help of a VE system, it is possible to approximate the experience of moving within an architectural environment of any scale. This type of simulation is called 'architectural walkthrough'. An architectural walkthrough can be employed for

- evaluating,

- communicating or
- documenting a designed environment.

Architectural walkthroughs may also be employed at several stages in the duration of the design of an environment:

- during the iterative design process, as a means of evaluating the design, or
- after the completion of the design process, as a means of communicating the design
    - before the actual construction, or
    - for showing the process of construction or
    - after the construction, to people who are not able to experience the environment, because of distance or other factors.
- A third category is the simulation of historically important buildings - a series of such applications was presented in the Virtual Heritage conference in Bath, 1996 - which have been constructed at a much earlier point in time (Figure 1.4); these buildings may either:
    - not exist today
    - be somehow damaged and in need of reconstruction or
    - are maintained in a very good condition.

Figure 1.4: View from a walkthrough within a model of the Dresden Frauenkirche (Jalili et al., 1996, p.93)

Models of these buildings may be designed and integrated into a VE system, for educational or research purposes.

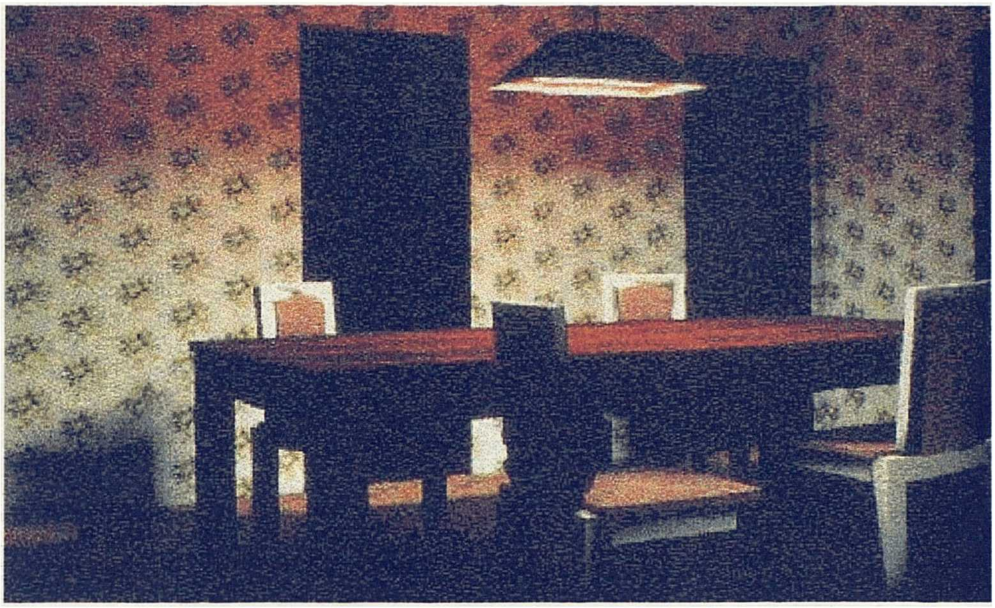

Figure 1.5: A view of a virtual dining room incorporating fixtures and fittings supplied by Matsushita Electric Works Ltd. (Vince, 1995, p.10)

A VE system can also be used as a presentation tool, for the purpose of marketing an environment as a product. In this case, the simulation of a designed environment may offer the possibility of switching between several alternative options, in which formal elements or characteristics of the environment may be altered. Potential buyers of this product can select the option of the environment that they prefer and consequently experience a walkthrough within a simulation of this environment. The Japanese company Matsushita Electric Works Ltd. (Figure 1.5)has marketed kitchen fittings and whole houses through this method (Vince, 1995, p.323).

Bryson (1994) has suggested that in a VE, several levels of metaphor can be employed:

- an overall environment metaphor determines the overall appearance of the environment and has an impact on the types of behaviours in the VE

- an information presentation metaphor determines how information about the environment is presented to the participant and
- an interaction metaphor determines how the participant interacts with the environment and its objects.

An architectural walkthrough is a clearly intrinsic overall environment metaphor, in that it simulates the experience of being inside the designed environment. This does not necessarily apply to the interaction metaphor, used for the navigation within the environment. Walking may not be a feasible way of moving in the VE, due to the size of the environment or the type of input devices which can be utilised. Information presentation metaphors may be constructed, for displaying information which is not necessarily perceived in a physical environment, but which may augment the walkthrough experience - i.e. schematic plans or maps for navigation, hidden structures or elements.

Finally, it is essential to mention the possibility of manipulating the form of a represented object, while being immersed in a representation of an environment displayed by a VE. A large part of the literature on computer aided geometrical design is concerned with the mathematical specification and properties of various surface and curve representations, but very little work has been done on the problem of how these representations can be modified interactively. Real-time, interactive modification of surface representations, may enable designers to perform modeling of objects and surfaces and consequently real-time design of environments, while being immersed in a VE (Slater & Usoh, 1994).

Up to now, designers had to keep an overall three-dimensional model of an environment in their minds, while they designed this environment. This model would be maintained or altered with the help of two-dimensional or three-dimensional representations, constructed by using several media. By modeling and designing whilst inside a VE, designers can approximately experience the result of their design, in real-time, while actually manipulating elements of it. This way the designer can carry out the modeling process, while being in an very direct relationship with the model.

VE systems which support this level of interaction with the participant are still at an experimental stage of development and most of this research is done with non-immersive VR systems. Kameyama & Ohtomi (1993) have introduced a modeling technique within an augmented reality installation, Fernando et al. (1994) have implemented a shared desktop VE for constrained solid modelling and Smets et al. (1993, as quoted in Slater and Usoh, 1994) have developed an immersive VE system which allows direct manipulation of virtual objects called MOVE - Modelling Objects in Virtual Environments. Finally, Slater and Steed (1994) and Slater & Usoh (1994) have also experimented with systems which support modeling of generic objects by an immersed participant[6].

Such experiments may lead towards systems which support the design of form within a VE. What is important about such a system is that it could afford the designer something that contemporary CAD systems lack as tools; that is, visual feedback of what you design, when you design it, as if you were inside the designed environment (Smets et al., 1995, p.204). With respect to the tools which would help a designer to 'carve' objects and define spaces out of the void in a VE, it is suggested that tactile feedback could be very useful in helping the designer be aware of the result of their 'carving' of an object. In a similar way that a designer has built a sketching skill - with the help of the tactile feedback perceived when pushing and dragging the pen against the surface of a piece of paper - a VE designer may build a certain skill at manipulating space, with the help of feedback which tells him how much of an object or space is carved out.

[6] In the first five chapters of this thesis, the operator of a VE system will be referred to as a 'participant'.

1.5.2 VE systems utilising architecture

The concept of a real environment (RE[7]), as it is being used in this thesis , stands for any type of environment comprising natural or artificial elements, which has, at least partly, been designed and constructed by humans. Since VEs are, by definition, built on the principle of imitating the spatial experience afforded by REs, it is suggested that both VEs and REs are similar in the way that they are experienced by humans. VEs and REs are also similar in that they both:

- are experienced as a type of space,
- can accommodate human activities,
- can potentially support the creation of viable communities.

It is understood, however, that VEs and REs are significantly different in many respects as well. These differences will be discussed in (5.3). However important these differences are, the experience of a VE still has a predominant spatial character. A VE is therefore experienced by the participant as a kind of three-dimensional space, comprising several objects and events, which do not necessarily have real-world counterparts. The environment defined by these objects and events is a setting for human activities like:

- navigation,
- interaction and
- communication.

To this extent, this thesis argues that the design of a VE is an architectural problem as well, and as such it may benefit from the use of architectural design knowledge. However, it is understood that not all VEs require the contribution of architectural design knowledge for their development. In the following section (1.6), the types of VEs which may benefit from the contribution of architectural knowledge are specifically defined.

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[7] The term 'RE' will be used as an abbreviation for 'real environment' in this thesis.

It is of course understood that the design of a VE is a very complex design task which requires the cooperation of several individuals specialising in various disciplines - like software engineering, ergonomics, mechanical and electronic engineering, architecture, graphic design. Frericks (1994) proposes the term 'virtual architect' for naming the designer who may contribute architectural knowledge to the process of designing a VE. He then goes on to describe a possible iterative process, through which the developers of a VE and the 'virtual architect' may cooperate in order to design and develop this VE:

1) The application requirements are defined by the developers.
2) The architect has to come up with the spatial composition - defining the geometry of the environment, including all graphical and non-graphical objects for interaction.
3) The developers use this spatial composition to implement an initial version.
4) From that point onwards, the developers and the architect may work together on the basis of mutual feedback, in order to optimise the VE for the requirements of the particular application.

It is, however, necessary to clearly explain why we may need to apply architectural principles in order to impose a certain spatial structure in designed VEs.

1.6 Justifying the use of architectural principles in VE design

"Cities have been built in the image, either conscious or unconscious, that people have of the world." (Cooper, 1974, p.130)

In the real world, architecture is the discipline which deals with our need to construct spaces which accommodate our needs. We need such spaces in order

- to protect ourselves from the forces of nature,

- to delimit the vastness of our world into a more comprehensible network of spaces within which we can move and act for our everyday needs. As was suggested in (1.3), we need to develop a framework as a system of meaningful places which gives form and structure to our everyday experiences; architecture and planning are the disciplines responsible for creating such frameworks.

Space in a VE is infinitely expandable and physically limited only by the computational power of the system which supports the VE. There may be no need for protecting participants from natural hazards but there is still a need for delimiting space in a VE in order to make it

- more legible and therefore easier to navigate
- easier to remember so that when a VE is experienced more than once the user may navigate in it more efficiently.

In order to delimit space in a VE, as we do in the real world, this thesis argues that there is a need to impose a certain form and structure onto the space. For the purpose of doing so, we need to develop an architectural framework, as a system of meaningful spatial elements in this VE which will ultimately make our interaction and navigation within the VE a structured and meaningful experience.

1.7 Specifying the type of VEs that this thesis deals with

Firstly, it is essential to specify the types of VEs, the design of which would not benefit from architectural knowledge and which are therefore not relevant to the argumentation of this thesis. An obvious example of such a VE is any simulation application, in which all objects and events that the VE comprises are modeled so as to accurately and realistically imitate their real-world counterparts. In such VEs, there is no need to design any novel spatial entities and therefore simulations will not be considered in this thesis (Figure 1.6).

Figure 1.6: Aerial view of urban model under construction (Jepson et al., 1996, p.76)

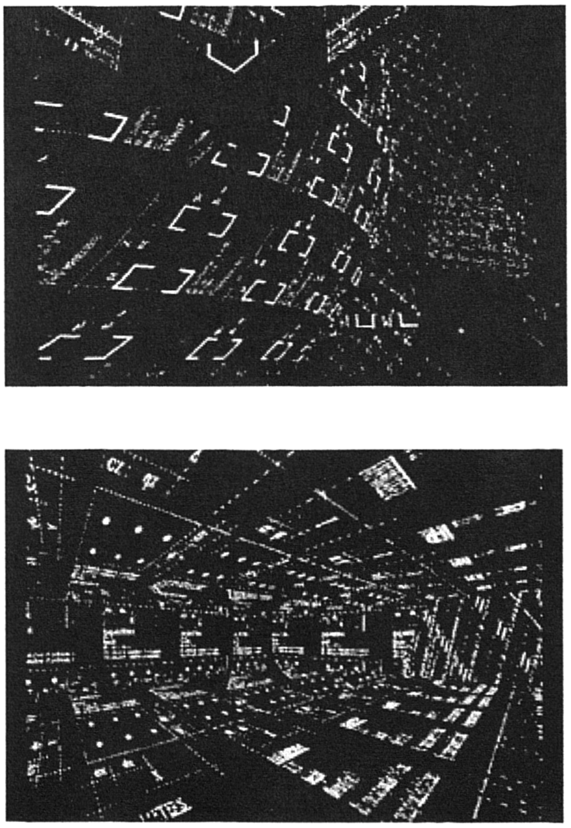

Figure 1.7: Two views of abstractions; 'Dataspace' by Florian Wenz (Schmitt et al., 1995, p.272).

In an attempt to classify VEs with respect to their level of realism, a report by World Design Inc. (1993, p.12) has identified a certain class of VEs, considered as the most difficult ones to design. These VEs are named 'abstractions' and *"they may be used to represent very complex material world information or information that has no physical representation....(In such cases), the designer must conceive an effective abstraction of the complex information and make it more easily understood and responsive to the user".* An 'abstraction' is therefore defined as a VE, consisting of several spatial entities and events and incorporating certain metaphors not intrinsic to the nature of the task, which supports interactive access to information which cannot be physically represented by any real-world counterparts. This thesis argues that such a VE may benefit from the contribution of knowledge and ideas from the discipline of architecture and therefore this thesis will focus on this particular class of VEs.

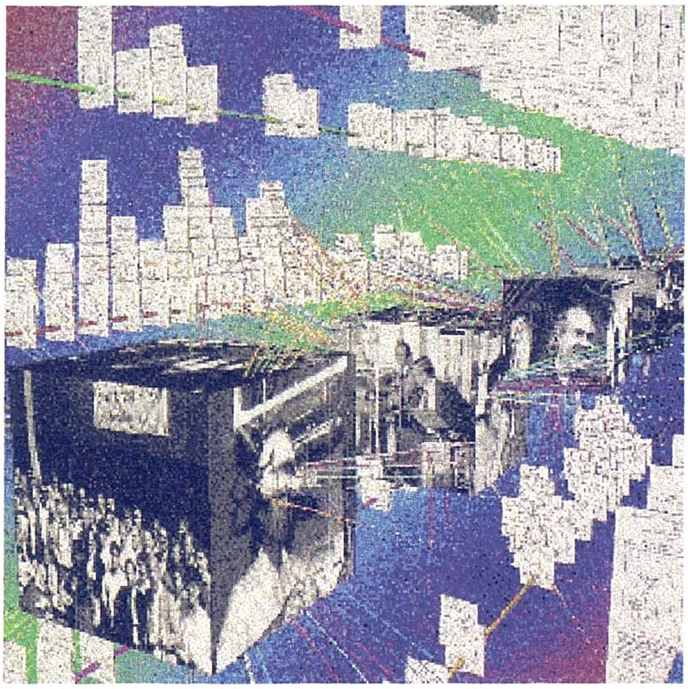

Figure 1.8: View of an interactive three-dimensional visualisation of large-scale data sets, applied as a browser for bibliographical databases (Blackmon, T. & Stark, L., 1996, front cover).

However, not all of these VEs are relevant to this thesis. Humans are good at manipulating real objects and at detecting patterns among these objects in three-dimensional space. The purpose of building an abstraction as an interactive visualisation of complex data structures - such as the contents of a library or a database - (Figure 1.7) is that these human skills may be employed for aiding the performance of humans in object manipulation and pattern recognition, within such structures.

One would then wonder why architectural principles and ideas may be needed for building a VE which supports a three-dimensional visualisation of data sets. Current examples of such VEs, employ systems which may assess the relations among objects and accordingly rearrange the representations of these objects in three dimensional space, in real-time, for the visualisation of data sets (Benford et al., 1995, pp.378-382 and Ingram & Benford, 1995). Such dynamically evolving representational environments are very effective in helping a participant to detect patterns or identify objects within complex data sets. This kind of system would not benefit from the contribution of architectural knowledge and therefore this thesis will not deal with such VEs.

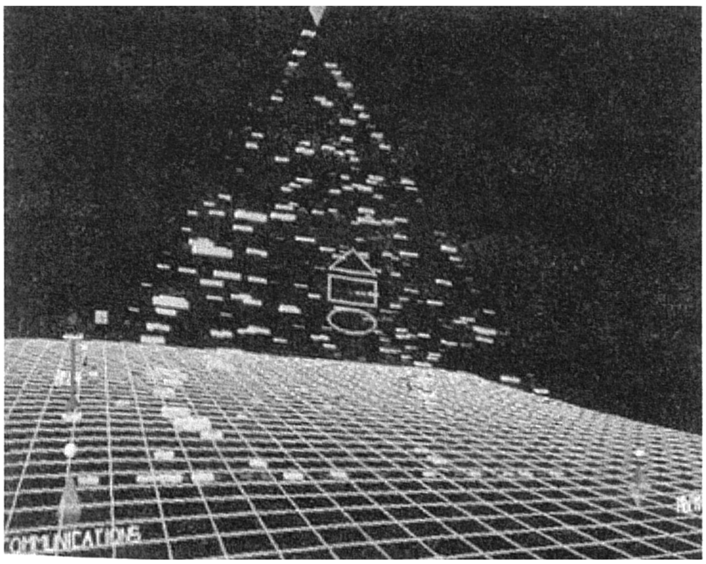

Figure 1.9: Populated information terrain implementation which supports cooperative information retrieval through the browsing of large data stores (Benford et al., 1995, p.381).

Existing examples of such dynamically evolving VEs (Figure 1.8) usually look like sparse constellations of abstract geometric primitives. It is difficult to imagine how a participant may navigate, let alone remember his way around such environments, due to their visual complexity and continuously evolving nature. It can also be argued that these VEs define spaces which are too vague to be studied and analysed. Since this thesis investigates the design of space in VEs for aiding navigation and wayfinding behaviour, the VEs which will be considered should be static enough to function as a setting for studying the dynamic activity of moving within a VE. Accordingly, the thesis will focus on VEs which have been designed as static visualisations of pre-determined databases, affording limited addition or subtraction of data.

One way of imposing form and structure in a VE, in which data structures are abstractly visualised, would be by integrating the representations of objects within a composition of spaces

- which functions as a context for the task taking place within the data sets
- which accommodates our navigation within these data sets and
- which aids remembering our way around these spaces.

1.8 The objectives of this thesis

In order to understand how we may design VEs by using such methods, we first need to understand:

1) What types of spaces - constituent elements or components - would a VE consist of

2) What is the significance of each of these elements for the user who navigates and acts within a VE

3) What types of objects would a designer have to design in order to define these types of spaces

4) How can we structure these spaces into compositions functioning as the context for an application.

These will be the main objectives of this thesis. The levels of analysis at which these issues will be investigated, in order to achieve these objectives are explained in the following sub-section.

It is understood that:

- this thesis suggests only one possible way of answering the problem of designing space in a VE and
- the above mentioned 4th objective will not be extensively met in this text. The scale of this project would not allow such a detailed and complex task to be completed within the available time limits. An attempt will be made to hypothesise about the first three objectives and ways of composing these elements into a whole will also be investigated.

1.9 Setting the context for the approach that this thesis follows

This thesis aims at developing an architectural way of thinking about designing space in VEs, by attempting to create an architectural framework for approaching this problem and by reaching useful conclusions relating to the spatial aspect of VE design. Given the lack of literature on this subject, it is impossible to achieve this aim directly, unless we firstly hypothesise about the design of VEs, on the basis of what we know about the design of space in the real world.

A VE system consists of

- the participant who operates it and
- the hardware and software components of the system.

All components of the VE system have to adapt to each other's needs for the benefit of the application. A VE system which adapts to the way that its participant perceives and behaves would however be a more user-friendly HCI than a VE system which expects participants to adapt their perceptual and behavioural 'selves' to the system's needs. Similarly, Nat Durlach (1995, p.277) argues that, since the human operator constitutes an important component of any VE system, the performance of the overall system depends on the performance of the human operator. Therefore, *"knowledge of how the human operator will perform in an envisioned VE system is essential to the task of predicting the performance of the VE system and to making wise choices in the design of the VE system."*

Humans, however, have evolved and existed in the real world and under these circumstances they have learned how to perceive, think and act. As a result, they cannot but carry the experience of space in the real world into their existence in VEs. This thesis then argues that we first have to study what we know about how humans perceive, behave and think about space in REs in order to hypothesise about how they may perceive, behave and think about space in VEs.

This suggestion does not necessarily mean that a VE should be designed precisely according to the way that a human perceives a RE. The design of a VE should be informed by knowledge of human perception, cognition and behaviour in the real world and at the same time, not be limited by this knowledge. It is essential to take into account the intrinsic characteristics of VEs, so that the potential of virtual reality as a medium, is fully utilised. Besides, a VE does not necessarily need to simulate a 'real' situation. It may also communicate a synthetic experience which cannot happen in the real world. A participant experiences the VE by using the same perceptual processes employed for perception in the real world; hence, if the patterns of information, which are being perceived are accurately constructed to simulate the perceptual mechanisms inherent in the participant, a non-realistic synthetic environment comes across as perceptually 'realistic' and thus believable (Carr and England, 1995, p.6).

Furthermore, it has to be clarified that an intention behind this thesis is to avoid the use of realistic forms and constraints in VEs, when this use is not necessary. Architectural form in the built environment is often dictated by physical constraints. Due to the lack of such constraints in a VE, elements of space do not need to resemble any kind of particular real-world spatial elements. However, most VEs today are designed by non-architects who have not been trained to compose three-dimensional space for accommodating human activities. As a result, the forms and spaces they come up with are mostly simulations of real world equivalents. While taking into account that specific applications may require the implementation of real-world constraints or the imitation of real-world forms, the use of such constraints and forms in many VEs implies lack of imagination and creativity and significantly limits the creative potential of VEs as a medium. It is however understood that most media have been utilised in uninspiring ways when they first became available to humans. Likewise, the very first cinematographers used a film camera for recording a performance on a theatre stage. Several artists had to experiment with film before they begun to realise that the possibilities of this medium far exceeded the expectations of the first cinematographers.

This thesis then argues that if we aim at generating new methods of composing form in order to define space in VEs, in accordance with the intrinsic nature of VEs as a medium - which is described in detail in (5.3) and in Bridges & Charitos (1996) - we may build on what is known about space in the real world, while avoiding the imitation of real world forms, when there is no specific need for them. An architectural way of thinking may prove of much help towards achieving this aim.

According to Carr and England (1993, p.25) the perception of the real world is not deterministic, since what is perceived does not only depend on the what the perceiver experiences, but also on the perceiver's subjective attitude towards this specific action of perception. Hall (1966, p.44) maintains that the perception of real space is not only a matter of what can be perceived but also of what can be screened out. We are screening out one type of information while paying close attention to another, according to perceptual patterns which, once set, remain quite stable throughout life. These patterns, which are culturally and socially dependent, substantially affect our attitude towards perception. This view is opposing the objectivist approach towards perception and is more in accordance with modern phenomenologists, who have strongly supported the subjective character of perceptual experience. Similar views have also been presented in Dreyfus (1972, pp.235-255).

1.10 The method that this thesis follows for achieving the objectives

It has so far been suggested that the design of a VE should be informed by knowledge of how humans perceive and think about space in the real world. This suggestion builds on the assumption that: if we want to design environments which are suited to the way that humans remember and think about space, we need to understand first how these processes work in the human mind. By designing environments according to this understanding it is more likely that humans will exist and act in these environments in the best possible manner. This assumption has determined the method, followed in this thesis which is described below.

1) At first, an attempt to answer the objectives of the thesis will deal with space in REs and will result in an initial set of hypotheses about these objectives with respect to a human in the real world. This attempt will study the nature of space, its structure and the way that space is perceived and remembered by the human who navigates in it at two levels of analysis:
    - At a phenomenological level, the thesis will first look into theoretical literature from the fields of philosophy, cultural and architectural theory, linguistics and poetry, in order to reach a subjective understanding of the true essence of the spatial phenomenon - chapter (2). Then, in chapter (3), the thesis hypothesises about the spatial and the space-establishing elements that REs consist of and

investigates the structure of these elements, on the basis of the literature from the same fields.

- At an empirical level - as presented in chapter (4) - the thesis examines literature supported by more objective evidence from the fields of environmental cognition, urban design, architectural and perceptual psychology, geography and artificial intelligence, for the purpose of reaching a better understanding of spatial knowing as a result of moving within REs and wayfinding. A large part of the literature review has focused on the issue of the spatial experience, as seen from a psychological and psychophysical perspective. This approach is briefly documented in chapter (4) and defines the context for the consequent investigation at a cognitive level.

It is understood that these two approaches are based on diametrically contrasting fundamental principles and scientific methods of investigation. Although none of these approaches has provided a comprehensive and convincing answer to the questions about space that need to be answered here, they may both contribute towards the aim of the thesis, each of them at a different level. Therefore they will both be investigated for the purpose of identifying possible points where they are in agreement.

At both the phenomenological and empirical level, the analysis keeps an ecological character, in the sense that an RE or a VE is considered as a coherent 'world', consisting of elements, all of which are interrelated in some way to each other and all of them existing in relation to the human subject. As Neisser clearly states: *"Perception involves the world as well as the nervous system."* (1976, p.55)

2) In chapter (5), the intrinsic characteristics of VEs, which are relevant to the problem of designing space in VEs, are identified on the basis of literature relating to issues of presence, interaction and perception in VEs. The original hypotheses about space in REs, presented in chapters (2), (3) and (4), are updated with respect to the characteristics of VEs. Accordingly, a final set of hypotheses on the nature and structure of space in VEs, is presented in answer to the four objectives of the thesis, based on what we should expect of a participant in a VE. These hypotheses form the hypothetical framework for the design of space in VEs that this thesis proposes.

3) It is, however, understood that this framework is subjective and speculative and needs to be evaluated by more objective, empirical methods of research. For this purpose, a series of pilot VEs were designed in accordance with this framework and ideas, for the purpose of implementing these hypotheses within the actual process of designing VEs. During the design of these pilot VEs, key issues concerning the design of form in order to define space in VEs, were identified, on the basis of their significance for the overall design and the difficulty the author faced when trying to make decisions about these issues. The aim of the 'evaluation stage' of this thesis will then be to draw conclusions on the impact that the arrangement of spaces has on the spatial behaviour and performance of subjects, in different scenarios of navigation and interaction within VEs.

Accordingly, a series of experiments were conducted in order to evaluate certain significant aspects of the framework along with these key issues, on the basis of user feedback. Chapter (6) documents the background to this empirical phase of the project along with two experiments about factors which may affect movement in certain spaces within VEs. Chapter (7) documents two experiments that deal with the impact of certain spatial characteristics of places on the spatial behaviour of subjects, who enter these places in order to perform a certain activity. Finally, chapter (8) documents two experiments which investigate the implications of the spatial arrangement of places and paths into domains within a VE, for the spatial behaviour of subjects who navigate the interior of these domains.

4) Finally, in chapter (9) the results of each experiment form a set of conclusions on the design of spatial elements in a VE. In the light of these conclusions and of the subjective experience of the experimental phase of the project by the author, aspects of the hypothetical framework which was proposed in chapter (5) are discussed. Finally, a set of new hypotheses for future work is formulated.

CHAPTER (2)

2. A PHENOMENOLOGICAL APPROACH TOWARDS UNDERSTANDING THE SPATIAL EXPERIENCE

As was suggested in (1.10), we first need to study what we know about how humans perceive, behave and think of space in REs for the purpose of designing environments where humans will exist and act in the best possible manner. We need to develop such an understanding of real space, before trying to suggest hypotheses about the experience of space in VEs.

In this chapter, an attempt to understand the spatial experience in real environments (REs) is made. The thesis will look into the fundamental issues of

- the concept of the 'space of lived experience',
- how is space defined in the real world,
- the essence of the spatial experience for the human,
- the possibility of identifying the components of the spatial experience and
- the different ways of thinking about space,

from a phenomenological point of view. Theoretical literature from the fields of philosophy, cultural and architectural theory, linguistics and poetry has been studied for the purpose of reaching a subjective understanding of the true essence of the spatial phenomenon.

2.1 The phenomenological approach

In the beginning it is necessary to define phenomenology and to explain the basis of the phenomenological approach. Our world consists of phenomena: *"Phenomenology may* *be defined as the study of how phenomena appear"* (Leach, 1997, p.83). This appearance requires a heightened receptivity and at the same time a deeper interpretative understanding of all the sensory input that the human perceives. Merleau-Ponty (1962, p.26) argues that the phenomenological approach attacks empiricism and intellectualism for *"taking the objective world as the object of their analysis, when this comes first neither in time nor in virtue of its meaning"*. He adds that both these approaches are incapable of expressing the peculiar way in which perceptual consciousness constitutes its object and he sums up the aim of phenomenology in short as: *"to scrutinize experience itself for its significance"* (1962, p.292).

Pallasmaa (1996, p.450) adds that phenomenology *"strives to depict phenomena appealing directly to the consciousness as such without any theories and categories taken from the natural sciences or psychology. Phenomenology thus means examining a phenomenon of the consciousness in its own dimension of consciousness."* In order to explain this approach, he quotes Husserl's definition of *"pure looking at"* a phenomenon, or *"viewing its essence"*. Finally, he suggests that a phenomenological approach to architecture requires *"'looking at' architecture from within the consciousness of experiencing it, through architectural feeling in contrast to analysis of the physical proportions and properties of the building or a stylistic frame of reference."*

The notion of an abstract space, as defined by empiricism, has been attacked by several authors who support a phenomenological approach. Leach (1997, p.83) quotes Lefebvre and argues that since the invention of the linear perspective, we have progressively learned to perceive space as increasingly abstract and to distance it from the body and the whole spectrum of sensations, thus impoverishing our understanding of space. Similarly, Pallasmaa (1996, p.449) identifies two wrong attitudes towards architectural thinking:

- The reductionist approach towards modern scientific thinking has resulted in every considered phenomenon being divided into its basic elements and relations and in viewing every phenomenon as the sum of these elements.

- Architectural design has intensively focused on form, increasingly overlooking the reality of how a building is experienced.

Similarly, Norberg-Schulz (1996, p.414) has stressed the significance of studying the concrete phenomena of everyday life, which are the *"real content of our existence"*, for developing an understanding of the real experience of space. On the other hand, he considers abstractions like atoms, numbers or all kinds of 'data' as tools which are constructed to serve other purposes than those of everyday life and which therefore are not relevant to an investigation of the essence of the spatial experience. What we really experience as space in the real world is not the abstract, three-dimensional, Cartesian space, which architects design with and which is mainly suitable for the analysis of physical phenomena. It is necessary to challenge several aspects of this traditional, empirical conception of space in order to define a model which is more suitable for the analysis of the spatial experience in REs. With reference to the spatial experience in VEs however, the possibility of making abstract phenomena manifested to humans as though they were concrete phenomena has to be considered as well.

Whilst, the authors quoted in this chapter have all attempted to improve our understanding of space by exploring the subjective way that we experience our world, in every realistic detail, without reducing it from its phenomenological associations, it must be made clear that a study of the metaphysical essence of the concept of space is not within the scope of this project. This attempt to approach the essence of the spatial experience aims at informing the design of space in the real world and consequently the spatial design of VEs.

Although phenomenology offers an in-depth model for understanding human existence and claims to reveal a richer understanding of the world, Leach (1997, p.84) uncovers one of its weaknesses: He quotes Derrida and argues that phenomenology is a self-referential system which lacks any normative foundations that could legitimise its claims. Nevertheless this weakness does not diminish the relevance of phenomenology as a method for investigating the essence of the spatial experience. Wittgenstein (as quoted by Pallasmaa, in Holl et al., 1994, p.41) argues that *"there is no such thing as phenomenology, but there are indeed phenomenological problems".* Therefore, the work presented in this chapter is intended to offer a more concise understanding of the spatial experience in relation to the human and his[6] body than empirical studies do and, as such, will form the basis of this thesis' investigation into how humans perceive, think of and remember their environment.

The literature reviewed here comes from the fields of philosophy, cultural and architectural theory, religious studies and literature. Furthermore, useful insights into issues of phenomenological analysis of the spatial experience may be found in the way that architectural space is represented by other forms of art, such as poetry (Heidegger, 1971), literature, cinema (Bridges and Charitos, 1996), video art (Charitos, 1993), photography and painting.

2.2 The space of lived experience

So far, the basis of the phenomenological approach, as the context for the investigation presented in this chapter, has been explained. It is now necessary to illustrate the difference between the traditional empirical conception of space, as it has been used in architectural thinking and design and the aspect of spatial experience that this chapter investigates.

In this direction, Lefebvre, H. (1997, p.144-5) has made the distinction between:

- The representational space that the architect conceives of, which is bound by media - paper, computer - and methods of representation - plan, elevation, section, perspective, facade, etc.; this is a geometrical, abstract and objective space, a

[6] This thesis will refer to all female and male humans as 'he' for reasons of convenience, without any intention of political incorrectness.

medium for objects and an object itself, which is thought to be true by those who use it for design.

- The lived space of the user which is not represented - or conceived - but a concrete space of the user's everyday activities, a space which is subjectively experienced by each individual user.

A similar distinction is made by Merleau-Ponty (1962, p.243-4) when he introduces the two possible ways that a subject may relate to space:

- Firstly, a subject may reflect about - or conceive of - space, think about the relationships that underlie this world, realising that they live only through the medium of a subject who traces out and sustains them. This geometrical kind of space, has interchangeable dimensions, homogeneous and isotropic. Here the subject can think of a pure change of place in a non-egocentric way, which would leave the moving body unchanged and a pure position distinct from the situation of the object in its concrete context.
- Secondly, the subject does not think - or reflect - about space but lives in it, 'lives among things' and experiences them - and consequently experiences space - in an egocentric way: *"my body and things, their concrete relationships expressed in such (relative) terms as top and bottom, right and left, near and far may appear to me as an irreducible manifold variety"*. This is a physical kind of space with its variously qualified regions.

The characteristics of the latter, egocentric and concrete kind of space, which is based on man's spatial experience have been summed up by Nitschke (as quoted in Norberg-Schulz, 1971, p.13) who attempts to contrast it with Euclidean space: *"(this egocentric space) has a centre which is 'the perceiving man', and it therefore has an excellent system of directions which changes with the movements of the human body; it is limited and in no sense neutral, in other words it is finite, heterogeneous, subjectively defined and perceived; distances and directions are fixed relative to man."*

Similarly, Heidegger (1971, pp.156-7) studied the space of lived experience from a phenomenological perspective and explained how it differs from an abstract notion of space. He firstly suggests that to say that we 'are' is to say that we 'dwell' and in doing so we persist and pervade through spaces; due to this fact, we are able to go through spaces. *"Even when we relate ourselves to those things that are not in our immediate reach, we are staying with the things themselves. We do not represent distant things merely in our mind, so that mental representations of these things run through our mind and head as substitutes of the things."* When we think of a thing in a location, this is not merely an inner experience but it gets us through to the distance to that location; we are not at some representational content in our consciousness but we are at that location of the thing.

Heidegger (1971., p.157) goes on to explain in more detail how we mentally 'exist' not only where the object of our body is located but that we may already be where we want to move towards: *"...in going through spaces we do not give up our standing in them. Rather we always go through spaces in such a way that we already experience them by staying constantly with near and remote locations and things. When I go toward the door of the lecture hall, I am already there, and I could not go to it at all if I were not such that I am there. I am never here only as this encapsulated body; rather I am there, that is, I already pervade the room, and only thus can I go through it."*

On the other hand, Heidegger (1971, pp.155-6) explains the process of abstracting space by making it measurable. However, the fact that we can measure and compute spaces and things by their characteristics - such as distances, spans and directions - does not mean that the nature of these spaces is also measurable with the aid of mathematics. This fact suggests that a geometrical conception of space is inadequate in quantifying the nature of space. Geometry may form a part of the syntactics of architectural space, but any geometry is an abstract human construct, rather than something natural, and as such cannot describe the complexity of the essence of the spatial experience.

In Heidegger's understanding of the way that subjects think about space when moving within it, subjects are at all times considering and mentally 'viewing' the space which is available to them for moving towards. Merleau-Ponty also proposes a similar concept.

2.2.1 Merleau-Ponty's understanding of orientation in space

Merleau-Ponty (1962, pp.248-250) refers to an experiment by Wertheimer where a subject's visual field is slanted with the help of a mirror, explaining the way that such a subject tries to orientate in this unnatural environment. Firstly, he argues that *"we need an absolute within the sphere of the relative (the unnatural environment which induces disorientation), a space which does not skate over appearances which indeed takes root in them and is dependent upon them, yet which is nevertheless not given along with them in any realist way and can survive....their complete disorganisation."*

He then introduces the concept of the 'spatial level' as a subjective system of spatial relations to which the subject 'anchors' his perceptual field in order to orientate and satisfy the above mentioned need for a stable environment. When this level is disturbed, the subject looks for cues or elements of the environment which will determine a new system of vertical/horizontal to which he will have to 'anchor' his field of view, in order to maintain a sense of orientation while moving. When this happens the spatial level tilts and takes up its new position: *"It is then a certain possession of the world by my body, a certain gearing of my body to the world. Being projected, in the absence of anchoring points..... (this spatial gearing) normally makes its appearance where my motor intentions and my perceptual field join forces, when my actual body is at one with the virtual body required by the spectacle, and the actual spectacle with the setting which my body throws round it. It comes to rest when, between my body as the potentiality for certain movements...and the spectacle perceived as an invitation to the same movements and the scene of the same actions, a pact is concluded which gives me the enjoyment of space and gives to things their direct power over my body."* (1962, p.250) At this stage, a 'spatial level' has been constituted and the subject feels orientated within an environment.

However, this 'spatial level' should not be confused with the orientation of one's body. According to Merleau-Ponty (1962, p.249), Wertheimer's experiment shows that the visual field can impose an orientation which is not that of the body. *"The vertical (of the spatial level) tends to follow the direction of the head only if the visual field is empty, and if the 'anchoring points' are lacking, for example when one is working in the dark."* Instead, he argues (1962, p.250) that the constitution of a spatial level is simply one means of constituting an integrated world: *"my body is geared onto the world when my perception presents me with a spectacle as varied and as clearly articulated as possible, and when my motor intentions receive the responses they expect from the world. This maximum sharpness of perception and action points clearly to a perceptual ground, a basis of my life, a general setting in which my body can co-exist with the world."*

Finally, an interpretation of the shift from one spatial level to the other is presented (1962, p.251): *"I go from one system of positions to the other without having the key to each.....the possession of a body implies the ability to change levels and to 'understand' space, just as the possession of voice implies the ability to change key (while singing). The perceptual field corrects itself and (finally I) transfer my centre of gravity into it."*

What is however most important from Merleau-Ponty's description of the spatial experience is that he considers (1962, p.249-250) the relation of the subject's body to the space which makes itself available for him to move through as being a central factor for the orientation of this subject in an unfamiliar environment: *"....What counts for the orientation of the spectacle is not my body as it in fact is, as a thing in objective space, but as a system of possible actions, a virtual body with its phenomenal 'place' defined by its task and situation. My body is wherever there is something to be done...the area of the (subject's) possible actions outlines in front of him, even if he has his eyes shut, a* *possible habitat."* This understanding of the spatial experience may be seen as related with Heidegger's description, presented in (2.2).

With reference to Wertheimer's experiment, Merleau-Ponty (1962, p.250) elaborates on the concept of the 'virtual body' and argues that *"the reflected room (the unnatural environment) miraculously calls up a subject capable of living in it. This virtual body ousts the real one to such an extent that the subject no longer has the feeling of being in the world where he actually is, and that instead of his legs and arms, he feels that he has the legs and arms he would need to walk and act in the reflected room: he inhabits the spectacle."*

2.2.2 Relevance of 'the space of lived experience' to the understanding of the spatial experience in VEs

There are certain similarities between the experimental case of orientating in an unnatural situation, that Merleau-Ponty refers to above, and the case of a subject navigating in a VE, while his body is located in the real world. We may argue that a subject who enters a VE becomes disorientated at first and gradually becomes conscious of a 'virtual body' which corresponds to his potentiality for moving within the space, which is available within his field of view in this VE. Depending on the interface - input/output devices and desktop/immersive mode - the consciousness of a 'virtual body' may occasionally mask the stimuli perceived from the real world and thus prevail over the consciousness of the body which exists in the real world.

The phenomenological understanding of the spatial experience, described above, provides a very realistic approximation of what the subject may feel when moving through space and as such may be of great help when trying to understand the behaviour of subjects who are moving within VEs. The concept of space is discussed from this perspective in the rest of this chapter.

2.3 Defining 'space'

The concept of 'space' is particularly suited to the analysis of the environment that the human lives in. From the moment we are born, the experience of space is undoubtedly apparent, surrounding all of us. This spatial experience, according to Norberg-Schulz (1971, p.9) is *"a dimension of human existence and not merely a dimension of thought and perception, essential for orientation and action in the environment."*

For Merleau-Ponty, (1962, pp.293-4) space is one of the main structures which express our 'being in the world': *"We have said that space is existential; we might just as well have said that existence is spatial, that is, that through an inner necessity it opens on to an 'outside', so that one can speak of a mental space and a world of meanings and objects of thought which are constituted in terms of those meanings."* Elsewhere in the same essay, Merleau-Ponty (1962, p.252) argues that *"being is synonymous with being situated."* Similarly, Thiel (1961, p.35) suggests that *"space is one of the conditions of material existence".*

In an attempt to define space, Benedikt (1991, p.125) quotes Kant and argues that the existence and nature of space is a truly basic, fundamental and universal quality of our mind's operation in relation to reality and within reality: *"Space and time, combined, appear to constitute a level of reality below which no more fundamental layers can be discerned."* In the same vain, Koenderink (1993, p.iix) asserts that *"space and time are the very form of the human mind. We cannot but perceive and think spatio-temporally.....we depend heavily on spatio-temporal expertise for plain survival...Such vital crafts as orientation, navigation, homing, manipulation, recognition and communication are to a large extent facets of optically guided behavior."* Similarly, Thiel (1961, p.35) defines the spatial experience, in the broadest sense, as *"a biological function, necessary for the continual adaptation of any organism to its environment, for the purposes of survival."* Experiencing space does not only involve the perception of visual sensory input but of auditory, olfactory, thermal and tactile input, along with the sense of proprioception - as defined in Gibson (1986, p.111) - all of which play their part in the establishment of a sense of space. This approach is in agreement with Hall's conception of space (1966, pp.41-63). However, as was explained in (1.3), the focus of this thesis is on the visual input, as the most significant for establishing a sense of space; consideration of the other kinds of sensory input whilst important are beyond the scope of this thesis.

The relation of spatial experience to orientation is explained by Norberg-Schulz (1971, p.9): *"Most of man's actions comprise a spatial character, in a sense that objects of orientation are distributed according to spatial relations. Space therefore, is...an aspect of any orientation, but only one of the aspects of the total orientation.....Man orients to objects; he adapts physiologically and technologically to physical things...(and) his cognitive or affective orientation to different objects aims at establishing a dynamic equilibrium between him and his environment."* But these objects, which are distributed in space, actually allow for space and the spatial experience as such.

Perceptual images are generated by the perceptual systems of the human as a result of phenomena. Piaget (1954, p.92) defines an object as *"a system of perceptual images endowed with a constant spatial form throughout its sequential displacements and constituting an item which can be isolated in the causal series unfolding in time".*
It may be concluded, therefore, that our world consists of phenomena and the most permanent relations between phenomena constitute an object. We survive in our environment by orienting ourselves to objects, which are being manifested to us through the psychological and cognitive processes involved in the perception of phenomena.

"Like the spider with its web, so every subject weaves relationships between itself and particular properties of objects; the many strands are then woven together and finally form the basis of the subject's very existence." (Jakob von Uexkull, as quoted in Norberg Schulz, 1971, p.9)

2.4 The essence of space

Space is, therefore, defined by objects, or elements of form which bind it. Merleau-Ponty (1962, p.242) argues that: *"there is no question of a relationship of container to content (between space and the objects that define it), since this relationship exists only between objects, nor even a relationship of logical inclusion.....since space is anterior to its alleged parts, which are always carved out of it. Space is not the setting (real or logical) in which things are arranged, but the means whereby the position of things becomes possible, This means that instead of imagining it as a sort of ether in which all things float, ...we must think of it as the universal power enabling them to be connected."*

Space is, in fact, void and this emptiness is its essence, which makes a building or a landscape useful. (Thiel, 1961, p.35) The essence of space is beautifully described in this extract of a poem by Lao-tzu (1929, as quoted in Chang, 1956, p.7)

"Moulding clay into a vessel, we find the utility,
in its hollowness;
Cutting doors and windows for a house, we find the utility,
in its empty space;
Therefore the being of things is profitable, the non-being
of things is servicable."

We become aware of objects via the stimuli provided by them and accordingly our sense of space is established by these objects, because they all possess the quality of form. However, *".....space is inherently formless. Its visual form, quality of light, dimensions and scale depend totally on its boundaries as defined by elements of form."* (Ching, 1979, p.108)

In architecture, form and space maintain a symbiotic relationship, in any scale. When architects design a building, they read the configurations of walls as the positive elements in a plan drawing, but conceive of the white space in between the walls, which represents 'space', as having shape and form and not merely as a background to the configuration of the walls. In fact, they design the forms of these voids so that they accomodate human needs and accordingly design the form of the elements which establish these voids.

In Heidegger's understanding (1971, p.154) the relations between the concepts of 'thing-location-site-space-place' are clarified in the following manner: a location comes into existence by virtue of a thing; this thing gathers the fourfold (heaven, earth, divinities and mortals) in such a way that it allows a site for the fourfold. Space is provided for by the localities and ways which determine this site. Only things that are locations in this manner allow for spaces. *"Space is in essence that for which room has been made, that which is let into its bounds."* He then goes on to relate the concept of 'space' to that of the 'boundary'; the word boundary - 'peras' in ancient Greek - meant the thing from which something begins its presencing. Consequently, he suggests (1971, p.158) that *"the location allows the human to enter into a site by arranging the site into space."* Building is the making of locations that allow for spaces. Therefore building is the founding and joining of spaces. *"Nevertheless, because it produces things as locations, building is closer to the nature of spaces and to the origin of the nature of 'space' than any geometry and mathematics."* Finally, he concludes that: *"spaces receive their being from locations and not from 'space'"*. (1971, p.154)

It may therefore be suggested that the essence of space for a human is the potentiality for activity, afforded by the arrangement of boundaries which define this space.

2.5 Abstracting the components which constitute the spatial experience

When defining the sense of space, experienced by a subject moving within an environment, this environment cannot be dissociated from the subject that experiences the space. Merleau-Ponty (1962, p.251) confirms the organic nature of the relation between subject and space by arguing that the origin of space is the gearing of the subject onto his world. In explaining this process of gearing (1962, pp.248-252), he clearly states that the co-existence of the subject and his body within an environment are fundamental in constituting a sense of space within this environment.

The approach of Norberg-Schulz (1971), Marleau-Ponty (1962), Piaget (1954) and Piaget & Inhelder (1956) is ecological, in the sense that they cannot conceive of the subject as dissociated from the environment: they regard the perceptual processes and the resulting spatial experience as dynamic - as opposed to passive - and as fundamental components of the subject's very existence. Gibson (1986) also suggests a similar relation between the human and the environment, but does not subscribe to the very notion of space. In specific, he proposes a similar model where a medium - air, water, etc. - mediates light and through this provides the animals, which inhabit the environment, the information necessary for their survival.

These views are in accordance with Heidegger's (1971, pp.156-157) approach: *"When we speak of man and space it seems as though space is something that is over and above and external to man. Space does not face man, neither is it an external object nor an inner experience...The very essence of 'being' of man is connected to 'dwell' and to the nature of staying ... among things...Man's relation to locations, and through locations to spaces, inheres in his dwelling. The relationship between man and space is none other than dwelling, strictly thought and spoken."* But as he mentions earlier in the same text: *"To be a human being means to be on the earth as mortal. It means to dwell..... man is* *insofar as he dwells."* (Heidegger, 1971, p.147) The concept of 'space' is very tightly connected to that of 'dwelling' and consequently to the essence of 'being' in the physical world.

However, when investigating the concept of space, it is not possible to abstract its essence, since it is not possible to dissociate space from the very spatial experience of the human. In Piaget's (1954, p.217) own words *"space is the product of the interaction between the organism and the environment in which it is impossible to dissociate the organization of the universe which is perceived from that of the activity itself."* The true nature of space resides in the intelligence that interconnects the subject's sensations.

It may be concluded, then, that the existence of a subject in a real environment cannot be conceived separately from the very experience of space, since it is dependent on the awareness of this "space" for survival in the environment. Every action has a spatial character and the sense of space, which a subject experiences as a result of perceiving the environment, cannot be dissociated from the activity of perceiving. This implies that the spatial experience cannot easily be reduced to its components in order to be analysed. Moreover, when considering the way that space is manifested, the perceiving subject and his body cannot be dissociated from the environment that he perceives.

"The universe is built up into an aggregate of permanent objects connected by causal relations that are independent of the subject and are placed in objective space and time. Such a universe...is imposed upon the self, to the extend that it comprises the organism as a part of the whole" (Piaget, 1954, p.351-352).

2.6 Types of space

Space can be conceptualized in different ways, according to the point of view that we approach it from. Mitropoulos (1975, p.199) has argued that these ways of conceptualizing space may be seen as *"spatially defined conceptual components"*, in the sense that our overall conception of space comprises these individual concepts, but it is not possible to dissociate them since they are interdependent of each other. Some of these ways are presented below.

Norberg-Schulz (1971, p.11) distinguishes the following five ways of thinking about space:

- 'Pragmatic space' of physical action, which integrates man with his natural environment;
- 'Perceptual space' of immediate orientation, which is essential to his identity as a person. Perceptual space has an egocentric and continuously varied character, although these variations are linked to form the meaningful totalities that we call experiences.
- 'Existential space', which forms man's stable image of his environment and makes him belong to a social and cultural totality;
- 'Cognitive space' of the physical world, which is an expression of man's ability to think about space;
- 'Abstract space' of pure logical relations, which offers a tool to describe all other types of space.

These concepts are hierarchically listed, so that as we move from pragmatic to abstract space, the content of information increases proportionally to the degree of abstraction.

These concepts refer to man who exists, acts in, perceives and thinks about space. Norberg-Schulz also employs the term 'expressive' or 'artistic space' to define spaces which have been created by man for the purpose of expressing the structure of the world[7]. He considers expressive space to be at the same level as cognitive space, because it is brought forth as a result of cognitive processes. He employs 'aesthetic

[7] It is, however, understood that the purpose of creating an 'artistic space' could be the subject of a debate which is beyond the scope of this thesis.

space' as a more abstract type of space, needed for the systematic analysis and description of the properties of expressive space.

Norberg-Schulz's work, however, focuses on 'architectural space', which he considers as a kind of expressive space. Architectural space has to adapt itself to the needs of pragmatic space and also facilitate orientation through making perceptual space legible. One of the main arguments in his book "Space, Existence and Architecture" (1971) is that architectural space is a concretisation of existential space. By identifying the elements and properties of existential space and the ways that these interact with each other, Schulz attempts to understand the elements, properties and underlying structure of architectural space, as seen from a phenomenological perspective.

He presents Nitschke's definition (1968, as quoted in Schulz, 1971, p.13) - which has been presented in (2.2) - of the egocentric and concrete 'space of lived experience' and maintains that this is a good definition of perceptual space but not of architectural space or existential space; architectural space exists independently of the perceiver and has centres and directions of its own. There is a need for a more stable system of schemata for perceptions to become meaningful, so that architectural space can be systematically studied. The concept of schemata will be discussed in (3.1).

The concept of 'hodological space' - from the Greek 'hodos' meaning 'way' - has been introduced by Lewin (1938, pp.24-70), as the space of possible movement, where the environment determines the directions of man's existential space- following Norberg-Schulz (1971). Mitropoulos (1974, p.11) also adopts this concept as a way of defining space dynamically. However, he maintains that *"when no movement, or no other human activity is of influence, then hodological space approaches Euclidean space... Although the designer has to decide upon the Euclidean space and communicate through it to the builder, he conceives or ought to, through the hodological one."*

Mitropoulos introduces the concept of urban space as *"a man's network"* (1975, p.202) and classifies space into types, as seen from the viewpoint of a pedestrian's spatial experience within an urban context; two of these types are relevant to this thesis' analysis of the spatial experience:

- 'Ambient space' is the objective, measurable space defined by surfaces and objects that we design and build and which corresponds to the lower-level perceptual processes which inform orientation in the environment.
- 'Hodological space' *"is identified with the activity of movement through space, not only towards a visible goal but also towards a nonvisible destination, which requires a mental map"*(Mitropoulos, 1975, p.201). *"It is the space that invites (almost demands) passage through itself."* (Mitropoulos, 1975., p.200) This is a subjective, behavioural kind of space, which is determined by the immediate state of mind of the subject or the specific conditions for movement. *"We are born with hodological space, but not with ambient space. We build ambient space allowing for hodological space."* (Mitropoulos, 1975, p.200).

In an attempt to explain the way that a pedestrian thinks when moving through urban space, Mitropoulos (1975, p.202) suggests that: *"You move through ambient space along which you perceive, and which is part of the measurable Euclidean space. Your activity of walking is not in 'space of possible movement' but your own hodological - intention based - space. Your mind and your body senses are in fusion. You anticipate the 'tube' - the notional corridor which connects where you are now with where you were coming from and where you are going to - and check by feedback provided by incoming perceptual information."*

The concepts of 'existential' and 'hodological space' are closely related; in fact, hodological space can be considered as a kind of existential space, which is determined by the directions of possible movement. Considering the types of space according to Norberg-Schulz, the concepts of 'existential' and 'cognitive space' appear to be relative to the analysis of spatial experience at a phenomenological level, for informing the design of REs, whilst 'perceptual space' seems more relative to such an analysis, at a psychological level. The concept of existential space is considered to be of primary importance for developing a better understanding of our spatial experience in REs and VEs respectively. Therefore, in the following chapter this concept will be discussed in detail. The aim of this discussion is the identification of the elements that a legible environment may consist of.

CHAPTER (3)

3. A PHENOMENOLOGICAL APPROACH TOWARDS IDENTIFYING THE CONSTITUENT ELEMENTS OF THE SPACE THAT WE EXPERIENCE IN REAL ENVIRONMENTS

As was suggested in (1.10), chapters (2) and (3) aim at answering the main objectives of the thesis with respect to the spatial experience of a human in the real world. In chapter (2), the nature of space, the essence of the spatial experience and possible ways of thinking about space were investigated from a phenomenological perspective. This chapter has set the context for the investigation of space in REs and VEs respectively in the rest of the thesis.

On the basis of this context, chapter (3) will attempt to provide specific answers to the objectives of this thesis by identifying:

- the spatial elements that REs may consist of
- the significance of these elements for a subject who navigates within an RE
- the way that these elements may be structured within an environment
- the elements of form which define the above mentioned spatial elements.

These elements will be identified on the basis of the nature and structure of the image that humans have of environments in the real world, as seen from a phenomenological perspective. In the end of chapter (2) it was suggested that the concept of 'existential space' (Norberg-Schulz, 1971), appears to be relevant to the systematic analysis of space, from this perspective. It is therefore essential to study this concept in detail in order to inform the design of REs and VEs respectively. Norberg-Schulz, however, defines existential space on the basis of the concept of 'schemata', which need to be explained first.

3.1 Schemata

It is understood that the concept of 'schema' has been mainly - but not entirely - based on empirical methods of research. Taking this fact into account, it is necessary to explain the concept of 'schema', before introducing the concept of existential space, as a context for identifying the components and structure of space in the real world. The term 'schema' was introduced by Kant in "Critique of Pure Reason" (1924) and is still being used today to express several relative but not identical concepts; those concepts which are relevant for the argumentation of this project, will be briefly presented here.

Eysenck and Keane (1990, p.283-285) define schemata as complex, structured clusters of concepts, which usually contain generic knowledge about stereotypical situations. There is considerable psychological evidence to support many aspects of the theory of schemata, but Eysenck and Keane also present several fundamental problems relating to the unconstrained nature and the specificity of the content of schemata.

Johnson (1987, p.19) quotes Thorndyke's similar definition of schema as *"a cluster of knowledge representing a particular generic procedure, object, percept, sequence of events or social situation. This cluster provides a skeleton structure for a concept that can be 'instantiated,' or filled out, with the detailed properties of the particular instance being represented."* Johnson (1987, pp.20-21) then tries to complement this interpretation by introducing Neisser's definition which he considers more suitable for exploring schemata, as organising structures of our experience and understanding at the level of bodily perception and movement.

According to Neisser (1976, p.14), all of the skillful activities that perceiving comprises, which occur over time, *"depend upon preexisting structures, called schemata, which direct perceptual activity and are modified as it occurs".* He acknowledges (1976, p.54) Bartlett's concept of the schema as the central cognitive structure in perception and he defines schema within the context of the perceptual process, as *"that portion of the entire perceptual cycle, which is internal to the perceiver, modifiable by experience, and somehow specific to what is being perceived. The schema accepts information, as it becomes available at sensory surfaces, and is changed by that information; it directs movement and exploratory activities that make more information available, by which it is further modified."* Schemata could be considered as information-accepting systems but can also function as plans and as the executors of these plans; they are patterns of action as well as patterns for action (1976, pp.55-56).

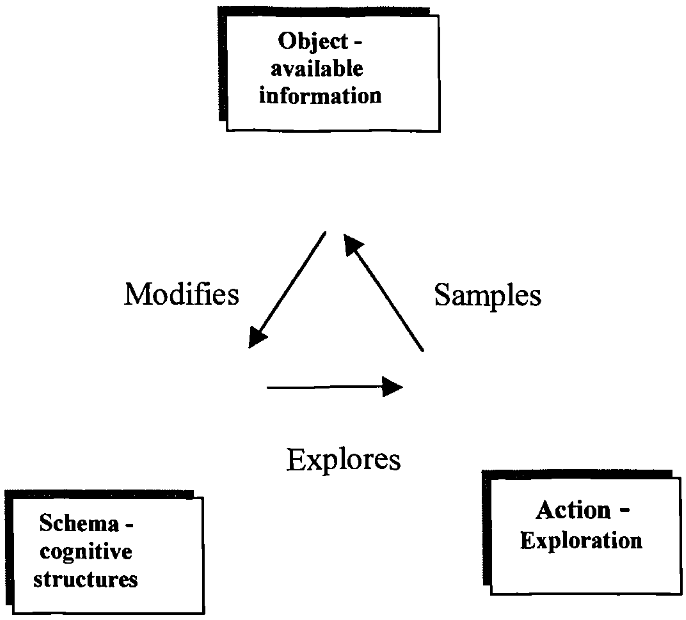

Figure 3.1: The perceptual cycle (Neisser, 1976, p.21)

Neisser (1976, p.20-21) explains the term 'perceptual cycle': *"Perception is a constructive process...At each moment the perceiver is constructing anticipations of certain kinds of information, that enable him to accept it as it becomes available. Often he must actively explore the optic array to make it available, by moving his eyes or his head or his body. These explorations are directed by the anticipatory schemata, which are plans for perceptual action as well as readiness for particular kinds of optical structure. The outcome of the exploration - the information picked up - modifies the original schema."*

It may be concluded, therefore, that it is by acting that we receive information from the environment through perceptual processes and that this information modifies our internal model of the world - based on schemata - which in turn controls our forthcoming actions. The fact that it is through action that that the development of a conception of geometrical space is brought about is argued by Piaget and Inhelder (1956, p.449): *"It is precisely because it enriches and develops physical reality instead of merely extracting from it a set of ready-made structures, that action is eventually able to transcend physical limitations and create operational schemata, which can be formalized and made to function, in a purely abstract, deductive fashion. From the rudimentary sensory-motor activity right up to abstract operations, the development of geometrical intuition is that of an activity, in the fullest sense."* Johnson (1987, p.101-138) also explains how metaphorically extended - image - schemata structure our understanding and reasoning by imposing certain constraints on our network of meanings and our inferential patterns.

From a biological point of view, Neisser (1976, p.54,62) defines the schema as a part of the nervous system: *"It is some active array of physiological structures and processes: not a centre in the brain but an entire system that includes receptors and afferents and feed-forward units and efferents...It is not likely that this physiological activity is characterized by any single direction of flow or unified temporal sequence...Nor does it all begin at one moment and end at another; the continuities of different subsystems* *overlap in varying ways, providing for a host of different kinds of information storage.....Schemata not only enable us to perceive present events but also to store information about past ones."*

Norberg-Schulz (1963, pp.41-43) suggests that schemata are based upon similarity between phenomena and that they are significant because they mediate the intended meaning. Schemata give form to the world, because they organize the phenomena as manifestations of objects. While the objects of science are constructed through approximately objective abstractions, the schemata result from the experience of equivalent situations and have to be understood as relatively 'impure' objects. Because they are closer to the real essence of a situation they are more useful for approximating the meaning of an experience than any abstraction. Accordingly Wittgenstein (1953, p.209) suggests that: *"It is only if someone can do, has learnt, is master of, such and such, that it makes sense to say that he has had this experience."*

After explaining his conception of 'schema', Norberg-Schulz (1963, p.43) presents some examples of schemata: *" 'Constancy-phenomena', for instance, imply that we have learned to perceive changing phenomena as representing the same object...The first schema to be acquired - by an infant - is 'proximity'. Later follow 'enclosure' and 'continuity' among others. 'Size constancy' is a schema which results from the operational experience that things maintain their size when moved. The perception of more complicated wholes - like works of art - presupposes schemata which may only be acquired through special training."*

Finally, Norberg-Schulz bases his concept and theory of existential space (1971) on Piaget's conception of 'schemata', as typical reactions to a situation. For Piaget (Gregory, 1987, p.696), the schema is an internal representation of some generalized class of situations, enabling the organism to act in a coordinated fashion over a whole range of analogous situations. On the basis of this notion of schema, Norberg-Schulz (1971, p.11) argues that the more stable spatial schemata are culturally determined and comprise qualitative properties resulting from the need for affective orientation to the environment. They are composed of invariable elements:

- universal elementary structures - archetypes,
- socially or culturally conditioned structures,
- personal idiosyncrasies.

3.2 Existential space

On the basis of his understanding of the 'schema' concept, presented above, Norberg-Schulz (1971, p.11) defines existential space as a relatively stable system of perceptual schemata, that is a system of three-dimensional relations between meaningful objects. If we consider the perceptual cycle according to Neisser - as presented in (3.1) and figure (3.1) - the term 'existential space' describes an individual's subjective image of the environment, comprising a system of topological schemata, that he uses at each time in order to inform his exploration - actions and movement - within this environment. Norberg-Schulz (1971, p.34) then argues that *"the experience of space consists in the tension between one's immediate situation and existential space. When our immediate location coincides with the centre of our existential space, we experience 'being at home'. If not we are either 'on our way', 'somewhere else', or we are 'lost'."*

Existential space cannot be understood in terms of man's needs alone, but only as a result of his interaction with an environment, which he has to understand and accept. Existential space, therefore, symbolizes man's 'being in the world', as defined in Heidegger's (1962, p. 146) words (Norberg-Schulz, 1971, p.27).

After defining existential space, Norberg-Schulz attempts to identify the conceptual components that this way of thinking about space consists of. In order achieve that, he interprets (1971, p.18) the Gestalt organisational principles, which are in accordance with Piaget's elementary topological schemata, and suggests that these principles consist in the establishment of the elementary properties of existential space:

- centres or places, which are brought about by the principle of proximity,
- directions or paths, which are brought about by the principle of continuity and
- areas or domains, which are brought about by the principle of enclosure.

He then argues that places, paths and domains are the basic topological schemata for orientation in the environment, and therefore he suggests that they should be considered as the constituent elements of existential space.

Similarly with the concept of existential space, Lynch (1960) has defined the concept of an 'environmental image', as a generalized mental picture of the exterior physical world, at an urban scale. The topological schemata which have been identified by Norberg-Schulz as constituent elements of existential space have also been understood by Lynch (1960) and Thiel (1961), as the basic elements of the 'concrete' space that we experience.

3.3 The elements of existential space

The thesis will adopt Norberg-Schulz's identification of the constituent elements of existential space as a starting point, but will also attempt to expand it, by making use of other relevant studies. As a result, a taxonomy of elements that existential space consists of will be proposed. Assuming that an ideal environment should be designed and structured on the basis of our knowledge about the way that humans perceive, remember and think about space, this taxonomy is seen as describing the components and structure required for making an environment legible and generally preferable. Such an environment may consist of:

- Spatial elements which are void and allow for passage through them or actions to take place in them;

- Space-establishing elements, which have a certain form and thus establish space by binding it; these elements are solid in the sense that they do not afford movement through them.

In the beginning, the spatial elements that an environment may consist of will be studied on the basis of:

- the theory of existential space (Norberg-Schulz, 1971) and
- the theory of the environmental image (Lynch, 1960).

Consequently, ways of structuring these elements in an environment will be proposed. Finally, on the basis of both above mentioned theories, the thesis will propose a taxonomy of space-establishing elements of an environment.

3.3.1 Centre and place

As a spontaneous reaction, every human thinks about space as being subjectively centred. The notions of the 'centre' and of 'home' are equally identified with the centre of one's world, the first point of reference employed at the beginning of life. The centre represents to man what is known in contrast to the unknown and uncertain world around. (Norberg-Schulz, 1971, p.18)

By 'centres' Norberg-Schulz (1971, p.19) also means *"places of action, where particular activities are carried out...Actions are only meaningful in relation to particular places, and are coloured by the character of the place...This character must be understood as a product of its interaction with its surroundings, which include other elements of existential space...We say that something (act or occurrence) 'takes place'...The places are*

- *goals or*
- *foci where we experience the meaningful events of our existence, but they are also*

- *points of departure from which we orient ourselves and take possession of the environment.*

This 'taking possession' is related to places which we expect to find or discover by surprise." Norberg-Schulz (1996, p.414) particularly stresses the necessity for a place as the setting for any activity: *"it is meaningless to imagine any happening without reference to a locality...different actions need different environments to take place in a satisfactory way."*

Dardel (as quoted in Relph, 1976, p.41) suggests *that "...we need a place as a base to set down Being and to realise our possibilities -a here from which the world discloses itself, a there to which we can go."* This distinction between 'here' and 'there' - or 'inside' and 'outside' - is also made by Norberg-Schulz (1971, p.20) who quotes Zutt: *"in the common dwelling we have a maximum of spatial security"* and goes on to suggest that *"for its definition, the place needs a pronounced limit or border".* Due to the fact that all places are in a way bound by certain limits, they can be experienced as an 'inside' in contrast to the surrounding 'outside'. For Relph (1976, p.114) 'existential insideness' - the degree to which people feel a part of a place - as opposed to 'existential outsideness' - which involves feelings of strangeness and separation from the place - is the foundation of the place concept.

The problem of inside/outside is created when places interact with their surroundings. The primary intention behind 'being in place' is that of 'being inside' away from what is 'outside'. Schulz (1971, p.25) argues at this point that *"Only when man has defined what is inside and what is outside, can we say that he really 'dwells' (in a space). Through this attachment, man's experiences and memories are located, and the inside of space becomes the inside of his personality."*; in other words, in this situation man can identify with the place.

Places can be analysed in terms of their two main aspects (Norberg-Schulz, 1996, pp.418-420):

- 'Space', which denotes the three-dimensional organisation of the elements which make up a place;
- 'Character', which is determined by the material and formal constitution of the place and which denotes:
  - the general 'atmosphere', the 'genius loci' (Norberg-Schulz, 1984), which is the most comprehensive property of a place and
  - the concrete form and substance of the space-establishing elements.

These aspects, however, cannot be easily extracted and studied separately since the interactions between them are too complex.

Therefore, when humans are dwelling in a place they are exposed to the space and the character of the place. For a human to be able to dwell in a place and 'gain an existential foothold' in the words of Norberg-Schulz (1996, p.423-424) he has to:

- Orientate himself within the place; he has to know where he is.
- Identify with the place; he has to know how he is in this place, to feel at home, to become friends with the environment which has to be experienced as meaningful to the human.

True belonging to a place presupposes that both psychological functions are fully developed. Norberg-Schulz also suggests that this argument is generally valid for the overall environment: *"It is not only important that our environment has a spatial structure which facilitates orientation, but that it consists of concrete objects of identification. Human identity presupposes identity of place."*

Therefore, it is argued here that a subject can 'dwell' in a place only when

- the relations between the inside and outside of the place are clearly defined by the boundaries of the place
- the subject can orientate in the place
- the subject can identify with the place, find the place meaningful.

Heidegger (1971, p.149) explains the meaning of 'dwell' as 'remain', 'stay in a place', but also 'be brought and remain in peace', 'be safeguarded'. It may then be suggested that humans need to feel secure and to identify with a certain space in order to engage into activity there. Accordingly, the concept of place can be described as the physical and spatial manifestation of a situation where these fundamental human needs are being satisfied.

Additionally, Norberg-Schulz (1996, p.421) suggests that, through the construction of places in the real world, humans express their need to:

- visualise their understanding of the world
- symbolise their understanding of the world and
- gather their experienced meanings in order to create a microcosm which concretizes their world.

"Visualisation, symbolisation and gathering are aspects of the general processes of settling and dwelling." It may then be concluded that by bringing together the different human needs which are satisfied by the place concept, we arrive at a formula where identity and security may support activity. A place is formed where this formula finds its physical counterpart.

Norberg-Schulz (Nesbitt, 1996, p.414) describes a place as *"a totality made up of concrete things having material substance, shape, texture and colour. Together these things determine an 'environmental character' - or atmosphere - which is the essence of place."* We cannot reduce the totality of the qualitative phenomenon of place to any of its properties, such as spatial relationships, without loosing its concrete nature. Therefore a place cannot be described by means of analytic, scientific concepts. Nevertheless, *"the properties of an enclosure - dimensions, shape, configuration, surfaces, edges, openings - determine the qualities of the place - form, proportion, scale, definition, colour, texture - which is defined by this enclosure"* (Ching, 1979, p.175) and accordingly the spatial experience. Volumetric proportions, dimensions, scale are all quantitative characteristics of a place which describe its form.

The form of a place, of course, affects the way that we experience it. A place that is being experienced as an 'inside' should generate a spatial sense of proximity, concentration, centralisation and closure." (Norberg-Schulz, 1971, p.20 and 1996, p.418) Limiting the size of a place corresponds with a centralised form, which primarily means concentration. An optimal physical manifestation of such a place therefore is 'round'. The round form consists of two elements, a centre and a surrounding ring. Schwarz (as quoted in Schulz, 1971, p.25 and p.20) suggests that the ring is a maximally closed form and describes its significance as a form symbolizing several people in a circular chain of hands , uniting at the centre of the ring: *"the ring has neither beginning nor end, it begins and ends everywhere. Curved back into itself, it is the most sincere and potent of all figures."* The closure of the ring can be increased through geometrisation, as Norberg-Schulz (1971, p.25) suggests, that is by making the ring circular: *"Geometrisation, in general, does away with all the causal directions of the topological form, and has always been used by man to make the intended relationship more precise."*

In the same vain, it can be suggested that there is an implicit quality pertaining to the intrinsic dynamics of a space, which are a consequence of its formal configuration. In terms of this quality, Thiel (1961, p.41) suggests the following classification of spaces:

- At the one pole are spaces characterised by a feeling of 'centralisation', completeness, closure, cohesion, symmetry and balance; their character symbolises the need for belonging to a place.
- At the other pole are spaces of a 'longitudinal' character which express a certain dynamism and openness to the world, a tendency towards mobility, freedom. expansion and change, which may be physical as well as spiritual (Norberg-Schulz, 1971, p.26); such spaces are usually paths and these will be studied in the next section.

There are, of course, spaces where both tendencies may co-exist and the character of such spaces is determined by the way that their combination is structured.

3.3.2 Direction and path

As mentioned in the previous section, the concept of place implies an awareness of an inside and an outside. This 'outside' is the larger context within which a place is always situated. Any interaction of the place with its surroundings implies directions. *"Any place contains directions...Aristotelis recognized the qualitative distinctions between above and below, in front and behind, right and left, which are rooted in man's constitution and in his relationship to the gravitational field."* (Norberg-Schulz.,1971, pp.20-21)

The direction of 'above-below' implies the notion of verticality, and Norberg-Schulz (1971, p.21) attempts to identify its meaning for the human: *"The vertical has been always considered the sacred dimension of space... (because) it represents a 'path' towards a reality which may be 'higher' or 'lower' than daily life."* The 'axis mundi' is thus more than the centre of the world, it represents a connection between the three cosmic realms, and it is the only central axis that a breakthrough from one realm to another can occur. (Eliade, 1958, p.111) However, verticality also symbolises man's ability to 'conquer nature' by raising vertical structures.

According to Norberg-Schulz (Norberg-Schulz, 1971, p.21-22) *"if verticality has something surreal about it, horizontal directions represent man's concrete world of action. In a certain sense, all horizontal directions are equal and form a plane of infinite extension. The simplest model of man's existential space is, therefore, a horizontal plane pierced by a vertical axis;"* on this plane, humans create paths which give their existential space a more particular structure. *"Man's 'taking possession of the environment' always means a departure from the place where he dwells, and a journey along a path which leads him in a direction determined by his purpose and his image of the environment. 'Forward' means direction of man's activity while 'behind' denotes the distance he has covered...The 'path' therefore represents a basic property of human existence and it is one of the great original symbols...Man's ways, however, also lead* *back home and the path therefore always contains a tension between the known and the unknown."* At this point Norberg-Schulz quotes Bollnow who argues that the movement-duality of departure and return divides space in to *"two concentric domains, an inner and an outer; the narrower inner is the domain of the house...and from there man advances in to the wider outer domain from which he also returns."* The concept of the house is discussed further in (3.8.1).

The concept of direction and its physical expression, the path, are brought about in existential space by the organisational principle - perceptual schema - of continuity and as such are linear by nature. *"Perceptually, as a schema, every path is characterized by its continuity. The path is imagined as a linear succession, as opposed to the place which is determined by the proximity of its defining elements and eventually by closure."* (Norberg-Schulz, 1971, p.22-23) Similarly, in (3.3.1) it has been suggested that paths are characterised by dynamism, and a tendency towards mobility whilst places are characterised by centralisation, cohesion and closure. Therefore, direction and continuity are the main spatial properties of a path (Norberg-Schulz, 1996, P.419). The concept of continuity may also be related to the concept of the rhythm, which is experienced when moving along a path, because of the succession of several formal elements which are situated along its length. This concept will be further investigated in (4.8.2).

Thiel (1961, p.40) attempts to classify unambiguous spaces according to their perceptible form, due to their overall proportions. He introduces the concept of 'run' as *"a space which has any one overall dimension (length, breadth or height) two or more times greater than any other dimension"*; a kind of space which has an implicit directional character and induces movement of the eye or the body. As such, it may be argued that the 'run' describes the physical requirements for a path.

With reference to its parts, a path always consists of:

- a starting point

- a direction to be followed through a sequence of places and events towards
- a goal/destination.

A place may function as a starting point or a destination of a path. The parts of a path will also be investigated in (4.8.2) from a cognitive perspective. Due to the events experienced while moving along the direction, the path is experienced as having a character of its own. *"What happens along the way is added to the tension created by the goal to be reached, and the point of departure left behind. In certain cases the path has the function of being an organizing axis for the elements by which it is accompanied, while the goal is relatively less important."* (Norberg-Schulz, 1971, pp.22-23)

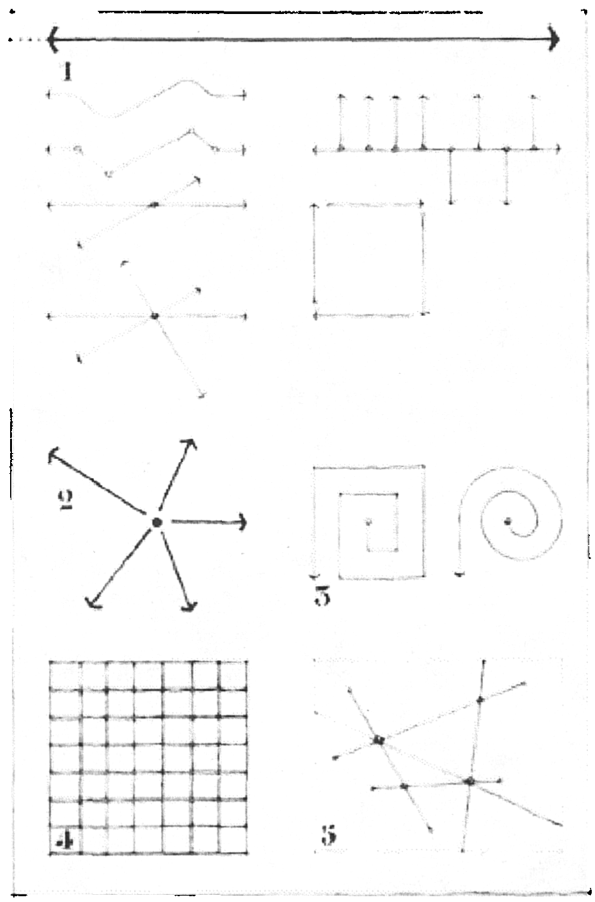

Figure 3.2: Types of path configurations: (1) linear, (2) radial, (3) spiral, (4) grid, (5) network, according to Ching (1979, p.271).

A path's configuration influences the organisational structure of the places it links but may also be influenced by this structure as well. Ching (1979, pp.270-271) identifies six kinds of path configurations: linear, radial, spiral, grid, network and composite. He also suggests that a path may relate to places in three different ways:

- a path may pass by places,
- a path may pass through places,
- a path may terminate in a place. (1979, p.282)

The significance of the path as a structuring element of existential space has also been stressed in analyses of the urban environment by Mitropoulos and Lynch. Mitropoulos (1975, p.202) defines urban space as a network, meaningful only with respect to activities, and considering 'movement-through-space' as a basic activity of humans and as a means of organising the urban environment. He subscribes to the concept of 'hodological space' - which was presented in (2.6). Rather than straight lines, 'hodological space' contains 'preferred paths', which depend on: 'short distance', 'security', 'maximum experience' or other minimum or maximum prerequisites, which are determined in relation to the topographical conditions. When these demands are uniform, and no particular human activity influences the situation, hodological space approaches Euclidean space. Since the demands which define hodological space are determined by each individual, it is understood that this conception of space is clearly subjective. Accordingly, Norberg-Schulz (1971, p.22) suggests that *"investigations of people's movement in cities have shown that different individuals often choose different paths to reach the same place; the preferred path may vary according to his immediate state of mind or situation."*

3.3.3 Area and domain

A place is usually related to several directions by a system of paths, which expresses man's possibilities of movement, the range of his world. *"Paths divide man's* *environment into, more or less well known areas, which are qualitatively defined and which we call domains"* (Norberg-Schulz, 1971, p.23).

Muller (1961, as quoted in Norberg-Schulz, 1971, p.23) discusses the ancient symbolism of dividing the world into domains and explains that creating domains was an expression of man's general need for imagining his world as an ordered cosmos within an unordered chaos. *"By structuring the world into domains defined by natural directions, the ancient man gained an existential foothold...Taking possession of the environment implies structuring the environment into domains by means of paths and places...The domain can therefore be defined as a relatively unstructured "ground", on which places and paths appear as more 'pronounced' figures".* To illustrate this, Norberg-Schulz (1996, p.422) presents the example of the landscape in ancient Egypt which was structured as a model for the lay-out of the 'public' buildings, for the purpose of giving people a sense of security by symbolizing an eternal environmental order.

Domains may be defined in different ways:

- they may be delimited by strong natural elements - shores, rivers, hills - as 'edges' or 'paths', as described by Lynch (1960)
- they may be defined by the particular human activities carried out in the area, which create a certain "texture".

As is the case with places, so domains have a certain character, but this is influenced not only by physical and functional but by social and cultural functions as well.

A system of paths along with certain topographical conditions, may create domains of varying 'density' in our existential space. Domains comprising a network of paths of a higher density may be experienced as 'shapes', because physically and mentally we have 'conquered' them by means of more paths and therefore we can identify with them and 'read' their shape. Gestalt organisational laws can support the recognition of shapes in such patterns. Path networks of lower densities define a more 'neutral' ground. In this sense, we know the denser areas better so they , may be seen as places whereas the other areas remain domains. (Norberg-Schulz, 1971, pp.26-27) However, Schwarz (as quoted in Norberg-Schulz, 1971, p.20) argues that a domain can only become well known - in other words the subject can feel orientated and identify with this domain - if it is small and the compositions of paths and places within it remain within an imaginable scale. Nevertheless, a domain does not necessarily have to be structured but may be equally significant when it merely functions as a unifying 'ground'. The way that humans think about domains will be further investigated in (4.8.3) from a cognitive perspective.

3.3.4 Intersection between spaces

After analyzing the significance of each element of existential space, Norberg-Schulz (1971, pp.24-27) goes on to investigate the possible ways that these elements interact with each other. The space of interaction between a place and a path is always experienced as the locus of a tension between centralisation and longitudinality. As explained in (3.3.1), centralisation symbolises the need for belonging to a place, while the longitudinal nature of the path expresses a certain openness to the world and a tendency towards mobility.

The meeting point of two paths is a point which has very strong existential implications; there are several possible, expressive solutions, on the basis of the continuity principle. The choice as to which direction to follow is a basic problem of human life, especially when the goal to be reached is more or less clearly imagined. (Norberg-Schulz, 1971, p.26)

Thiel (1961, pp.44-45) identifies three types of situations that may occur when two or more spatial elements intersect:

- a 'merge' occurs when two or more spaces join in a manner such that there is no definite point of juncture and one space merges or flows into the other
- a 'port' exists when a constriction occurs when passing from one space to the other and

- an 'end' exists when a juncture of one space with another is neither a merge nor a port.

The ambiguity inherent in a merge can be reduced with the positioning of space establishing elements.

Finally, Ching (1979, p.195) identifies the four possible ways by which two spatial elements may relate to each other:

1) A space may be located within another space

2) The two spaces may be interlocked

3) The two spaces may be adjacent

4) A third space may be linking the two spaces.

These ways determine the nature of the intersection needed to accommodate for the interaction between the two spaces.

3.3.5 Threshold

When places interact with their surroundings, a problem of 'inside' and 'outside' is created. Any place has to be entered and so a direction is introduced. This direction unites the inside with the outside, so it influences a place by stretching its inside towards the outside. A certain spatial element has to accommodate this transition. This element which usually has the form of an opening - door or window - may be generally defined as a 'threshold'. According to its formal qualities, the threshold expresses the degree of continuity in existential space. *"No wonder why the door has always been one of the important symbolic elements of architecture. A door can close off and open up, unite and separate. Psychologically, it is always open and closed at the same time, although one of the aspects is dominating, as any door may be opened. The opening makes a place alive; it generally expresses what the place 'wants to be' in relation to the environment."* (Norberg-Schulz, 1971, p.25)

Eliade (1987, p.25) refers to the entrance of a church in a city as a threshold that separates the two spaces - the interior and the exterior - and also indicates the distance between two modes of being, the profane and the religious: *"the threshold is the limit, the boundary, the frontier that distinguishes and opposes two worlds - and at the same time the paradoxical place where those worlds communicate, where passage from the profane to the sacred world becomes possible...the threshold, the door show the solution of continuity in space immediately and concretely; hence their great religious importance, for they are symbols and at the same time vehicles of passage from the one space to the other."*

As the entrance to a temple symbolises the dividing line between the sacred and the profane worlds for the human, so the threshold of a house is regarded by Cooper (1974, p.141) as one of the most important dividing lines between private space as a symbol of the inner self and the other public world. The location of the threshold varies in different cultures and Cooper (1974, p.142) argues that this location in contrast to the outside world is symbolic of how people relate to the rest of the society.

At this stage, it is not clear whether the threshold should be defined as a spatial element or an element which establishes space. Additionally, the difference between thresholds and intersections has not been made specific. These ambiguities will be clarified when these concepts will be introduced as parts of the design framework for VEs in (5.5.3) and (5.6.3).

So far the elements which constitute existential space have been defined, mainly on the basis of the relevant theory proposed by Norberg-Schulz (1971). In the following section, the possibility of identifying such elements is investigated on the basis of the theory of 'environmental image', proposed by Lynch (1960).

3.4 The image of the urban environment and its elements

According to the approach followed by Norberg-Schulz, the elements of space have been investigated so far, with reference the way that humans think about the environment that they generally exist in; this implies that they are either static in a place or that they are moving within this environment. It is, of course, understood that in reality, humans are always involved in some sort of movement within their environment, whether this is merely a slight turning of the head or running along a path. In this section, the elements that an environment consists of will be studied from the perspective of a subject who navigates in the urban environment.

Kevin Lynch's (1960) approach to this problem, could be considered the first ever systematic attempt for analysing our environment according to the way that people think about it and for creating a taxonomy of the elements it comprises. Even though his research methods are clearly empirical, his results have been widely accepted and used in environmental research at a psychophysical, cognitive or even phenomenological level. Additionally, The study of Norberg-Schulz and most other studies, presented in this chapter, are generally in agreement with Lynch and use quotes from his work. While taking into account that the study of Lynch

- is empirical in method and
- is only considering subjects who navigate, mainly by car, within the urban environment of large American cities,

his theory is thought to be complementary to the taxonomy of spatial elements which has been presented in (3.3) and as a result it will be dealt with in this chapter.

3.4.1 The environmental image

The concept of the environmental image was first introduced by Lynch (1960, p.4) as *"the generalised mental picture of the exterior physical world that is held by an* *individual".* He suggests that this image is the product of both immediate sensation and of the memory of past experience, and it is used to interpret information and to guide action. As such, the environmental image is central to the processes of orientation and way-finding: *"The environmental image is the result of a two-way process between the observer and the environment. The environment suggests distinctions and relations and the observer...selects, organises and endows with meaning what he sees. The image so developed now limits and emphasises what is seen, while the image itself is being tested against the filtered perceptual input in a constant interacting process. Thus the image of a given reality may vary significantly between different observers."* (Lynch, 1960, p.6) According to this description, the concept of an 'environmental image' is in many ways similar to:

- the concept of the 'cognitive map' which will be dealt with in the next chapter and
- to the concept of spatial schemata that existential space consists of, as introduced by Norberg-Schulz.

An environmental image may be analysed (Lynch, 1960, p.8) into three components:

1) Identity: firstly, an image requires the identification of an object, which implies its recognition as a separable entity. This is called identity, not in the sense of equality with something else, but with the meaning of individuality or oneness.
2) Structure: secondly, the image must include the spatial or pattern relation of the object to the observer and to other objects.
3) Meaning: finally, this object must have some meaning for the observer, whether practical or emotional.

We may try to reduce the environmental image to each of these three components for the purpose of analysising it, as long as it is understood that in reality these components always appear together.

Lynch also introduces the concept of 'legibility' (1960, p.2), as a kind of visual quality of a cityscape which determines the easiness with which the observer may recognise the parts of the cityscape and may organise them into a coherent pattern. He later (1960, p.9) defines imageability/legibility more precisely as *"a quality of any physical object which gives it a high probability of evoking a strong image in any given observer. It is that shape, colour or arrangement which facilitates the making of vividly identified, powerfully structured, highly useful mental images of the environment."*

3.4.2 The elements of the environmental image

The main objective of Lynch's work, in 'The Image of the City' (1960), is to uncover the role of the form of the city itself, as a causal factor of the environmental image. In order to achieve that, he studies the feedback, given by numerous inhabitants of three different cities, and analyses the different environmental images that these cities engender to their citizens along with the interesting ways that these images are being represented by them. As a result of this analysis, he classifies the contents of environmental images, which are referable to physical forms, into five types of elements presented below. (1960, pp.46-48)

3.4.2.1 Nodes

Nodes are the strategic spots in a city into which an observer can enter, and which are the intensive foci to and from which he is traveling (Lynch, 1960, p.47). They may be seen as points, in the context of a city, but could, in fact, be places that can be entered, when seen in the human scale.

Nodes may be:

- An intersection of paths,
- a place of a break in a path,
- a crossing or convergence of paths,
- a moment of shift from one structure to another,

- or simply a place which gains its importance from concentration of use or physical character.

Nodes may function as foci or symbols within a domain and in this case they may be called 'cores'. (Lynch, 1960, pp.47-48)

The intersection of paths or a place of break along a path are very significant for the observer who navigates in a city: *"Because decisions must be made at junctions, people heighten their attention at such places and perceive nearby elements with more than normal clarity...Elements located at junctions may automatically be assumed to derive special prominence from their location."* (Lynch, 1960, pp.72-73) *"Junction nodes at major intersections and termini (of paths) should reinforce those critical moments in a journey, by their form."* (Lynch, 1960, p.84) People also seem to associate the transition from one channel of movement to another, which may be experienced as break point along a path, with the transition between major structural units. In theory, every path intersection is a node, but it has to be stressed that an environmental image cannot carry too many nodal centres. The significance of path intersections for a navigating subject will be investigated from a cognitive perspective in (4.8.2).

In the case of nodes as concentration points, a strong physical form may not be absolutely essential for the recognition of a node, but it certainly makes the node more memorable. *"The most successful nodes seem both to be unique in some way and at the same time to intensify some surrounding characteristic."* (Lynch, 1960, p.77)

3.4.2.2 Path

The spatial element of a path, which was identified as one of the constituent elements of existential space by Norberg-Schulz - as presented in (3.3.2) - is similarly identified by Lynch (1960): *"Paths are the channels along which the observer customarily, occasionally, or potentially moves...People observe the city while moving through them,* *and along these paths the other environmental elements are arranged and related."* (Lynch, 1960, p.47) For most people, paths are the predominant elements in a city.

The image of a path is determined by several qualities, also identified by Lynch (1960, p.50-61):

- Identity, mainly depends on how obvious and significant are the destinations and the origins that define the path.
- Continuity is a functional necessity for a path. This sense may be interrupted by an intervening object or a significant change of width.
- Directional quality depends on how easily can one direction be distinguished from the reverse.
- Scalability depends on how easily can the observer sense their position along the length of the path or grasp the distance they have traversed or they have yet to go. Features that may facilitate scaling may also give a sense of direction. Scaling may be accomplished by a sequence of known landmarks, nodes or even repetitive objects along a path.
- Concentration of a certain activity along the path's length, may give it prominence.
- Noticeable spatial characteristics, such as extreme width or narrowness, intensified by the height of surrounding buildings may strengthen the image of a path. However, people seem to be more influenced by the functionality and importance of a path than by its spatial characteristics.

Other qualities which seemed to be a bit less important were:

- special facade characteristics or proximity to special features,
- the visual exposure of the path itself or of other parts of the city from the path,
- its structural significance in the context of the path network,
- its name.

When considering more than one path, their intersection becomes a vital point. Humans tend to impose geometrical regularity in their surroundings, unless obvious evidence refutes it, therefore perpendicular intersections seem easiest to handle. Insignificant and not very clear change of direction usually results in wrong perception of the whole network.

Finally, the significance of a starting point and a destination, as parts of a path - suggested in (3.3.2) - is confirmed by Lynch (1960, p.54): *"People tended to think of path destinations and origin points: they liked to know where paths came from and where they led. Paths with clear and well known origins and destinations had stronger identities, helped tie the city together, and gave the observer a sense of his bearings whenever he crossed them."*

3.4.2.3 Districts

Districts - or regions - are the relatively large city areas, conceived as having two-dimensional extent, which the observer can mentally 'enter', and which are recognisable as having some common, identifying character. They can be identified from the inside, and occasionally can be used as external reference, when they are visible from outside. (Lynch, 1960, p.47)

The physical characteristics that determine districts are thematic continuities which may consist of a variety of components: texture, space, form, detail, symbol, building type, use, activity, inhabitants, topography. 'Knowing' the size of the district may partly depend on how well its structure can be grasped. Social connotations and names are also significant in establishing a district as thematic unit. The main requirement for the legibility of a district is the constitution of a thematic unit which contrasts with the rest of the city; the internal homogeneity is less significant. (Lynch, 1960, pp.67-69)

Districts have various kinds of boundaries, ranging from hard, definite and precise to soft or uncertain. Other regions have no boundaries at all. Edges - which are defined in (3.4.2.4) - can set the limits and reinforce the identity of a region but they have less to do with constituting it. A node however, can create a district by radiating around it a sense of proximity to the nodal point. Regions are primarily reference areas, which we think of rather than directly experience, but they can be useful organizing concepts. (Lynch, 1960, p.70)

Regions may be introvert or extrovert, according to their degree of connection to surrounding elements. Similarly, regions may stand alone in their zone or may be linked to other regions, making a continuous mosaic of districts. In the latter case, the contrast and proximity of each area may heighten or weaken the thematic strength of each. (Lynch, 1960, pp.71-72)

3.4.2.4 Edges

Lynch finally introduces two elements in his taxonomy - edges and landmarks - which generally function as space-establishing elements rather than elements of space. He (1960, p.47) defines edges as *"the linear elements which are not used or considered as paths by the observer;"* they are usually, the boundaries or linear breaks in continuity between two kinds of areas. They function as lateral references rather than coordinate axis.

The strength of an edge depends on:
- its visual prominence,
- its continuous form,
- how easily it can be penetrated by cross movement. (1960, p.62)

"While continuity and visibility are crucial, strong edges are not necessarily impenetrable." Edges can function as:
- isolating barriers, more or less penetrable, which close one region from the other, or they may be
- uniting seams, lines along which two regions are related and joined together.

Edges may also be paths, and like paths they can have directional qualities. (1960, p.65)

3.4.2.5 Landmarks

Landmarks are space-establishing elements. Similarly with nodes they can be seen as another type of point-reference but on the other hand they are external to the observer; since they establish space, a subject cannot enter them. They are simple physical elements which may vary widely in scale. (Lynch, 1960, p.48)

- Some landmarks are distant and they can be used as radial references or to symbolize a constant direction; they may even be mobile, if their motion is sufficiently slow and regular. People who were unfamiliar with a city (Lynch, 1960, pp.81-82) seemed to use the more distant, prominent points as landmarks for general directional orientation or in symbolic ways.
- Other landmarks may be local when they are visible in restricted localities; such landmarks could be small in terms of scale and could be signs or other objects which function as clues for identity, direction and structure. Local landmarks are much more frequently employed than distant ones, but their use depends on the familiarity of a subject with the environment. Sounds and smells reinforce such visual landmarks, although they did not seem to constitute landmarks themselves. (Lynch, 1960, p.83)

"Since the use of landmarks involves the singling out of one element from a host of possibilities, the key physical characteristic of this class is singularity, some aspect that is unique or memorable in the context." (Lynch, 1960, p.78)

Lynch has identified several criteria which may contribute to the overall significance of a landmark and consequently to how easily it is singled out within the context of a city:

- Form: Landmarks become more easily identifiable if they have a clear, prominent form or if their form *contrasts* with the background. *"Figure-background contrast seems to be a principal factor."* (Lynch, 1960, p.79)

- Location: Elements may be made prominent because of their location and thus be established as landmarks. This may happen either by making the element visible from many locations or by positioning so that it sets up a local contrast with nearby elements. Location at a junction of paths involves decisions and strengthens a landmark: *"the nodes established at those junctions are not only strengthened by the presence of landmarks but may provide a setting which almost guarantees attention for any such mark."* (Lynch, 1960, p.84)
- Function and Association: If an element is associated with a particular activity or if a certain meaning, sign or history is attached to the element, it may signify a landmark. Additionally, if the function or meaning associated with the element contrasts with that of its background, then its prominence as a landmark may also be amplified.

A sequential series of landmarks, in which one detail calls up anticipation of the next and key details trigger specific moves of the observer, appeared to be a standard way in which subjects of Lynch's case studies traveled through the city. *"For emotional security as well as functional efficiency, it is important that such sequences are fairly continuous, with no long gaps, although there may be a thickening of detail at nodes. The sequence facilitates recognition and memorization...(However), recognition may break down when the sequence is reversed or scrambled."* (Lynch, 1960, p.83) The significance and impact of landmarks within an environment will also be further investigated in (4.8.1) from a cognitive perspective.

Finally, it has to be stressed that none of the above mentioned elements exist in isolation in the real environment. Districts are structured with nodes, defined by edges, penetrated by paths, and may include several potential landmarks. Elements regularly overlap and pierce one another (Lynch, 1960, pp.48-49). However, Lynch's research did not manage to clearly identify the interrelations between these elements. It should also be mentioned that the image of a given environment varies according to the way that this environment is being viewed; in other words, according to how is an observer moving within the environment and from which point of view he observes. Thus an expressway may be a path for a driver and an edge for a pedestrian.

3.4.3 The correspondence between the studies of Lynch and Norberg-Schulz

As mentioned in (3.4), the study of Lynch (1960) is empirical in method. It is however presented in this chapter because it was seen as strongly related to the theory of existential space (Norberg-Schulz, 1971) Norberg-Schulz (1971, p.15) quotes Lynch's concept of 'environmental image' as corresponding to that of a spatial schemata which constitute a subject's existential space. He also acknowledges that Lynch attempts to interpret an existential dimension of the environment of the city. Before interpreting Piaget's organisational schemata and introducing the elements of existential space (1971, p.18), Norberg-Schulz (1971, p.15) quotes Lynch (1960, p.7) who identifies the fundamental properties of space and concludes that the world may:

- be organized around a set of focal points or
- be linked by remembered routes or
- be broken into named regions.

This identification is in agreement with the definition of the three elements of existential space by Norberg-Schulz - place, path, domain.

It may be concluded that this taxonomy of spatial elements has been partly based on the work of Lynch (1960) and that both approaches are largely in agreement, although they differ in the scientific method that they follow. In specific:

- Both have identified 3 types of spatial elements:
    - The concept of the 'place' corresponds with the concept of the 'node'; both are focal points within the environment and can be entered - which implies definition of 'inside' and 'outside'.
    - The concept of the 'path' has been used by both but different aspects have been studied by each.

- The concept of the 'domain' corresponds with the concept of the 'district' - other names that have been used for this concept are: region or area; again different aspects of this concept have been studied by each.

- Lynch has identified two types of space-establishing elements:
  - 'edges' and
  - 'landmarks'

  mainly because of the fact that they are the elements that do not allow an observer to enter them. They always remain external to the observer. An edge may be entered but in this case it will be probably experienced as a path. Norberg-Schulz did not analyse these elements in his taxonomy, but concentrated on the types of spaces that they define. These elements will be investigated in more detail in (3.6).

3.5 Organising the spatial elements into a whole

"Places, paths and domains are the basic schemata for orientation, that is, the constituent elements of existential space. When they are combined, space becomes a real dimension in human existence." (Norberg-Schulz, 1971, p.24) In the previous sections (3.3) and (3.4), the elements which may constitute a subject's existential space - or environmental image - have been identified, mainly on the basis of theories proposed by Norberg-Schulz (1971) and Lynch (1960) respectively. In this section, an attempt is made to investigate ways of structuring these elements into configurations within real environments.

Eliade (1987, pp.20-22) explains that ancient man felt the need to define the space that he would live in within the vast, amorphous expanse of space that surrounded him. The need for defining a part of space and constituting it as sacred is not only religious and spiritual but also functional since *"in the homogeneous and infinite expanse,... no point of reference is possible and hence no orientation can be established."* (Eliade, 1987, p.21) In order to be able to orientate within his environment, he defined a sacred fixed point of reference from which he structured the world around him. *"For nothing can begin, nothing can be done, without a previous orientation - and any orientation implies acquiring a fixed point. It is for this reason that religious man has always sought to fix his abode at the 'centre of the world'. If the world is to be lived in, it must be founded - and no world can come to birth in the chaos of the homogeneity and relativity of the profane space"* (Eliade, 1987, p.22) This central point was often consecrated by erecting a vertical element, like a pillar or pole, which symbolised the passage from the world of the gods above to the earth below. Through this act of sanctifying a certain space, man began to transform the amorphous, homogeneous chaos of space into his world, or in Norberg-Schulz's words, gained an 'existential foothold' in his environment. Even modern man (Cooper, 1974, p.130) has built his cities in the image, either conscious or unconscious, that he has of the world.

Norberg-Schulz (1971, pp.25-26) argues that a place is usually related to several directions by a system of paths. The paths are determined by human activities and by topographical conditions and because these are somehow related, paths are usually connected, forming some kind of network, the pattern of which depends on the character of the paths that comprise it. This system of paths, therefore, expresses man's possibilities of movement, the range of his world. Finally, Norberg-Schulz also argues (1971, p.27) that *"human identification with the environment presupposes varying densities and above all dense 'foci', which serve as basic points of reference."*

It may then be concluded that the environment surrounding a subject needs to have

- a certain centre
- other minor dense foci which serve as points of reference in the environment and
- varying densities in the patterns created by paths

so that the subject is able to feel orientated and to identify with his environment.

It is essential to consider the way that spatial elements may be arranged within an environment since this arrangement may determine their relative importance and functional or symbolic role in the organisation of this environment. Ching (1979, p.205) identified and analysed five possible generic categories of spatial organisation within a building. In this thesis, these categories are assumed to apply to configurations comprising spatial elements of all scales:

1) Centralised, whereby a number of secondary spaces are arranged around a central dominant space in a stable, concentrated, introvert and geometrically regular composition. Such arrangements may be used
   - for establishing a certain point or a place in space
   - for terminating an axial composition or
   - for serving as an object-form within a defined volume of space. (Ching, 1979, p.206-7)
2) Linear, which consist of a series of spaces that are directly related to one another or are linked through a separate linear element - i.e. path. Such organisations share the same characteristics with paths - direction, movement, extension; as such their beginning, their end or the rhythm of repetition of spaces in the series may be emphasised. The form of a linear organisation can relate to other forms in its context by:
   - Linking them along its length
   - Serving as a barrier to separate them
   - Surrounding and enclosing them within a field of space. (Ching, 1979, p.214-5)
3) Radial, which combines elements of both centralised and linear organisation. It consists of a dominant central space from which a number of linear organisations extend in a radial manner. Similarly with centralised arrangements, the central element is of a regular form but the character of a radial organisation is extrovert with its linear elements reaching out to the context. (Ching, 1979, p.224)
4) Clustered, whereby spaces are grouped by proximity or the sharing of a common visual characteristic, such as shape or orientation. However, elements of such an arrangement may be dissimilar in all their characteristics but may relate to each other by proximity or by another ordering device - symmetry or axis. A

clustered organisation is flexible and can accept change without significant change of its character. (Ching, 1979, p.230)

5) Grid, which consists of elements whose position in space and interrelationships are regulated by a two or three-dimensional grid pattern or field. The organising power of this arrangement lies in the regularity and continuity of its pattern that is more powerful than the elements it organises. The identity of the structural pattern is not altered if any of the elements are changed, therefore the grid is flexible in changes, growth and expansion. (Ching, 1979, p.238-9)

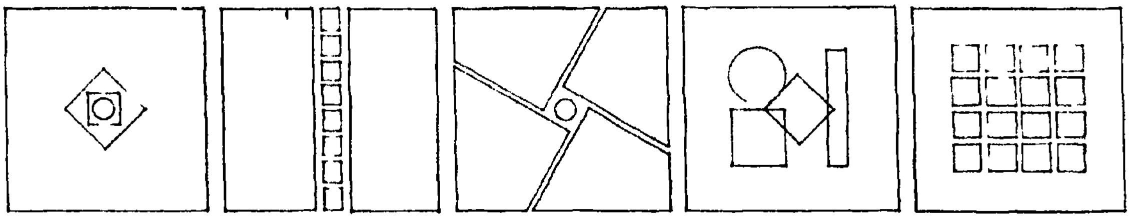

Figure 3.3: Types of spatial organisations: centralised, linear, radial, clustered, grid - from left to right - according to Ching (1979, p.205):

3.6 Space Establishing Elements

After having identified the types of spatial elements that the image of an environment may consist of, it is necessary to investigate the types of elements which may establish space within an environment. As argued in (2.4), space is established by objects or things which bind it, because all things have form. Thiel (1961, pp.35-36) argues that the visual experience of space results from the visual perception of light-defined relationships between positions and qualities of certain things. He goes on to classify these things, in terms of how their form is experienced by an observer, into:

- 'Objects', which may be thought of as three-dimensional convex forms, existing as visual entities in a larger space than that which they may help establish;

- 'Surfaces', as two-dimensional plane forms, limited in visual effect to the space they help establish, although in reality they may be a part of a larger object when experienced in a different context;
- 'Screens', as perforated surfaces, or closely-spaced objects, which are an intermediate condition between the two above mentioned types. (1961, p.35)

Apart from generating functional space, these things, by their relationships to one another and the nature of their organisation, may also communicate meanings. These could either be:

- Literal, denotative meanings of form and space, which are experienced by the subject as notions of place, domain, path, hierarchy and order and which are the central concerns of this thesis;
- Connotative meanings, which Ching understands as *"associative values and symbolic content that is subject to personal and cultural interpretation and can change with time."* (1979, p.386)

It is suggested that spatial meaning may be communicated to a subject by means of signs or symbols. This meaning may be:

- explicit, as consequence of an object's feature,
- implicit in the spatial arrangement of boundaries.

'Edges' and 'landmarks' are identified by Lynch (1960) as two of the constituents elements of the urban environment. Both of them are understood to be space establishing elements because they always remain external to the observer. On the other hand, spatial elements are entered and this, by definition, is their main purpose and function. Therefore, it is suggested that space-establishing elements in the real world may be classified, in terms of context-specific function and significance, as:

- landmarks
- edges or boundaries.

3.6.1 Landmarks

Landmarks generally act as points of reference for orientation or may communicate some meaning to the observer. As space establishing elements, they cannot be entered and they may vary widely in scale. Their main characteristic is singularity within their environmental context. Norberg-Schulz (1996, p.418) argues that man-made environments comprise such 'things' - as landmarks - which may serve as internal foci and emphasize the gathering function of a settlement -a place.

3.6.2 Edges or boundaries

The term 'edge' is used here in a more generic sense than the term used by Lynch (1960). Accordingly, edges are all the objects in any environment which mainly function as boundaries; in other words they suggest a spatial form out of the void in varying degrees of explicitness, by virtue of their own form.

Norberg-Schulz (1996, p.419) traces the origin of man-made boundaries:
"Any enclosure is defined by a boundary...

- *The boundaries of a built space are known as floor, wall and ceiling.*
- *The boundaries of a landscape are structurally similar and consist of ground, horizon and sky.*

This structural similarity is of basic importance for the relationship between natural and man-made places. The enclosing properties of a boundary are determined by its openings...in general the boundary (and in particular the wall) makes the spatial structure visible as continuous and/or discontinuous extension, direction and rhythm."
He also refers to walls in particular as *"lateral boundaries which particularly contribute to the character of the urban environment."* (Norberg-Schulz, 1996, p.420)

In the same vein, Cooper (1974, p.143) describes a ritual lodge made by the Pawnees aborigines, with a function of symbolizing man's abode on earth and identifies in it the correspondence between the lodge's:

- Floor - plain
- Wall - distant horizon
- Dome - arching sky and
- Central opening on top of the ceiling or dome - the zenith or place of the god.

3.7 The levels of existential space

In this last section of chapter (3), an attempt is made to identify the structure of existential space, in terms of the quality of scale. Following Relph's (1976, p.20-21) interpretation of Norberg-Schulz's work, it can be argued that existential space is horizontally and vertically structured:

- In the horizontal sense, the structure of existential space consists of the elements that have just been described - place, path, domain, threshold and intersection.
- In the vertical sense, existential space comprises five different levels of gradually diminishing scale:

1) The 'geographical level' has a cognitive character. It is 'thought' rather than 'lived', but may influence the more directly experienced levels. Paths and places of geographical space have and abstract character; they do not represent what is directly known, but are potential elements of existential space. The content of this level primarily consists of domains. (Norberg-Schulz, 1971, p.28)

2) The 'landscape level' has always the function of forming the continuous background of our spatial experience. It results from man's interaction with the natural environment. A landscape with weak formal properties does not offer the same possibilities for orientation and identification as a landscape where large and small dimensions accentuate each other reciprocally. (Norberg-Schulz, 1971, p.28-29)

3) The 'urban level' comprises structures which are mostly determined by man's own activities, by social interaction and by his interaction with a man-made environment. The primary quality of the urban image is the single identifiable place. The most elementary typical urban images are those of 'enclosure' and of the 'cluster', which are the direct expressions of functions taking place and of social togetherness respectively, and can often appear in combination. Norberg-Schulz (1971, p.29-30) quotes Lynch (1960) and argues that: *"Man needs an urban environment which facilitates the image-making, needs districts which have a particular character, paths which lead somewhere, and nodes which are distinct and unforgettable places."*

4) The 'house' is a private space that we find within the urban level; it really brings us 'inside' and represents the need for being situated. This is where humans find their identity and this is where the fundamental function of 'dwelling', as defined by Heidegger (1971), is fully expressed. (Norberg-Schulz, 1971, p.31) Because of its symbolic significance, the concept of the house will be further investigated in (3.7.1).

5) The 'thing' is the lowest level of existential space. Things are objects of a specific form, known by man in the most direct way possible because the human body is directly relating to them. This renders them as significant elements of our phenomenal world. The elements of this level may serve as foci in the house or in a place. (Norberg-Schulz, 1971, pp.31-33) *"The things 'explain' the environment and make its character manifest. Thereby the things themselves become meaningful. That is the basic function of detail in our surroundings."* (Norberg-Schulz, 1996, p.421)

Humans exists in relation to physical, psychic, social and cultural objects and these form all levels of our environment. As we move from the level of landscape towards the level of the house, Norberg-Schulz (1971, pp.31-33) identifies a growing precision of form and structure and an increasing tendency towards geometrisation. We imagine the things that we do not know on the model of things known and therefore we tend to represent aspects of levels that we cannot conceive of with aspects of levels that we directly experience.

Finally, it is suggested that since horizontal and vertical structures co-exist within the construct of existential space:

- levels can contain each other and
- on each level we may find any of the previously identified elements of existential space.

3.7.1 The house

The centre of a man's existential space is a particular type of space, the house. Because of its central importance in the way that humans think about their environment, it is essential to study the symbolic significance of the house for any human.

Cooper (1974) uses Jung's theories of dreams, his concepts of the archetype, the symbol and the collective unconscious - see Stevens (1994, pp.32-43) for definitions of these terms - to interpret the symbolic meaning of 'house' in dreams. The archetypes are the functional units of the collective unconscious and could be described as *"identical psychic structures common to all humans which together constitute the archaic heritage of humanity."* (Stevens, 1994, p.33) Jacobi (as quoted in Cooper, 1974, p.131) describes the archetype with the analogy of *"a 'psychic mesh' with nodal points within the unconscious, a structure which somehow has shaped and organised the myriad contents of the psyche into potential images, emotions, ideas and patterns of behaviour. The archetype can only provide a potential or possibility of representation in the conscious mind, for as soon as we encounter it through dreams, fantasies or rational thought, the archetype becomes clothed in images of the concrete world and is no longer an archetype: it is an archetypal image or symbol."* Cooper (1974, p.131) therefore argues that if we think of *"the archetype as a node of psychic energy within the unconscious, then the symbol is the medium by which it becomes manifest in the here and now of space and time. Thus the symbol, although it has objective visible reality, always has behind it a hidden, profound, and only partly intelligible meaning which represents its roots in the archetype."*

Cooper then goes on to suggest that in trying to comprehend the self, which is the most basic of archetypes, man tries to use physical forms or symbols which are visible and definable and also very close and meaningful to him. After considering the body, which is the most obvious physical entity that could represent the self, Cooper (1974, p.131) argues that *"on a less conscious level, man frequently selects the house , that basic protector of his internal environment...to represent or symbolise what is tantalizingly unrepresentable."* In short, she suggests *that "the house reflects how man sees himself"* and she presents evidence from analysis of contemporary architecture, poetry and literature to support this suggestion.

A similar approach towards considering the significance of the house for a human - which is in agreement with Jung's emphasis on daydreaming as opposed to dream - is presented in Bachelard (1982). His thesis argues that the house should not be considered simply as an object. We carry with us as an integral part of our selves, our memories of all the places that we have found shelter in, all our images of protected intimacy mainly from our childhood. *"The house we were born in has engraved within us the hierarchy of the various functions of inhabiting"*. (Bachelard, 1982, p.42-93)

When we come to a new house, an entire past comes to dwell in this house with us. We come with *"a personal space bubble"*, as Cooper (1974, p.131) calls this extension of ourselves which relates to our memories of all places we have felt protected enough to daydream in. As we live in a new space, we project something of ourselves onto the physical fabric of the new house. In this sense, Cooper (1974, p.131-2) argues that the house might be viewed as both

- a medium for sending psychic messages from the self to the objective symbol of self
- a way for revealing the nature of self from this objective symbol.

Bachelard (Cooper, 1974, p.131) has also suggested an analogy between the house and the self, in which:

- the house and the non-house may be seen as the basic divisions of geographic space and
- the self and the non-self may be seen as the main divisions of psychic space.

He has also stressed the importance of two very important and different parts of the house:

- its interior, which reflects how man sees himself as viewed from within or revealed only to the most intimate people and
- its facade, which reflects how man projects himself to the public or the self that he chooses to display to others.

Finally, Bachelard (1982, ch.1) considers verticality and concentration as the basic properties of a house and he discusses the cellar and the attic, as particularly meaningful places within the house context.

On the basis of various anthropological and religious studies, Cooper (1974, pp.141-143) suggests that men in many parts of the world have built their cities, temples and houses as images of the universe. The house is also seen as sacred, giving man a fixed point to structure the world about him. She then argues that *"somewhere through the collective unconscious, man is still in touch with this symbolism. Our house is seen, however unconsciously, as the centre of our (subjective) universe and symbolic of the (objective) universe."* This connections are more evident on primitive peoples; modern man retains the connection of the house as a symbol of the self but may have lost the archaic connection between house-self-universe. Bachelard (1982, p.31-87) also stresses the symbolic significance of the house *"Our house is our corner of our world. It is our first universe, a real cosmos in every sense of the word."*

Finally, Norberg-Schulz (1971, p.31) quotes Alberti's analogy of calling the house 'a small city' and agrees to the extend that they may both consist of the basic elements of existential space, but there are substantial differences in the way they are determined by these elements. The city mainly lives by means of its paths, whereas the house is a function of place.

3.8 Concluding remarks

In this chapter, the concept of a 'concrete', existential space, as an individual's subjective environmental image, which informs his exploration within the environment, has been investigated. Norberg-Schulz (1971) and Lynch (1960) have attempted to approach and systematically analyse the nature of existential space, from different perspectives but with similar results. These results, which may be seen as suggestions for a taxonomy of constituent elements of our environment and of their structure, have been presented in this chapter.

Both Norberg-Schulz and Lynch try to explain how we experience and conceptualise existential space and how this conception is essential for our existence in this space. Norberg-Schulz's analysis refers to the whole scale of environments that surround the human and goes as far as attempting to identify how the elements interact with each other. His suggestions are not supported by experimental evidence and are speculative, since they follow a phenomenological method of analysis, based on literature that covers a wide area of mainly theoretical knowledge. Nevertheless, Norberg-Schulz's ideas approach successfully and convincingly the nature of the spatial experience and refer to the whole range of scale levels in our environment. Because of its generalised character, this approach could provide the main starting point for the analysis of the spatial experience in VEs.

On the other hand, Lynch's approach follows an empirical method of research and is based on evidence provided by personal experiences of numerous observers, who lived in three carefully selected cities of a different character. As a result, his conclusions are better established and more believable and therefore his work has been extensively used in several aspects of environmental research, since it was first published in 1960.

However, Lynch did not manage to provide convincing suggetsions for the interrelations between the elements of the environmental image. Additionally, the organisational structure that he proposes is more specific to the urban environment of American cities, where movement by car is dominant. It would, therefore, be limiting to adopt the model of environmental structure that he proposes, word by word, in the design of a VE. Nevertheless, his work is of great value to this thesis but should be selectively used.

On the basis of the studies by Norberg-Schulz and Lynch, this chapter has provided an indication of how we could start thinking about the elements of form and space which could be designed in a VE and of their possible structure. In the following chapter, the way that we conteptualise and remember space in the real world will be investigated from a cognitive perspective. As with chapter (3), the aim of this investigation will be to identify the elements that our mental representation of an environment consists of, on the basis of literature documenting empirical methods of research.

CHAPTER (4)

4. A COGNITIVE APPROACH TOWARDS IDENTIFYING THE CONSTITUENT ELEMENTS OF THE SPACE THAT WE EXPERIENCE IN REAL ENVIRONMENTS

In the previous two chapters, this thesis investigated human spatial knowledge of real environments and focused on the 'concrete' aspect of spatial experience. These chapters aimed at identifying which are the elements that comprise our image of the environment, as seen from a phenomenological perspective, and in which ways are these elements structured.

During the last three decades, several disciplines have investigated human ability to navigate and learn about a spatial environment in every scale. Environmental psychology, cognitive psychology, geography, and artificial intelligence have all dealt with issues of environmental perception, cognition and behaviour from their individual point of view. This chapter will look into literature from these disciplines in order to investigate the spatial experience from an empirical perspective.

As Ittelson (1973, pp.8-9) acknowledges, recent psychological approaches have dealt with the environment as a source of 'information' and not a source of stimulation for the senses - via stimuli; in other words, perception has been studied in terms of the information-processing theory. Accordingly, this chapter will study the way that a subject acquires spatial information from the environment, for the purpose of identifying:

- which are the components that the acquired spatial knowledge consists of and
- in which way are these components structured.

Consequently, the results of this chapter will be compared with the findings of the previous chapter, for the purpose of investigating whether these two different ways of analysing spatial knowing are in agreement.

It has to be made clear though that this chapter will not attempt an analysis of the relations between environmental cognition, assessment, decision-making and action, as these issues are well beyond the scope of this thesis. It is also understood that this study considers the frame of reference of a subject who is moving within an environment; issues of perception and interaction with individual static or mobile objects are not considered. Although this assumption makes wayfinding and navigation literature highly relevant, it is understood that such literature will mainly be used in the context of spatial knowledge acquisition and not in relation to wayfinding actions and behaviour.

4.1 Identifying a theoretical framework for the study of environmental perception

Before embarking on the study of environmental knowledge, it is useful to determine the framework according to which the problem of environmental perception - in real and virtual environments - will be studied in this thesis. A detailed account of all theories of visual perception would, however, be beyond the scope of this thesis. Instead, while taking all recent theories into account, an attempt will be made to briefly compare the relevance of the most widely accepted theories - the ecological and computational approaches - to the specific problem of environmental perception, for the purpose of defining a background for this thesis.

It is not possible to look for one coherent theory, which could answer all aspects of perception, at all levels of description, and which could be used as a framework for the study of human perception in the real world and consequently in VEs. Gordon (1989, pp.225-226) argues that: *"there is as yet no satisfactory general theory of visual* *perception. No theory has adequately united a full analysis of the environment and the cognitive aspects of seeing. No general theory has thoroughly incorporated and explained the motor aspects of seeing....There are too many irreconcilables between various theorists to permit any general fusion of ideas. Differences between empiricist views of perception and those of the Gestalt theorists or Marr and Gibson are such that they cannot all be right. Nor does it seem right to suppose that the truth must lie between the rival views; they are too different for that."*

All the above mentioned theories may be partly relevant to the problem of explaining perception and none of them is wholly irrelevant. Selecting one approach largely depends on the level of description, where the particular aspect of perception is being investigated. The Gestalt and the neurophysiological approaches, for example, do not necessarily contradict each other, but deal with different levels of the problem of vision. They are, however, contradictory in their fundamental philisophical assumptions, that is phenomenology and empiricism respectively.

Rumelhart and McClelland (1985, p.193) suggest that psychology, in general, is properly concerned with all three levels of description - computational, algorithmic, and implementational - as proposed by Marr (1982) for the problem of visual perception. Psychological theories and the information-processing theory, in particular, are mainly concerned with the algorithmic level, whereas physiological studies belong to an implementational level. Moreover, Ulman (1980) argues that direct-perception theorists were wrong in considering two levels of explanation, namely the ecological and the physiological, and agrees with Marr for the need of an algorithmic level which comes between the two and organises physiological knowledge. Accordingly, this chapter will operate at this algorithmic level, or in other words in the cognitive, psychological level of explanation, which stands between the stimulus and the response (Bruce & Green, 1990, p.389) within an environmental context..

Bruce and Green (1990, p.223) suggest that the constructivist/computational and the ecological approaches may be regarded as complementary, and as having a lot in common, with the ecological framework operating at a more global level of analysis than the computational accounts. They consider (1990, p.374) the ecological level as a 'higher' level of theory, but one that can guide the details of an algorithmic specification of some process. They acknowledge, however, that many ecologists regard their theoretical orientation as antithetical to that of information-processing theorists like Marr.

Recent neurophysiological findings provide evidence supporting the concept of a 'retinal image', as the starting point of human vision and are consequently in support of the constructivist approach. This may be the case, at a physiological level; at a higher level though, with respect to the subjective experience of the perceiver, the perceptual input may be seen as a pattern of light extended over space and time, which Gibson (1986) called 'the ambient optic array'. Bruce and Green (1990, p.377) concluded that Gibson was not entirely right about what this optic array specified: instead of all objects and events, only a limited class of spatial properties - distances, slants, textures of surfaces - can actually be specified by this pattern of light. They agree, however, with direct theorists that the control of action by information in the structure of light can be studied without reference to physiological processes. (1990, p.379)

On the other hand, Gordon (1989, p.172) argued that Marr and others who worked in the field of artificial intelligence have adopted a faulty model of the perceiver, which does not account for the contribution of motor activity. The constructivist approach significantly reduces the dynamic aspect of the visual experience, by freezing it to a static image, and depriving it from the important element of the temporal pattern of light in the changing optic array, for the purpose of analysing it. Gibson's theory, however, dealt with motion as an integral part of the perception of any environment. Another argument against the computational approach is that by omitting the phenomenological aspects of perception, it cannot ever do full justice to its subject matter. The parallel distributed processing model may be able to meet some of these criticisms, although the mechanistic approach and the inadequate treatment of phenomenology will remain as its weaknesses.

Bruce and Green (1990, pp.287-309 and 321-342) present recent studies which attempt to bring together aspects of Gibson's theory on the perception of movement with the information-processing approaches, into a common framework. These studies accept Gibson's arguments for optic flow as a source of information about the environment, but do not adopt the assumption that such information is picked up directly. They also suggest that human motion processing is flexible, because it is being performed by several specialised systems instead of a single general-purpose one. Undoubtedly, when time-based phenomena like actions and events in the real world or in VEs are considered, a more dynamic conception of perception is needed and such a conception is provided by the ecological approach. The importance of the ecological level of analysis is that it applies to real behaviour in real situations.

In the same vein, Bruce and Green (1990, p.381) agree with the direct position that properties of the world can be detected without cognitive processes of inference, interpretation and judgement - as in the case of the optic flow analysis or in the elaboration of forms in Marr's primal sketch. On the other hand, they concur with indirect theorists, that such processes are of an information-processing nature. The fact that there are no cognitive processes involved in the detection of such properties does not necessarily imply that they are of a 'direct' nature, as Gibson (1986) suggested.

Furthermore, it is difficult to accept that Gibson's theory does not consider any kind of representation, short-term or long-term memory, schemata, or mental maps, as playing a role in the perception of the environment. Fodor and Pylyshyn (1981, as quoted in Bruce and Green, 1990, p.391) explain the difference between this understanding of visual perception and the constructivist approach which aknowledges the involvement of socially and culturally related representations: *"What you see when you see a thing* *depends upon what the thing you see is. But what you see the thing as depends upon what you know about what you are seeing."* The ecological approach has little to say about 'seeing as' and is better at explaining 'seeing'. It is, however, understood that: *"Most human activity takes place within a culturally defined environment... people see objects and events as what they are in terms of a culturally given conceptual representation of the world."*

A very important fact which is particularly relevant for perception within VEs, is that a VE is a highly unnatural, artificial kind of environment. Gordon (1989, p.238) suggests that we cannot expect one single theory to explain perception in the natural and in an artificial environment. There may be one set of mechanisms, described by one set of laws, which will ensure that a function of the human perceptual system is achieved under some specific circumstances; but there can be no such inbuilt mechanism to allow us to perform artificial tasks such as flying an aeroplane, or navigating by 'finger-flying' in VEs. This is something which we should learn to do. Such tasks as navigating or interacting with VEs undoubtedly involve learning. Perception under such conditions is learned, interpretative and constructive, and this may be true of perception when the situation is in any way artificial or unnatural. A VE is a display which represents real life scenes and phenomena, but may also retain a symbolic character as a display. A subject who interacts with the VE extracts meaning from this symbolic display. Meaning clearly implies knowledge, and consequently learning has to be involved. One could not possibly perceive the meaning of a word or of any other symbolic object without learning. It is clear, therefore, that navigation or interaction in VEs involves learning, and inferrential processes for extracting meaning, essential for the perception of VEs.

It is concluded therefore, that this thesis will not wholly adopt either the constructivist or the ecological approach, in terms of the debatable issues mentioned above. It is understood that the ecological approach provides a better context for considering time-based phenomena like actions and events in the real world or in VEs and applies to real behaviour in real situations. As such the ecological approach is considered more relevant to issues of designing space within the context of a real or virtual environment. However, this approach does not consider any kind of representation - schemata, mental maps or components of existential space - as playing a role in the perception of an environment and as such is in contrast with most of the literature reviewed in this chapter.

The constructivist approach, on the other hand is relevant for artificial environments, like VEs. This is due to the fact that perception in VEs involves learning, and inferrential processes for extracting meaning. It is understood that this thesis mainly focuses on the way that spatial information is stored and recalled rather than the specific process of vision and the extraction of information from a perceived image. In this sense, the issue of the debate as to whether a mental image exists or not should not be taken in to account in the investigation of this thesis. Moreover, the need for studying the processes involved in the acquisition and retrieval of spatial knowledge from the environment implies the adoption of an information-processing approach, which is in accordance with constructivist theories.

It is, therefore, assumed that

- both the constructivist and ecological approaches are empirical
- there is some common ground between the two approaches, as was earlier suggested
- both approaches are relevant as a background for the analysis of spatial knowing, followed in this thesis.

4.2 Environmental perception

Before investigating the processes involved in the acquisition and retrieval of spatial information for a navigating subject, it is useful to set the context for this investigation by defining the terms:

- environmental perception
- environmental cognition
- spatial orientation and wayfinding

and by clarifying how these areas of environmental analysis relate to each other. By setting this context, the thesis aims at understanding the processes involved in perceiving, remembering and recalling aspects of environments, as seen from an empirical perspective.

Perceptual psychology, in general, investigates the perception of artificial stimuli, which can be controlled in a laboratory situation. On the other hand, environmental psychology deals with subjects in real-world settings, which in contrast with artificial stimuli, occur in some spatial and temporal context which surrounds the observer and where this observer interacts with the space in a dynamic way. (Ittelson, 1973). The general goal of environmental psychology is to explain behaviour in relation to the physical and social environment (Garling et al., 1984, p.26).

Traditional studies of spatial perception before 1970 had mainly dealt with the perception of objects in space, distance, orientation and movement. After 1970, the newly introduced discipline of environmental psychology dealt with subjects perceiving in the context of environments, which were assumed (Ittelson,1973, pp.12-13) to be necessarily larger than the subject which they surround: *"large enough to permit, and indeed require, movement in order to encounter all aspects of the situation "*. An object is usually observed by a subject but an environment has to be explored by somebody who is not merely a subject but a participant. Ittelson (1973, pp.12,18) also puts forward the transactional view that *"Perceiving is relevant and appropriate to the environmental context in which it occurs.... Man and his environment are never encountered independently...Rather than defining a situation in terms of its components (subject and environment), the components can be defined only in terms of the situation in which they are encountered. The environment is thus seen as a total, active, continuous process, involving the participation of all aspects."* The fact that it is impossible to dissociate the perceiving subject from the environment that is being perceived has also been identified by the phenomenological studies presented in (2.5).

In the context of environmental perception, Ittelson (1973, p.13-14) has identified the following properties of environments:

- The quality of surrounding, which forces an observer to become a participant;
- The quality of a multiplicity of sensory modes;
- The necessary existence of peripheral - outside the focus of attention - background information along with the central information perceived,
- The fact that environments always provide more information than can possibly be processed by a participant;
- Environmental perception always involves action; environments are never passively perceived. They define the potentiality for actions, they demand qualities which call forth certain kinds of actions and they offer different opportunities for the control and manipulation of the environment itself.
- Finally, environments have a certain individual atmosphere or ambience which is determined by social, aesthetic and systemic qualities.

4.2.1 Environmental perception, cognition and action

According to Ittelson (1978, as quoted in Bell et al., 1996, p.66), environmental perception comprises:

- cognitive,
- affective - emotional -
- interpretive and
- evaluative components,

which operate at the same time across several sensory modalities. This thesis will mainly concentrate on the cognitive component of environmental perception, which is the subject of study for the discipline of environmental cognition. However, it has to be clarified that perception and cognition cannot be considered as two separate systems which can be isolated in order to be studied. (Ittelson, 1973, p.10) Perceptual and cognitive processes are inextricably woven within the function of perceiving: *"perceiving is inseparably linked to, and indeed indistinguishable from, other aspects of psychological functioning (like memory)"* (Ittelson, 1973, p.12).

Environmental cognition - or environmental knowing - is the study of the subjective awareness, information, images, impressions and beliefs that individuals and groups have about the elemental, structural, functional and symbolic aspects of real and imagined physical, social, cultural, economic and political environments, the ways that these conceptions arise from experience, and the ways in which they affect subsequent behavior with respect to the environments. (Moore & Golledge, 1976, pp.3-5) A less generalised definition which is particularly relevant for this thesis is put forward by Garling and Evans (1991, p.4): *"Environmental cognition encompasses the cognitive processes involved in the acquisition and representation of predominantly spatial information in real-world settings."*

Most researchers in this field, who understand environmental perception as a process based on information processing, agree that our existence in the environment implies our involvement in a continuous, constructive and cyclic perceptual process. This process was explained by Neisser (1976, p.20) in (3.1). Bell et al. (1996, p.67) have also described the perceptual cycle: *"we bring expectations, experiences, values and goals to an environment; it provides us with information and we perceive it through activity."*

Passini (1992, pp.59-60,90) argues that the information acquired about the environment by a subject involved in the perceptual cycle, may be obtained from various sources:

- From sensory input related to the environment; a distinction between the various types of sensory information has been made by Passini (1992), McDonald and Pelegrino (1993) and Downs and Stea (1973, p.23). They identify two kinds of spatial learning:

- Primary spatial learning, which involves direct input of information experienced through moving within the environment from the architectural and spatial characteristics of a setting;
- Secondary spatial learning, which comes from vicarious information sources: various types of environmental descriptions through the use of certain media like information booths, signs, maps, graphic representations or through linguistic communication - spoken or written.

- From a person's memory and knowledge of the setting, of other similar settings or of past experience in general.
- Information might further be obtained by inference through any combination of sensory and memory information.

The cycle of environmental perception involves the following important psychological processes (Evans and Garling, 1991, p.6):

- environmental cognition,
- environmental assessment
- decision making and
- action.

Although each individual process has been the subject of extensive research in the last 25 years, the integration of the four components is still a relatively unresearched issue. (Evans and Garling, 1991, pp.6-9)

According to this widely accepted model, Evans and Garling (1991, p.5) assume that an individual receives information from the external environment which in turn results in a psychological response; on the basis of this response, some output, termed 'action', occurs. Certain goals, motives and attitudes towards action alternatives also influence this action. Before acting, an individual will perceive and form preferences for different action alternatives. The representation of the environment as well as individual choices and their implementation are influenced by other cognitive factors, such as previous experience, perceptual and representational abilities, hierarchically organised goals and decision rules. Actions may be seen as the implementations of decisions taken by the individual. (Evans and Garling, 1991, pp.5-6) However, actions or potential actions are also critical components in deciding what environmental knowledge is accumulated and how it is used. (Golledge et al., 1985, p.150)

Additionally, Bell et al. (1996, p.67) suggest that the purpose of actions, involved in the perceptual cycle, is the acquisition of information for the purpose of:

- Orienting ourselves in this environment by means of simple exploration;
- Finding strategies for using the environment to meet needs and goals;
- Establishing confidence and feelings of security within the environment.

Through action therefore, we perceive environmental information - sensory, memory, inferential - which is essential for plan and decision making preceding our actions.

4.2.2 Levels of environmental analysis

People's responses to the environment, according to Ittelson (1973, p.16-17), can be analysed at five different interrelated levels:

1) Affect: the direct emotional impact of a situation generally determines the direction of subsequent relations with the environment.
2) Orientation: the identification of escape routes and, in general, the location of positive and negative features - or affordances according to Gibson's definition (1986, p.36) - in an environment results in an initial mapping of the situation which facilitates more detailed exploration of this environment.
3) Categorisation: the process of developing concepts and conceptual categories for analysis and understanding of the environment, as a result of events which have been experienced.
4) Systemisation: the systematic analysis of relationships within the environment, which involves:

- the identification of predictable sequences of events and their separation from random or unique occurances
- the postulation and verification of causal connections
- gradually bringing into order a complex set of interrelationships which characterises the environment.

5) Manipulation: which involves the activity of the subject within the situation. In specific, the subject learns the potentiality for intervention and of their consequences as changes in the environment and in relation to his own needs and purposes.

Although it is not possible to isolate and individually study environmental knowledge at each of these five levels, this thesis will focus on the cognitive component of environmental perception at an orientation and categorisation level. This chapter, in particular, will attempt to study and categorise the spatial knowledge that humans acquire from their environment as a result of their efforts for orientating within this environment.

4.3 Spatial orientation and wayfinding

Considering the kind of activity that subjects are involved in when inside an RE or a VE, it is suggested that they are likely to be involved in the following two situations:

- navigating or in other words moving - dynamic activity - within the environment with the intention of going somewhere or for exploring an unknown area;
- being relatively static - static activity - at or around a fixed position within this environment and doing something there.

It is understood that subjects may be alternatively shifting from one situation to the other while involved in a particular task within an environment, but it is assumed that at any one time they are either in the one or in the other situation.

As was explained in (1.3), however, this thesis focuses on the design of space in VEs, with the intention of aiding navigation and wayfinding behaviour. Accordingly most of the literature presented in this chapter deals with spatial knowledge which has been developed by subjects, as a result of their navigation within an environment. In this sense, Bell et al. (1996, p.79) propose an informal model for spatial cognition which emphasises, as a primary goal of this human activity, the movement of the human from one position to another. In this context, they define 'wayfinding' as the adaptive function that allows us to move through an environment efficiently and locate valuable items or meeting places in there. During wayfinding, we continuously have to decide where to go next and how to get there or plan for other future actions. These plans and decisions are made with the help of environmental information, the several types of which have been analysed in (4.2.1). The environmental information available to a person is the most important variable in determining a wayfinding solution and in this sense, the provision of adequate environmental information is a crucial design issue. All types of directly or indirectly perceived information may be seen as information support systems to wayfinding. (Passini, 1992, pp.76, 82)

It is, however, necessary to define 'orientation' in this context. Passini (1992, pp.27-28) argues that a subject has a 'sense of orientation' within an environment when he is able to maintain a direction while moving, or to point to a direction, independently of his location in space and independently of cues originating from the environment. Passini (1992, p.35) does not differentiate between the cognitive processes of 'wayfinding' and 'spatial orientation' which he both defines as *"a person's ability to mentally determine his position within a representation of the environment made possible by cognitive maps."* In agreement with the cyclic process of environmental perception - explained in (4.2.1) - Passini (1992, p.46) also suggests that wayfinding comprises three distinct abilities:

- a 'cognitive mapping' or information-generating ability that allows us to understand the world around us,
- a 'decision-making' ability that allows us to plan actions and to structure them into an overall plan,

- and a 'decision-executing' ability that transforms decisions into behavioural actions.

Both decision making and decision execution are based on information generated by cognitive mapping. It is this cognitive process that allows us to distinctly know our 'place' within the environment, and the relationships between all of the objects that the environment hold. At this stage, it is necessary to explain the concept of cognitive maps and the process of their generation.

4.4 Cognitive maps

The term 'cognitive map' was coined by Tolman (1973) and could be defined as *"a semantic long-term memory representation of the properties of and the components in an environment that has been acquired through repeated encounters with the environment."* (Garling et al. (1984, p.25) Burnette (1974, p.170) has suggested that the 'cognitive map' is our mental image of the environment which we 'anticipate' for our actions and as such, is a necessary part of our ability to plan behaviour. This cognitive representation is a hypothetical construct which describes a person's knowledge or thought with reference to a segment of the external world. (Golledge et al, 1985, p.126)

Downs and Stea (1973, pp.9-10) suggest that *"human spatial behaviour is dependent on the individual's cognitive map of the spatial environment"*. They call the process of acquisition, amalgamation and storage of information, available in the environment, 'cognitive mapping' and the product of this process at any point in time, 'cognitive map'. *"Given a cognitive map, the individual can formulate the basis for a strategy of environmental behaviour...Cognitive mapping is a basic component in human adaptation...it is a coping mechanism through which the individual answers two basic questions quickly and efficiently:*

- *Where certain valued things are;*
- *How to get to where they are from where he is."*

It has to be clarified though that cognitive maps are not literally like maps. They are cognitive representations that function like cartographic maps but do not necessarily have the physical properties of these maps. (Downs and Stea, 1973, p.11) In fact, Garling et al (1985, p.150) assume that the only similarity between a cognitive map and a real map is the integration of metric spatial relations between components, in terms of distance and direction. However, Evans et al. (1981, as quoted in Bell et al., 1996, p.93) argue that cognitive maps become more similar to cartographic maps as an environment becomes more familiar.

It may not be possible to accurately describe cognitive maps, but it still is important to understand the character of these spatial representations. Evans and Garling (1991, p.4) argue that cognitive maps are 'schematic representations' for familiar environments, which include information about important features of these environments. The importance of schemata as structures which organise our spatial knowledge has also been stressed in (3.1).

In the same vein, Neisser (1976, pp.123-124) defines cognitive maps as a synonym of ‘orienting schemata’, that is as active, cognitive, information-seeking structures, which accept information and direct action and exploration. He also suggests that cognitive maps and perceptual schemata are related in two different ways that can both be illustrated in Lynch's (1960) analysis:

- a cognitive map is essentially a perceptual schema, though on a larger scale;
- a cognitive map contains embedded perceptual schemata of environmental elements like landmarks and edges; these elements are real entities in a real city and their corresponding schemata, apart from being components of the map, direct perception and pickup information in their own right.

Since cognitive maps are related to schemata, it may be suggested that the concepts of

- Tolman's (1973) 'cognitive map',

- Lynch's (1960) 'environmental image' and
- Schulz's (1971) 'existential space',

are also closely related: they all refer to cognitive structures of spatial information comprising perceptual schemata, which are being used for interpreting incoming perceptual information and for guiding action. Indeed, Norberg-Schulz (1971, p.33) described his concept of existential space as a simultaneous totality, where the levels interact to form a complex, 'dynamic field', which is neither continuous nor uniform. This concept of a 'dynamic field' is similar to that of the cognitive map. Parts of the field are experienced through perception, but the general image exists independently of the individual situation. The degree of our acquaintance with an area of any level is determined by the elements and sub-elements known. In general, existential space consists of several overlapping and interpenetrating such systems, which interact with each other. According to Norberg-Schulz, it may then be suggested that a subject's existential space consists of several overlapping and interpenetrating cognitive maps of segments of his environment.

In an effort to describe the components of cognitive maps, Bell et al. (1996, p.106-107) argue they consist of

- places,
- the spatial relations between places and
- action plans.

It is important to mention the concept of 'travel plans', as significant integrated parts of action plans, with respect to navigational decision-making. Action plans and in specific, travel plans are useful in bridging the gap between the mental representation of the environment and the intentional behaviors of people in this environment. (Bell et al., 1996, p.79, 107). Moreover, Garling et al. (1984) stress that:

- the process of spatial knowledge acquisition for cognitive maps is connected with the formation of travel plans at the early stages of this acquisition and that
- at the later stages of spatial knowledge acquisition, the execution of the earlier travel plans determines the conditions for the acquisition of spatial knowledge.

It is, however, necessary to investigate the nature of cognitive maps as mental representations in more detail.

4.5 Nature and characteristics of cognitive maps

The exact form and nature of cognitive maps, as mental representation of spatial knowledge in human memory, is a controversial issue. Although this issue is more often discussed in the context of the nature of mental images and not cognitive maps, it will briefly be addressed in this sub-section as it is thought to provide a better understanding of the way that we think of and remember space in general.

There are two major approaches on this issue (Bell et al.,1996, p.96 and Smyth et al. 1994, pp.314-315):

- The analogical view suggests that the objects and events in our mental image of the environment map directly onto an analogous representation of the real environment; images are like percepts and not like pictures in that they are interpreted knowledge involving a great deal of processing and therefore they become coherent and organised in memory.
- The propositional view argues that all knowledge as a product of perceptual processing - whether it is the result of visual or verbal information - is represented in a non-specific and abstract manner, where the meaning of the scene or the map is described. In such representational systems, knowledge is represented as a set of symbols arranged to constitute statements of facts or rules. (Cohen, 1993, p.47) In other words, this abstract representation of the environment consists of *"a number of concepts or ideas, each of which is connected to other concepts by testable associations such as colour, name, sounds and height. When we call on this propositional map, we search our memory for various associations and these are reconstructed and represented as a mental image or as a sketch we draw."* (Bell et al, 1996, p.96)

Current thinking (Kosslyn, 1980) combines the two approaches and argues that cognitive maps comprise both analogical and propositional elements. Long-term knowledge of the environment may be stored in memory as a network of propositions and analogical information, which is used for quickly constructing an analogical image for solving a particular problem.

Finally, a third kind of memory representation is involved in the acquisition of spatial knowledge (Cohen, 1993, p.47). Procedural representations encode knowledge about how to perform actions and this knowledge is stored in the form of procedures; such knowledge is necessary at the stage when planned actions are executed and will be specifically related in (4.8.2) to the acquisition of route knowledge.

Hirtle and Jonides (1985, p.208-9), however, argue that cognitive maps generally consist of spatial and non-spatial information and that an adequate model for this mental representation of physical space could not be built around a strict Euclidean conception. On the basis of experimental evidence, they suggest that along with spatial knowledge, cognitive maps also include non-spatial information that is used to built a hierarchical, multilevel structure, which corresponds to spaces with no predefined hierarchies. Evidence of hierarchical structure in cognitive maps is also presented in McNamara et al. (1989). This structure includes (Hirtle and Jonides, 1985, p.210) hierarchies, reference points, distance knowledge and semantic information about landmarks in space. Similarly, Garling et al. (1984) have argued that the mental representation of environments must integrate:

- spatial information - location, orientation, distance, density - and
- non-spatial information - semantic labeling, affective qualities, cluster membership.

The issue of perceived distance between locations, as an element of cognitive maps, has also been the subject of extensive research. (Sadalla and Magel, 1980, Sadalla and Staplin, 1980, Thorndyke, 1981) These researchers assume a model (Thorndyke, 1981, p.543 and Kosslyn, 1983, pp.125-127) according to which we scan our mental representations in order to make judgements like distance estimations about the represented environment. According to this model, Bell et al. (1996, p.97) suggest that the more information we must scan in our memory while making a mental simulation of our journey along a route in a cognitive map, the further the distance we assume that has been traversed.

Finally, the main characteristics of cognitive maps are summarised by Downs and Stea (1973, p.18) as:

- Incompleteness and discontinuity, since certain parts of environments may be selectively omitted, according to their meaning and significance for the individual;
- Distortion, as both distance and direction may be mentally transformed by an individual;
- Schematisation, since cognitive maps are products of a schematisation process as stressed in (4.4);
- Augmentation, (Bell et al., 1996, p.89) when nonexistent features are added to a representation.

4.6 The acquisition of spatial knowledge

At this stage, it is important to identify which aspects of environmental knowing should be investigated further for informing the objectives of this thesis. Carr (1970, p.526) argues that the basic characteristic of urban settings is that they have a 'form' - an ordered internal arrangement in time and space - which persists independently of particular actors and which tends to determine human actions within these settings. Environmental form (Carr, 1970, p.525) facilitates the individual in planning for actions within such settings by making it less necessary to specify a plan in detail. It is when we carry out our plans in real environmental situations that environmental form provides support for certain actions and constraints others. However, human action also heavily depends on how people perceive these supports and constraints.

When we navigate and try to find our way within an unknown environment, we cannot rely on a cognitive map since the acquisition of this map requires previous experience in the environment. Our actions within such an environment depend on:

- how environmental form may facilitate our wayfinding and navigation and
- on our expectations which influence how we 'read' the environment as we actively view it; these expectations are a result of our own memory and experience of previously visited environments. (Devlin, 1976) Accordingly we infer a structure on the environment which may facilitate navigation.

If it is assumed that our perception of environmental form is influenced by our past experiences of remembered environments, then it is suggested that the way that environmental information is acquired and structured in our memory of environments - cognitive maps - is relevant to the way that we try to 'read' a newly experienced environment. Most conceptual models of environmental knowledge and structures are associated with the processes of acquisition, representation and accessing of such knowledge. In this sense, the components of acquired, represented or accessed spatial knowledge may correspond to the elements that the environment comprises, as we conceptualise and remember it. It may then be suggested that the nature and structure of these components can inform us of how could the corresponding constituent elements of environments be individually designed and structured so that environments become more legible. Additionally, the way that environmental form is designed has a direct effect on the quality of the cognitive map that an individual will generate for a particular environment. In this sense, by appropriately designing and structuring the elements of an environment we may support the generation of cognitive maps for future wayfinding.

Therefore, irrespective of whether we refer to an unknown or a previously experienced environment, it is important to understand how environmental knowledge is acquired and which are its components. Such an understanding will

- lead to a hypothesis about the environmental elements that we 'read' as we navigate within a newly experienced environment and the structure of these elements that we may anticipate and will consequently
- inform us of how to design environmental form in order to facilitate the generation of cognitive maps.

As was argued in (4.3), subjects within a RE or a VE are likely to be involved in the following two situations:

- either navigating within the environment or
- being at or around a fixed position within this environment and doing something there.

It is also understood that subjects may be alternatively shifting from one situation to the other. It is suggested that according to the situation that a subject finds himself in, he may view the same environment from a different perspective and therefore identify different elements within this environment. In this sense, the components of spatial knowledge will be investigated in this chapter, from the perspective of

- A navigating and wayfinding subject
- A subject who is involved in a static activity.

4.7 Scale and frame of reference in an environment

For the purpose of understanding the way that humans view their environment for acquiring environmental knowledge, it is relevant to explain the concept of a 'frame of reference'. Acredolo (1976, p.165) defines as frame of reference: *"a system or strategy that underlies and to some extent controls what an individual uses to code location within the environment"*; i.e.: a subject visiting an unfamiliar city may adopt the cardinal directions as a frame of reference whereas another subject may rely on more concrete features like street names and salient landmarks, instead of the more abstract coordinate axes.

Piaget and Inhelder (1956) were the first to describe three different stages in the development of spatial cognition, which correspond to Piaget's theory of the general stages of cognitive development. (Golledge et al., 1985, p.129-130) According to this research work, there is a general progression from

- an egocentric, topological to
- a projective and finally to
- a more abstract, metric, Euclidean kind of knowledge.

Moore (1976, pp.150-151) describes these three stages as developmental levels of the spatial reference systems which determine our understanding of space:

- undifferentiated egocentric reference system
- differentiated and partially coordinated into subgroups based on fixed references
- operationally coordinated and hierarchically integrated.

It may then be argued that the situation that a subject finds himself in, while viewing the environment, may also imply the use of a different frame of reference according to which this environment is perceived:

- when being in a fixed position he may be in an egocentric - local - frame of reference
- when navigating in order to explore or move to a position he may be in an environmental - local - frame of reference
- when considering his position within a global context - or frame of reference - he is in neither of the above mentioned situations in that he is not acting but thinking about the environment.

However, Kuipers (1982, as quoted in Garling et al., 1985, p.151) has argued that the systems of reference in a cognitive map are mainly local/environmental rather than global, as in the case of a map; in this sense, he criticises the map metaphor, which has been used for describing a cognitive map. Additionally, it has to be mentioned that these three frames of reference correspond to the three stages of the development of spatial knowledge, according to Piaget and Inhelder (1956) and Burnette (1974).

It is suggested that these systems of reference are necessary for 'keying' the cognitive map to the environment. Garling et al.(1985, p.152) argue that

- infants remember directions relative to the body axes while
- for adults, it is more plausible to assume that they remember systems of reference as part of the perceptual characteristics of the spaces they have experienced.

Finally, it is assumed that the way that a subject relates to his environment also depends on the scale of this environment. This thesis deals with what Garling et al. (1985, pp.158-159) have named large and medium-scale environments, which completely surround the person and thereby encompass the 'world behind the head' as well as those parts that are located before one's eyes at any particular moment. If the fact that several obstacles may obstruct the view is taken into account, it may be suggested that these environments cannot be perceived in their entirety from any single vantage point. Therefore, the acquisition of spatial knowledge in such environments, by direct observation, requires the integration of successive perceptions involving movements of the eyes, the head and the body, across long time spans.

In general, a large or medium-scale environment could be defined as an environment that cannot be perceived at once; the size of this environment, however, is less crucial. In such an environment the predominant frame of reference for an adult would be an environmental/local frame.

4.8 The components of spatial knowledge for a navigating subject

As was suggested in (4.6), the issues of spatial knowledge acquisition and of the components of this knowledge need to be investigated. The first study that has identified these components, from the perspective of a subject who navigates in an urban environment, was the work of Lynch (1960). According to this work, which was presented in (3.4), the environmental image consists of paths, edges, districts, nodes and landmarks. More recent research on the same issue is generally in agreement with Lynch's concepts but has concentrated on more generic components of a cognitive map and on the process of acquiring spatial knowledge.

The acquisition of spatial knowledge is primarily based upon direct environmental experience (Gale et al., 1990, p. 3) - or primary/direct environmental information as described in (4.2.1). Such experience usually comes from actively moving, as opposed to being passively transported through the environment. This experience is continuously evaluated and errors about locations are corrected, through the use of feedback from spatial behaviour (Downs and Stea, 1973, p.23).

Both developmental - Piaget and Inhelder in (4.7) - and learning theories of spatial knowledge emphasise the increasing complexity of an individual's knowledge of the environment. Golledge et al. (1985, p.129) also argue that the spatial knowledge acquisition of an adult, at a microgenetic level, mirrors the general developmental sequence observed for children, at an ontogenetic level. (Moore, 1976, p.146) This argument is in agreement with Burnette's (1974, p.179-182) model of the mental imagery of man-environment relations.

A point of view which is accepted by many of the scientists in this field (Siegel & White, 1975, Golledge et al., 1985, Gale et al, 1990 McDonald and Pelegrino,1993) suggests that spatial knowledge comprises three indistinguishable components, all of which form the three consecutive stages in the knowledge acquisition process:

- 'landmark knowledge',
- 'route knowledge' ,
- 'configurational' or 'survey knowledge' of the environment.

The acquisition of spatial knowledge which progresses through these three stages is described by Golledge et al. (1985, p.130): *"After landmarks become known, paths and routes are established between landmarks. Spatial knowledge along routes passes from topological properties to metric (abstract) properties. Landmark and path sets are* *organised into clusters where there is a high level of coordination within cluster but only topological information about cluster relations. Finally, an overall coordinated frame of reference develops such that Euclidean properties are available within and across clusters. This is often referred to as survey knowledge."*

The role of travel and route navigation is considered (Gale et al., 1990, p.4) fundamental in the process of the development and acquisition of spatial knowledge. In fact, route knowledge is the key for integrating the other two spatial knowledge components as it lies in an intermediary position between landmark and survey knowledge (Allen, 1985, as quoted in Gale, 1990, p.4). Siegel and White (1975) have also argued that routes are most important elements within a cognitive map.

The three stages of spatial knowledge acquisition will be discussed in detail in the rest of this section. These elements are assumed to correspond to three of the main elements of space - landmark, path, domain - as these were defined in the previous chapter.

4.8.1 Landmark knowledge

When we are exposed to an environment, firstly, we acquire declarative or 'landmark knowledge' by recognising the objects which are predominant, within the context of the environment as seen from a subjective, egocentric perspective. Siegel and White (1975), McDonald and Pellegrino (1993) and Golledge (1991, p.44) have also suggested that the first and simplest stage in the process of spatial knowledge acquisition involves the recognition of landmarks. As Gale et al (1990, p.4) argue, landmark knowledge *"includes the ability to state with certainty that an object or place exists and the ability to recognise it when it is within the perceptual field"*. At this stage, we have only acknowledged certain objects, persons, things, events or generally 'cues' of a specific location, which we refer to as landmarks, but we have not taken into account their surrounding context.

A definition has been suggested by Lynch (1960, p.48) - as mentioned in (3.4.2.5) - according to which 'landmarks' are point-references within the urban environment, the use of which involves the singling out of one element from a host of alternate possibilities. Similarly, Gale et al (1990, p.3) define landmarks as points or zero-dimensional elements of spatial knowledge. The elements of a landmark or declarative knowledge structure (Golledge, 1991, p.45) are characterised by identity, location, magnitude and temporal existence.

Siegel and White (1975) who considered landmark knowledge as a necessary condition for wayfinding to occur, have described landmarks as the strategic foci to and from which a subject travels. Indeed, landmark knowledge should not necessarily be seen as only involving significant objects which cannot be entered - as defined by Lynch (1960) - but could also be involving places or nodes, according to the situation that the perceiving subject finds himself in:

- If the subject navigates through the environment he may perceive the element as a node, which may be further signified by a salient object;
- If the subject is relatively static and located within the vicinity of a landmark, he may perceive the spatial element as a place, defined by boundaries, within which he may perform a particular activity.

In the context of the overall cognitive map, he may still consider this place/node as a landmark. Similarly, Gale et al (1990, p.3) relate landmarks with other non-directional spatial elements like nodes and places.

In the same vein, Sadalla et al.(1980, p.517) propose the relevant concept of 'reference points' - in the context of large-scale environments - as those places whose locations are relatively better known and which serve to define the location of adjacent non-reference points. They argue that the cognitive location of many points in space is either stored or retrieved in relation to these smaller set of reference points; however, reference points should not be considered as synonymous to landmarks but rather as a subset of landmarks.

The concept of a 'landmark' has multiple referents: (Sadalla et al., 1980, p.516)

- Discriminable features of a route which signal navigational decisions;
- Discriminable features of a region - domain - which allow the subject to maintain a general geographical orientation (Appleyard, 1969);
- Salient information in a memory task.

Those different referents that the landmark concept may denote, suggest that landmarks may play a role in a variety of spatial abilities.

Salient features like landmarks and other important characteristics of the setting - like specific turns of routes - are very significant for the acquisition of spatial knowledge. Heft (1979, pp.172-4) suggests that in a relatively undifferentiated setting - which lacks environmental features - as is the case with most laboratory situations and may often be the case in VEs as well, subjects tend to rely on geographical orientation for wayfinding. On the other hand, in differentiated settings, subjects will tend to utilise environmental features for wayfinding. These feature may *"serve as guideposts for navigational decisions involving changing and maintaining course direction. In a differentiated environment which is rich in potential landmarks, alternative route-learning strategies involving the use of distinctive landscape features at navigation choice-points are available for consideration."* The results of this study (Heft,1979, p.184) supported the view that subjects rely on characteristics of the environment when learning a route through an unfamiliar environment. These subjects utilised prominent objects as landmarks and also attended to other salient characteristics of the setting, like topography of the area or the characteristics of a path. In particular, this study concluded that:

- when prominent environmental features are available at choice points, subjects will utilise them in learning the necessary navigational decisions.
- If such features are not available, but still the environment is differentiated, then subjects will utilise other natural characteristics.

- If the environment is not differentiated then subjects will may resort to learning particular navigational choices; memory of particular turns was among the most frequent strategies used in this study.

In agreement with the criteria that Lynch (1960) had suggested for contributing to an object or building being characterised as a landmark, Appleyard (1969, pp.131-159) has provided evidence that the following features of landmarks may contribute to their overall significance within the context of the environment:

- Form: If an object has prominent physical features - sharp contours, bright surfaces - or definite size disparities between itself and the environment then it more easily influences memory.
- Function and Association: If an object has high usage or performs a symbolic function - it evokes meaning such as a church, town hall etc. would from the built environment - it may signify a landmark.
- Location: If the object is located at an intersection of paths then we may be able ot locate it easier within the context. Smyth et al. (1994, p.312) elaborated on this by concluding that landmarks become positioned in space when they are crossed by many routes, therefore becoming a major part of the organisational framework for the map of the environment.

Devlin (1976, p.66), however, suggests that function is a significant parameter which may influence the way that people identify with objects or places as landmarks. In the cases of:

- an environment with a lack of prominent objects, which stand out as clear landmarks or
- when people move frequently and are not expected to stay long enough near an object so as to identify it by virtue of its form,

functionality may become a more important parameter according to which individuals will associate with an object and identify it as a landmark.

4.8.2 Route knowledge

Before investigating the second stage in the process of spatial knowledge acquisition, it is useful to understand the concepts of 'movement' and 'route' within an environment. Human spatial movement is defined by Golledge (1991, p.47) as the deliberate process of changing location over time for some particular purpose, which is often associated with solving a problem. Such movement involves traversing of distances and change of directions, for the purpose of successfully travelling between origins and destinations. This process, which involves the utilisation of procedural knowledge - defined in (4.5) - is referred to as a 'route'. The physical expression of any *route* is a *path*. Gale et al. (1990, p.3) stress the one-dimensional character of paths and routes as components of spatial knowledge. Knowledge about routes is particularly significant as a part of the representation of an urban environment: *"paths have a vital role; there is nothing one could call a cognitive map without the path type element"* (Devlin, 1976, p.66)

After acquiring landmark knowledge, we begin to think of the routes which connect the originally identified landmarks. 'Route knowledge' is characterised by the knowledge of sequential locations - landmarks - without the knowledge of general interrelationships (Hirtle & Hudson, 1991, p.336). Evans et al. (1981), Garling et al. (1982, as quoted in Garling et al., 1985, p.159) and Golledge (1987, p.141) support the hypothesis that landmark knowledge is acquired before route knowledge. In fact, Golledge suggests that *"when paths or systems of paths have been learned, the location of landmarks can be recalled more exactly because the paths reduce the number of possible locations that a given landmark could potentially occupy. This seems to be consistent with the idea that landmarks function as anchor points in spatial representations of the environment"* as it has been suggested by Couclelis et al. (1987)

Route knowledge (Golledge, 1991, p.47) *"requires:*

- *an ability to order or sequence information about location cues and distance segments connecting these cues,*

- *an ability to evaluate the temporal dimension of navigation,*
- *an ability to determine direction with respect to previous and consequent route segments and to a general frame of reference and*
- *an ability to estimate the nature and severity of barriers that might occur along a given route."*

Procedural knowledge, therefore, builds on a declarative knowledge base[8] and adds to this base new and more complex abilities for linking information and translating such information into movement.

Golledge et al. (1985, p.144, 149) suggest that knowledge of a route is focused on key loci, representing points where choices are made. The organisation and acquisition of information, with respect to such 'choice points' along a route which is being navigated, leads to a natural segmentation of the route. These individual route segments become concatenated and increasingly differentiated and, with repeated exposure to the task involving navigation, they eventually form a complete representation of the whole route. Golledge et al. also provide evidence by sketch maps which shows that:

- at first, well identified route segments are formed in the vicinity of primary nodes, with incomplete segments in the rest of the structure;
- at the end, all segments of the route are complete, cues and features at specific points are included and distance and directional accuracy are high.

Like declarative knowledge, procedural knowledge appears to be hierarchically organised both with respect to choice points and the segments that these points anchor (Golledge, 1991, p.47). Golledge et al. (1985, p.149) quote studies by Doherty (1984) and Shute (1984) which support these hypotheses. With reference to children who are residents in a neighborhood, these studies argue that choice points are differentiated among known locations in the overall knowledge of an environment by constituting major nodes of this structure. Differentiation among locations depends on the degree of

[8] A clear distinction between these two types of knowledge has been made in Gale et al.(1990, p.20).

exposure to the environment. Locations that are more familiar to individuals are recognised faster and more accurately with more detailed information stored in memory. On the other hand, Golledge et al.(1985, p.149) argues that the amount and variety of information recalled about route segments depends on the type of object anchoring the segment.

It is important to mention that the level of user interaction with the environment is fundamental for the acquisition of route knowledge. Gale et al. (1990, p.21) have argued that active engagement in navigation enhances the proceduralisation of route knowledge, considerably more than passive viewing - slide projection or video viewing - does. Learning 'about' may come by seeing, but apparently learning 'how to' comes only by knowing. When an important event happens during navigation, our nervous system captures both what it sees and what it is doing; thus we associate places with actions, kinesthetic feedback and with all other sensory input, in order to produce the knowledge necessary for informing navigation. Bell et al.(1996, p.95) also agree that spatial learning based on actual navigation in the environment may be more difficult to obtain, but benefits from the advantages of the ecological context and perhaps more accurate representation of travel distances for each journey.

When we acquire route knowledge, more information is coded at 'intersections' of paths, which may function as choice points, as opposed to between intersections. Gale et al. (1990, p.20-22) suggest that the combination of actual or potential navigation choices, coupled with the greater complexity and richness of the scenes, make intersections the foci of route knowledge. In addition, the novelty of having fresh visual stimulus where new views are first seen may contribute significantly on focusing attention and encoding information. Indeed, in their experiment (Gale et al., 1990), scenes at intersections were selected and stored with the highest frequency. This fact is attributed (Gale et al., 1990, p.21) to the specific goal of the task that was given to the subjects of this experiment. In order to accomplish the requirement of reaching a particular location via a prescribed route, each subject had to remember the essential choice points at which a change in direction had to take place and which action to take at each of these points. It may, therefore, be suggested that subjects remember what they need to remember and functionality may determine the way that spatial knowledge is remembered. Devlin (1976) has emphasised the significance of functionality for the acquisition of landmark knowledge - as explained in (4.8.2).

The results of a study by Golledge et al.(1985) which dealt with the significance of landmarks and scenes, located on routes that had to be navigated and learned, are in agreement with the above. Both landmarks and scenes which were anchored at points where decision had to be made, were significantly better recognised and recalled than those landmarks and scenes which were not important for the decision-making process of the navigation task. Therefore, it can be argued that nodes or intersections of routes are particularly significant because they are the main decision points in an real environment or a VE. Additionally, important implications for the design of REs and VEs has the fact that landmarks are identified as such in an environment when they are placed at an intersection of routes - as was explained in (4.8.1).

It is also important to identify the parts that knowledge of a route comprises. As an answer to this issue, Golledge (1991, p.48) and Gale et al. (1990, p.4) suggest that route knowledge is a series of procedural descriptions involving a sequential record of:

- the starting point or anchor point
- subsequent landmarks, the distances between them and intermediate stopping points
- the destination for each route.

This suggestion is in agreement with the description of the parts of a path, proposed in (3.3.2).

Furthermore, Golledge (1991, p.48) and Gale et al. (1990, p.4) agree that the procedural knowledge representation must contain productions associated with

- decision points, along with

- the knowledge and description of the appropriate actions to perform at those choice points.

They also suggest that route knowledge at a more detailed level includes:

- information concerning secondary and tertiary landmarks along the route,
- distances between landmarks
- relations of landmarks and route segments to a larger frame of reference
- the angle of turns between segments of the route. (Thorndyke and Hayes-Roth, 1980, p.5)

Finally, with respect to the estimation of distances between two locations in an environment, Sadalla and Staplin (1980) have found that routes with more intersections were thought to be longer than routes with fewer intersections. Similarly, Sadalla and Magel (1980) have concluded that routes with more turns were estimated to be longer than routes with fewer turns. Golledge (1991, p.49) suggests that the distance between two points along a route may be a function of the amount of information stored in memory that must be processed to mentally traverse this section of the route between them. With the support of Thorndyke and Hayes-Roth (1982), Golledge also argues that distance and orientation estimates appear to depend on whether a subject has experienced direct or secondary environmental information.

4.8.3 Configuration or survey knowledge

As was argued in (4.8), the acquisition of route knowledge is essential for integrating landmark knowledge with the more detailed 'configuration knowledge'. This final stage of the spatial knowledge acquisition process is in the 'configuration' of this knowledge. It is therefore assumed that the characteristics and properties of cognitive maps which have been described in (4.4) and (4.5) also apply to this most complete component of spatial knowing. As knowledge accumulates about an environment and as distance information becomes more precise, notions of angularity, direction, continuity and relation emerge (Golledge, 1991, p.49). We begin to think of the interrelationships of all the environmental elements that have been mentioned so far, by utilising the properties of distance and direction within three-dimensional space.

There is general support, at a theoretical and empirical level, for the notion that spatial knowledge acquisition progresses from route knowledge to a more integrated frame of reference for structuring spatial information, which is called configurational or survey knowledge (Gale et al., 1990, p.5 and Golledge et al., 1985). Moreover, the distinction between route and configuration knowledge as two different but not clearly distinguishable types of spatial knowledge is widely accepted (Siegel and White, 1975, Cousins et al., 1983 and Evans, 1980).

Route knowledge implies the knowledge of sequential locations without the knowledge of general interrelationships: *"Landmark and path sets are organised into clusters where there is a high level of coordination within cluster but only topological information about cluster relations"* (Golledge et al., 1985, p.130) On the other hand, configuration knowledge is more holistic and incorporates an Euclidean as opposed to purely topological understanding of the environment, since it generalises beyond learned routes and locates both landmarks and routes within a general frame of reference (Hirtle & Hudson, 1991 p.336 and, Darken & Sibert, 1996, p.4). In this coordinated frame of reference, Euclidean properties are available within and across clusters (Golledge et al., 1985, p.130). Configuration knowledge adds associational and relational components to the declarative and procedural knowledge, on which landmark and route knowledge are based, and achieves a type of spatial understanding that is more abstract and metric than can be found in declarative and procedural structures. (Golledge, 1991, p.49)

There is, however, some evidence that the priority of either route knowledge or configuration knowledge, in the order of spatial knowledge acquisition within a new environment, depends on whether primary - from navigation - or secondary - from maps - environmental knowledge is acquired. (Thorndyke & Hayes-Roth, 1980) Moreover, the nature of the transition from route knowledge to configuration knowledge is largely unknown (Gale et al., 1990, p.5). Irrespective of which type of knowledge is acquired first and what constitutes the mechanism of transfer from the one to the other type of knowledge, survey knowledge is fundamentally different from route knowledge and this fact will suffice for the objectives of this thesis.

Configuration or 'survey knowledge' is a non-sequential, two dimensional holistic organisation of object locations and route interrelations in space. Spatial configuration is consequently map-like in nature (Darken and Sibert, 1996, p.4). It is hierarchical in structure (Hirtle & Jonides, 1985) and consists of networks and sub-networks of places, varying between large, general areas to small, specific areas (Darken and Sibert, 1996, p.4). When we try to remember the positions of places, we use heuristics or strategies which make the task easier (Tversky, 1981). The hierarchical nature of survey knowledge was also assumed by Golledge (1991, p.49) in the sense that *"elements of the environment that have relevance for everyday use have salience attached to them that make the recognition or identification and use much more simple."*

Survey knowledge does not involve 'fine grain' knowledge about the spatial relations of objects. This representation does not necessarily correspond with the absolute positions and directions of places represented. For instance, our conception of distance between two points may be altered if a significant object or event is placed on route from the one point to the other. We form a very subjective, topological representation of the environment, which is continually changing depending on our environmental experience, our expectations and emotions.

The transition of procedural knowledge to survey knowledge is attributed by Thorndyke and Hayes-Roth (1980, pp.51-52) to extensive navigation in the environment. They illustrate the notion of survey knowledge by explaining that as the subject is aware of a more holistic picture of his environment, he can in some sense 'look through' opaque obstacles in the environment to their intended destination without reference to the connecting route; this gives a certain 'translucency' to the environment.

4.9 The integration of elements within a cognitive map

After investigating the components that spatial knowledge about an environment consists of, it is necessary to consider how these components are integrated within a cognitive map. Appleyard (1976) and Devlin (1976, as quoted in Smyth et al, 1994, p.312) have argued that:

- Routes were the prevalent elements in their graphic representations of cognitive maps, for subjects who had experienced an environment for a relatively short time;
- Other subjects who had spent longer time in the same environment, emphasised on landmarks or boundaries of areas. It has to be mentioned, however, that these subjects were generally thinking in terms of areas and landmarks, which signified each area.

Lynch (1960, p.78) who agrees with this view, suggests an explanation: *"there seemed to be a tendency for those more familiar with a city to rely increasingly on systems of landmarks for their guides - to enjoy uniqueness and specialisation, in place of the continuities used (at an earlier stage when route knowledge prevails)."*

On the other hand, Smyth et al. (1994, p.312) refer to a study by Evans, Marrero and Butler (1981) as evidence which suggests that

- landmarks may originally function as places on a route for subjects who have little experience of the environment but
- as these subjects experience the environment for longer periods of time and their cognitive maps become more detailed, the same landmarks become positioned within the context of the overall network of routes and so they become nodes within the survey representation of the environment.

It is not clear whether these two views are in agreement in terms of the order with which the components of spatial knowledge are being integrated into a cognitive map. However, the fact that these components, although not clearly distinguishable, are certainly different in nature is more relevant for this thesis. This fact greatly contributes towards an understanding of the way that an individual 'reads' and remembers his environment.

Couclelis et al. (1987, p.99) present a different approach towards structuring a spatial representation, which may be of particular interest for the design of VEs. They refer to properties of cognitive maps and argue that there is ample evidence indicating:

- a tendency towards regionalisation - the breakdown of space into discrete regions - and route segmentation - one dimensional regionalisation,
- the important role of salient spatial elements - landmarks or cues - for orientation, recall and recognition of other cues and
- the presence of a hierarchical organisation in the structure of both regions and systems of landmarks,

in such cognitive representations. On this basis, they put forward a model for spatial cognition according to which primary nodes or landmarks - reference points - anchor distinct regions in cognitive maps of any given environment. In this sense, Bell et al. (1996, p.98) argues that *"we may imagine the world as a sea containing islands of known regions (or districts) within which distance estimates are fairly accurate, but between which knowledge is less precise. Within each island one particularly reference point, often a landmark, may serve as a cognitive anchor for the entire region."*

Finally, there is evidence (deJonge, 1962; Tzamir, 1975; as quoted in Evans, 1980, p.280) which suggests that path structures with parallel streets and perpendicular intersections are more readily comprehended than intersections of paths at acute angles. Lynch (1960) had also found that even when some streets were intersecting at angles smaller than 90^0, several subjects tended to view them as perpendicular.

4.10 The components of spatial knowledge for a static subject - places and nodes in the context of a cognitive map

After considering the acquisition of spatial knowledge from the perspective of a subject who navigates within an environment, it is necessary to investigate the way that a relatively static subject views his environment.

Devlin (1976, p.66) suggests that *"although paths are necessary as routes, the functional demands.....guide where one is going."* The functionally defined goals of one's route are places, which come to serve a vital role in the mental map of an environment. *"They serve many of the purposes of a landmark. They are initially goals of an outing, but in time they help structure the region (area) and become subgoals with important wayfinding implications."* At this point, it is necessary to clarify the meaning of the words: landmark, node and place, since they seem to be used in the above mentioned literature for signifying relatively different concepts.

For a subject who exists in an environment, generally consisting of domains, nodes connected by paths, places and landmarks within nodes or domains:

- we may refer to places as nodes or landmarks, in the context of the overall cognitive map - or for a global frame of reference - if the subject is navigating within the environment, but
- we may refer to the node as a place, from the perspective - or with respect to the local frame of reference - of a subject who has just entered a node in order to involve himself in an activity and who is not moving within the environment but is relatively static within this node's boundaries.

In support of this conception, Burnette (1974, p.180) suggests that Lynch's node concept may correspond to the archetypal concept of the cave or home in a similar way that Cooper (1974) has related the place with the concept of a house as a 'symbol-of-self' - as presented in (3.7.1). The node is the symbol for the 'place' as an 'activity setting' and can also be seen as a point locus for primary sensorimotor activity; the design of such a setting for a particular activity may also be related to the affective pursuit of the ideal of happiness for the user of this place.

Considering places as anchor points, Golledge et al. (1985, p.130) propose a theory according to which places may be hierarchically ordered within an environment on the basis of their significance for the individual. This cognitive hierarchical ordering can be described by a system of nodes and the paths that link them. Golledge et al. (1985, pp.142-3) have classified these nodes into a hierarchy of four types:

1) Origin and destination nodes are primary nodes, like a person's home or place of work and they are the anchor points from which the rest of the hierarchy starts;
2) Interstitial second and third order nodes identifying key choice points where single or multiple actions were mandated;
3) Lower order nodes that help define expectations with respect to the location of choice points;
4) Miscellaneous cues that were trial or episode specific, became attached to route segments, acted as a general referent and provided 'security information' - because of familiarity - during wayfinding.

Garling et al. (1984, p.10) propose a much more open model of spatial knowing according to which, the concept of place refers to all spatial elements represented in cognitive maps; these maps then comprise places, spatial relations between places and travel plans. In this sense, the properties of a place are its name, perceptual characteristics, function and spatial scale. A place in the cognitive map is then assumed to be represented as information about this set of properties. In support of this assumption, they quote evidence provided by Pezdek and Evans (1979), for the fact that the above mentioned properties are learned independently of the locations of places. Apart from these properties however, places also have psychological, affective attributes like pleasantness, aesthetic quality and complexity.

There is also support (Brewer & Treyens, 1981) for the hypothesis that place schemata play an important and complex role in the memory of places. In fact, subjects seemed to relate the experimental place that they experienced to their long-term knowledge of all places of similar function they had known. It also became evident that place schemata cannot be considered as rigid frames but are capable of subtle readjustments according to situations. The role of schemata in the memory of places may be related to the way that Bachelard (1982) defines the concept of a 'house', as the most intimate and personal type of place for each individual - as explained in (3.7.1).

Finally, the importance of plans for influencing the way that a subject acts in, thinks of and feels about a place has been stressed by Ward et al. (1988). They assert that behaviour is place specific in the sense that *"people do different things in different places"* and also argue that a place elicits the behaviour (Barker, 1963 as quoted in Ward, 1988, p.5) and particularly the cognitive and affective responses of a subject to this specific place. However, they also suggest that planning for different goals measurable alters how a place is cognitively and effectively represented and consequently the way that a plan is cognitively and affectively represented presumably influences how a subject behaves.

4.11 Acquiring secondary environmental information from signs

Secondary environmental information has been defined in (4.2.1) as the information which is indirectly acquired in relation to a setting, from vicarious information sources like signs, maps and other types of environmental descriptions - spoken or visual. Information acquired through such vicarious sources is usually filtered and distorted. This thesis, however, will only deal with signs, as objects which afford secondary spatial information, and not with other objects or systems which support navigation - i.e. maps, text, information booths etc.

Signs according to Passini (1992, pp.90-92) communicate environmental information needed to make wayfinding decisions; they tell the viewer what is where and they also specify when and how an event is likely to occur.

Passini classifies signs as:

- Directional signs, which designate direction towards a place, an object or an event in form of a name, a symbol or a pictograph and an arrow.
- Identification signs, which are the most elementary state of description of a location, usually perceived when the destination is reached; they identify an object, a place or a character in a real or virtual environment.
- Reassurance signs, which act as checkpoints after a wayfinding decision is made, to reassure the subject that they are on the right track.

A sequence of directional signs may be employed for the purpose of aiding subjects in finding their way towards a particular destination within an unfamiliar environment. Several key issues involved in the use of such a sequence of signs in urban environments are identified by Passini (1992. pp.92-107:

- Brief, clear and visually structured message and indication of the decision needed to be taken by the operator, are all factors which enhance the effectiveness of a sign;
- Signs with a similar message, or those which are a part of the same directional system, should be consistent in their graphic identity and also in the location that they are placed within the virtual environment;
- The continuation of directional signs should not be interrupted or discontinued as this will result in certain disorientation;
- The complexity and intensity of sensory stimulation provided by the surroundings may reduce the reception of information from the operator and the effectiveness of the sign system.

Many of these issues may be of relevance to the application of sign systems in VEs.

Finally, Butler et al.(1993) have found wayfinding signs to be more effective aids for subjects in an unknown, complex building than 'you-are-here' maps. They attribute this to the fact that signs provide local spatial information indicating which specific decisions and actions a subject should perform, with a minimal memory load, in order to find his way. They also suggest (1993, p.172) that when subjects follow signs, they generally prefer routes that minimise the energy required to reach goals.

4.12 Correspondence between elements of existential space and components of spatial knowledge

Research on the issue of spatial knowledge acquisition has been presented in this chapter, on the assumption that an environment, whether real or virtual, which facilitates the generation of cognitive maps would be preferable to an environment which does not do so. However, as Evans (1980, p.280) argues, few investigators have studied the relationship between environmental legibility and preference or feelings of personal satisfaction or competence. He only cites the research work of S. Kaplan, who found that setting features that enhance map formation also increase preference. According to Kaplan, preference for an environment is related to this environment's 'coherence' and 'moderate uncertainty':

- Coherence (Bell et al., 1996, p.54) is the degree to which a scene 'hangs together' or has organisation. Structural features that provide coherence include continuous texture gradients, thematic colour or graphic patterns and variable but identifiable physical forms.
- Moderate uncertainty is provided by variety, moderate complexity, moderate spaciousness and occasional structural irregularities. (Evans, 1980, p.280)

Following Lynch's definition of legibility - as presented in (3.4.1) - we may then argue that subjects would prefer to navigate or perform several activities in a legible environment, which facilitates the formation of cognitive maps. In this sense, the way that spatial knowledge is acquired is directly relevant to the design of real and virtual environments.

Accordingly, the components of a cognitive map, as presented in this chapter may be seen as supporting the taxonomy of spatial elements which was presented in the chapter (3). In particular:

- We relate to landmarks as objects in a direct, experiential manner by seeing and identifying them. However, the components of landmark knowledge could also be seen as places or nodes, according to the activity that the subject is involved in.
- We relate to routes by moving along them, while navigating within an environment. The routes, as components of a subject's route knowledge, are the paths of a subject's existential space.
- Domains, however are mainly thought of rather than experienced since we cannot directly experience them as a whole. A survey representation involves the regionalisation of the environment. This need for thinking of our world in terms of regions may be seen as corresponding with the need for imagining a world in terms of districts or domains, as suggested by Lynch (1960) and Norberg-Schulz (1971) respectively.

CHAPTER (5)

5. A FRAMEWORK FOR DESIGNING THREE-DIMENSIONAL CONTENT IN A VIRTUAL ENVIRONMENT

In the previous three chapters, literature from the areas of philosophy, architectural theory, perceptual psychology, environmental cognition, geography and artificial intelligence has been reviewed for the purpose of studying the structure and significance of spatial elements in the real world. It was assumed that by understanding how we think of and how we remember spaces, we may begin to comprehend the spatial structure that we try to infer onto an environment when we experience it for the first time. It was also assumed that if the form of spatial elements and the overall structure of space in a real environment was designed according to this understanding, then this environment would be legible, would facilitate the generation of cognitive maps and consequently wayfinding and would eventually be pleasant to be in.

On the basis of this assumption, the thesis has so far attempted to:

- identify a taxonomy of the space-establishing and spatial elements that a real environment consists of,
- understand the characteristics of these elements and their spatial significance for humans and
- understand their possible structure within an environment.

This chapter investigates the relevance of this taxonomy and structure of real space for space in VEs. To achieve that, an understanding of the intrinsic characteristics of VEs is necessary. This is achieved by identifying the differences between REs and VEs.

Taking these characteristics into account, the taxonomy and structure of spatial elements, in REs is related to the nature of space in VEs. The results are:

- a taxonomy of the possible constituent elements of space in a VE,
- certain hypotheses about their characteristics and spatial significance for a navigating subject and
- certain hypotheses about the way that they could be structured within a VE.

These results are assumed to be a framework for supporting the spatial design of the particular type of VEs which was defined in (1.7). As such, this framework constitutes the hypothesis on which this thesis is based. This framework may inform the design of form in order to formulate space and convey spatial meaning in a VE, for the purpose of implicitly enhancing the spatial awareness of its participant and ultimately aiding his orientation and wayfinding within this VE. As in the case of urban environment design, a VE may be designed so that the conveyed sense of space allows users to anticipate forthcoming events and directs them towards spaces significant for the goal of a particular task. Additionally, as it was suggested in (4.12), a legible environment which facilitates the formation of cognitive maps, is preferred by subjects for navigating and performing several activities in. In this sense, the use of this framework may aid the design of legible VEs, which are preferable for navigation and which make the execution of several tasks more pleasant, as well.

5.1 A model for the analysis of virtual environments

Ellis (1993, p.3) has proposed a model for understanding a human environment. According to this model, any environment is a theatre of human activity, which may be considered to have three parts: content, geometry and dynamics. On the basis of Ellis' model, Kalawsky (1993, p.12-13) has suggested that the synthesis of a virtual environment should consist of the same three parts:

1) The 'content' of a VE consists of the objects of the environment; these objects are described by their properties - position, orientation, velocity, acceleration - and characteristics - colour, texture, energy, etc. An 'actor' is a special type of object which has the capacity to initiate interactions with other objects. A distinct kind of actor is the self or 'avatar' as defined by McLellan, H. (1994). There is at least one unique actor in the VE system that provides the point of view according to which the VE is rendered. All parts exterior to the self are considered by Ellis (1993, p.4) as the field of action.

2) The 'geometry' of a VE is considered to be the description of properties of this environmental field of action; such properties are the dimensionality, the metrics and the extent of the environment. Kalawsky (1993, p.13) acknowledges the fact that this definition is valid for a single participant in the VE who has only one point of view to the environment. It is understood, however, that each participant may have multiple viewpoints which provide him with views to the VE. Ellis (1993) defines as an 'environmental trajectory', the time history of an object through the environmental space. Given starting conditions and dynamic relationships, we may compute an environmental trajectory of an object through the environmental field of action. Since kinematic constraints may preclude an object from traversing the space along specific routes, these constraints are also part of the environment's description.

3) The 'dynamics' of a VE describe the rules of interaction between the actors and the objects. An interaction consists of the transfer of energy or information from one element to the other, which is manifested in the change of properties or characteristics of the interacting elements. Examples of such dynamics could be the simulation of classical laws of motion or the way that objects behave after a collision.

If we consider that the content of VEs corresponds to a description of all objects or 'rigid bodies' - as Ellis describes them - within an environment, then environmental space is seen as the Cartesian product of all the elements of the position vector - components of the content - over the possible range, defined by the geometric property of extent. (Ellis, 1993, p.4) This description of space, according to the model that Ellis and Kalawsky propose, may be adequate for the needs of many VR applications, but is certainly not adequate for the needs of this thesis. It, therefore, has to be appropriately extended to take the elements of space into account. According to the objectives of this thesis therefore:

The content of a VE consists of:

- 'Solid' objects or positive space-establishing elements described by their properties and characteristics, which can either be passive or active - actors;
- 'Void' or negative spatial elements which are determined by taking the spatial relationships of objects and the geometric spatial attributes into account. Such spatial elements may be analysed in terms of their characteristics such as colour, texture or volumetric proportions but not in terms of properties like position, orientation or velocity.

It is assumed that when designing spaces in a VE,

- we model each space-establishing element by individually defining their characteristics and consequently
- we generate spatial elements by defining the properties of space-establishing elements and thus defining space.

This assumption shows that a spatial element is not seen as an object - a certain software entity - within the VE system. This thesis will ultimately attempt to develop an understanding of VE design, according to which a spatial element is thought of as an object or another component of the VE's three-dimensional content, which is described by properties and characteristics, rather than a part of the environmental field of action, which merely functions as the arena where 'solid' objects are arranged, according to Ellis (1993) and Kalawsky's (1993) approaches.

Further explanation of these concepts or a detailed description of the science of VEs is beyond the scope of this thesis. This chapter will only focus on the aspects of VE technology which are closely relevant to the subject of this thesis. Specifically, it will attempt to identify the characteristics of VEs, as these have been experienced by the author of the thesis.

5.2 Classifying virtual environments

Before identifying the characteristics of VEs though, it is necessary to define the kind of VEs that this analysis refers to, even more specifically than in (1.7). For this purpose, it is essential to introduce the following ways of classifying VEs.

5.2.1 Classifying VEs according to the way that participants experience them

VEs may be classified, in terms of the way that they are being manifested, or in other words displayed to the participant, into:

1) 'Immersive VEs' imply that a participant experiences the illusion that he is 'immersed' in a synthetic, representational, three-dimensional world, through the use of a head mounted display device and a head tracker, which tracks the movements of his head and accordingly updates the display; at the same time he is isolated from any real world visual stimuli. He may navigate or interact with elements of this world in ways similar to the ways that he interacts with real world elements, with the help of appropriate 'six-degree-of-freedom' input devices[9].
2) 'Non-immersive' or 'desktop VE systems' use a computer screen as a display while the participant maintains visual contact with the real world. In some cases the display may be stereoscopic with the help of a pair of lightweight stereo glasses which are synchronised with the display refresh rate, through a signal

[9] Input devices which allow for six-degrees-of-freedom manipulation of the user viewpoint, that is translation along the (x,y,z) axes and rotation around the (x,y,z) axes of the three-dimensional space in a VE.

emitted from a device positioned on the top of the monitor. Although desktop systems do not immerse the participant in the representation, navigation and interaction may still be controlled:

- by six-degree-of freedom input devices or
- by other more conventional two-degree-of freedom devices, like the mouse; in this case appropriate conventions need to be learned by the participant for navigating in three-dimensional space.

3) A 'projection-based VE' utilises a projection system as a display, on one or more screen surfaces that may surround the participant. Since a projection covers a larger part of the field of view, the participant is partly immersed in the representation, but he still maintains a visual contact with the real world and, most importantly, with his own body. Such a system may support the co-existence of many participants who can see each other while being in the same VE. In this case, only one of the participants may be the actor who determines the update of the viewpoint in the display through the movement of his head. A special case of a projection-based system is the CAVE (Figure 5.1) (Hedberg, 1996, p.28).

Figure 5.1: A projection-based CAVE system (Pyramid Systems Inc, 1998).

4) Hybrid or 'augmented reality VE systems' are identified by Vince (1995, p.13) as another class of VEs, which allow the user to view the real world with virtual images superimposed over this view.

5) Finally, 'mirror worlds' are identified by Brill (1994, p.33) as the type of VE system, where the participant enters the world from a secondary position of indirectly watching himself move within the VE. The representation of the participant may either be:

- His real image recorded by a video camera and integrated within the VE in real time, as in the case of the Mandala system (Figure 5.2) (Warme, 1994) or Myron Krueger' s artificial reality installations (1991).
- A graphics based representation which is animated in real time and the movements of which are mapped to the real movements of the user through the use of tracking systems positioned on the body of the participant. This way the participant has full control of his computer graphics based representation that he may see on any kind of display, i.e. the Waldo system (Figure 5.3) (Brill, 1994, p.33).

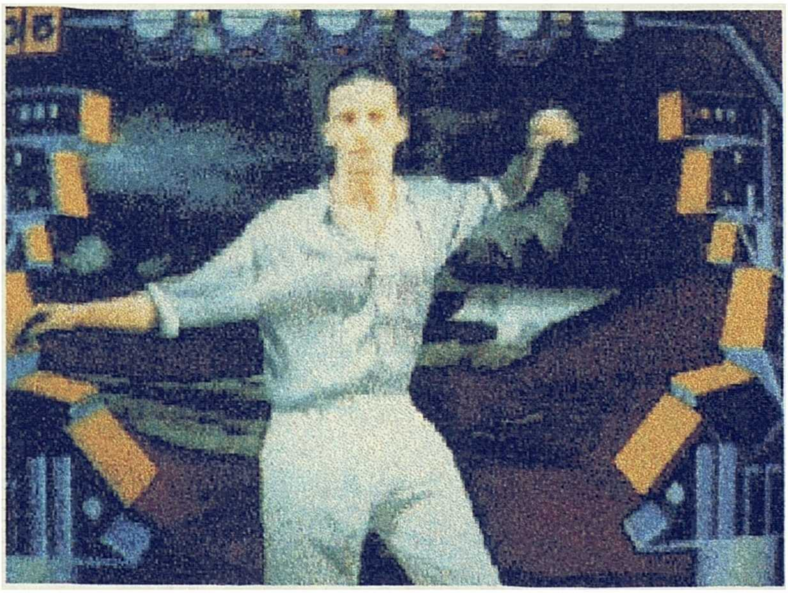

Figure 5.2: View of an application with the Mandala system which allows the participant's image to merge with the graphical representation in a VE (Brill, 1994, p.33).

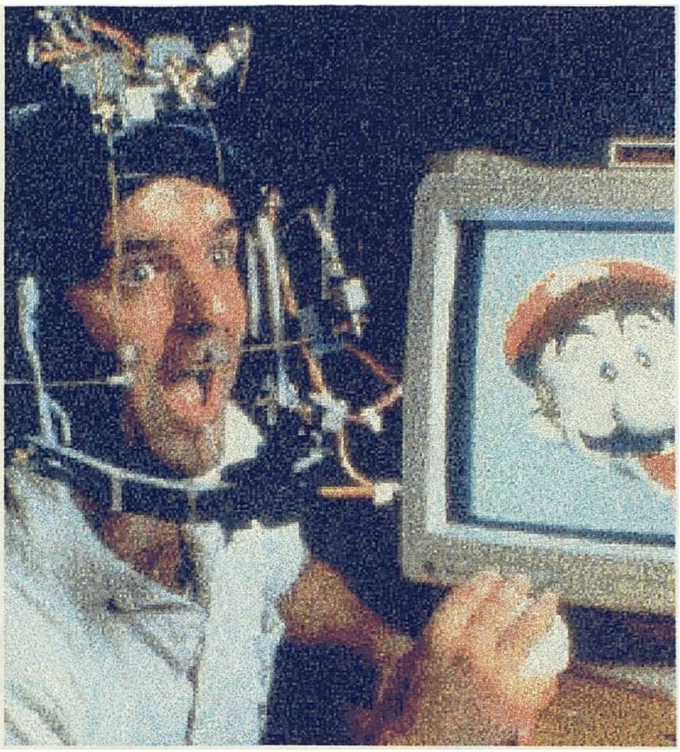

Figure 5.3: A head-mounted WALDO unit senses movements and transfers them to a digital puppet (Brill, 1994, p.33).

5.2.2 Classifying VEs according to size

Darken & Sibert (1993) classify VEs according to their attribute of size into:

- Small VEs in which all or most of the environment can be see from a single viewpoint such that important differences between objects can be discerned, i.e. a virtual wind tunnel. These worlds tend to focus attention on one object or a group of related objects.
- Large VEs (Kuipers and Levitt, 1988 as quoted in Darken and Sibert, 1993) are defined as spaces whose structure is at a significantly larger scale than the observations available at an instant. This definition is in agreement with the definition of large and medium-scale real environments as presented in (4.7). Following this definition (Garling et al., 1985, pp.158-9), a large VE completely surrounds the person and thereby always extends outside the field of view of the

participant. Considering also the fact that several obstacles may obstruct the participant's view, it may be argued that *"in a large VE there is no vantage point from which the entire world can be seen in detail"* (Darken and Sibert, 1993). An exception to the definition by Garling et al. (1985, p.159), which is particularly relevant for environmental knowledge of VEs, is the activity of viewing an environment from the air. Due to the finite character of VEs, it is often possible to position a subject's viewpoint at a bird's-eye-view and to directly perceive the whole environment at once. In this case, however, it is not possible to see detail in the VE. This aspect of VEs, however, should be particularly taken into account when considering the generation of cognitive maps into VEs.

- An infinite VE is one in which we can travel along one dimension forever without encountering the 'edge of the world'. If a VE is infinite in all its dimensions it is a fully infinite VE. If it is only infinite in only n of its dimensions, it is a semi-infinite VE (Darken & Sibert, 1993).

5.2.3 Classifying VEs according to density

Darken and Sibert (1993) classify VEs into three types in terms of their density:

- A sparse VE has large and open spaces in which there are few objects or cues to help in navigation, i.e. a simulation of the surface of an ocean. They also report that their experience with such simulations has shown that in such a VE subjects become easily disorientated.
- A dense VE is characterised by a relatively large number of objects and cues in space, i.e. the simulation of an urban area.
- A cluttered VE is one in which the number of objects is so overwhelmingly large that it obscures important landmarks or cues, i.e. some information visualisation applications.

5.2.4 Classifying VEs according to the level of activity in them

Finally Darken and Sibert (1993) identify two types of VE according to the level of activity within these environments:

- Static VEs, in which the positions and values of objects do not change over time. In a variation of such worlds, the positions of objects could remain static but the values of these objects may vary, so that their appearance may change and accordingly the slightly increased complexity of the world may inform navigation. In general, static VEs provide the most controlled environments and are the logical arena for a preliminary study.
- Dynamic VEs are environments in which objects move about, thereby increasing the complexity of the navigation task. The movement of the objects can be
  - deterministic, if it follows predetermined paths or
  - non-deterministic, if the paths are random in some sense.

  Accordingly, a VE may be characterised along a continuum as
  - fully determined, when all objects move deterministically, to
  - fully non-determined, when all objects move randomly.

5.2.5 The type of VE which this thesis refers to

This thesis focuses on desktop VE systems, mainly due to the practical limitations determined by the resources available for the experimental stage of the project. These resources afforded the use of a desktop system for evaluation of the hypothesis, which is proposed in this chapter as a result of the literature review. It is however suggested that many of the conclusions drawn may be valid in the context of immersive VE systems as well. This suggestion may be evaluated by further experimental work in the future.

In terms of scale, this thesis refers to large or medium scale environments, neither too small to function as the setting for the evaluation of the hypothesis nor infinite, since these could not be supported by the hardware resources available and would not benefit the aims of the evaluation either.

In terms of density, this thesis refers to neither sparse nor cluttered but relatively dense VEs which include enough objects and cues to inform navigation and to maintain a level of complexity and consequent interest in the environment. The attribute of environmental complexity which may be experienced in a very dense VE has a direct impact on the frame rate of the VE's display. It is therefore understood that we can only design VEs as complex as the power of our rendering engine permits them to be, so that the frame rate does not drop significantly and the participant does not perceive a 'jagged' or very slow movement within the VE.

Finally, in terms of the level of activity within an environment, this thesis deals with fully static VEs. Since this project is concerned with the impact of environmental characteristics on human spatial behaviour, it was considered that the use of dynamic environments would result in an ever-evolving spatial context which would make the task of analysing the impact of this context on spatial behaviour too complex.

5.3 Differences between REs and VEs

Virtual and real environments may be similar in the way that they are manifested to the human, because they are experienced via the same perceptual processes employed for perception in the real world; on the other hand, they are significantly different in many respects. Since we have lived and evolved in REs, we know them and understand their nature. By identifying the differences between VEs and REs, we may begin to understand the nature of VEs.

Some of these differences may be seen as problems, which are due to the limitations of current VR technology and which may be overcome as this technology evolves;

particular emphasis will be given to the significance of representing the human body within the VE, in this section. Other differences may be seen as intrinsic characteristics of VEs, which are again causally related to the state of the art of VR technology. The identification of these characteristics is assumed to lead to a better understanding of the individual nature of VEs as a medium.

5.3.1 Limitations of VEs

This thesis argues that the character of the spatial experience provided by the most advanced, immersive VE systems available today, is far from realistic. This is due to the following limitations of current VR technology:

- VE systems cannot approach the resolution and complexity of experiencing a RE,
- output devices provide feedback for only three - visual, auditory, tactile - of the five senses and
- participants do not receive enough visual, auditory or tactile kinesthetic information from the representation of their bodies in the VE.

This last suggestion is discussed in more detail in the next sub-section.

5.3.2 The human body and its 'avatar' in a VE - Sense of presence

A fundamental factor which affects the spatial experience in a VE is that participants cannot see their bodies, since head mounted displays do not allow for any visual input from the real world. McLellan (1994, pp.33-35) names as 'avatars' the only representations of the participants' bodies, which are displayed to them in an immersive VE system. An avatar could be a cursor, an approximation of a hand or a human body or any other complex object. This avatar can be controlled by tracking devices which monitor the movements of the participant's body and accordingly update the graphical representation of the avatar. In the case of a projection-based or a desktop VE system though, the participant can view his own body but at the same time he has a 'through-the-window' view of the representation (Vince, 1995, p.13), which is assumed to make him feel less surrounded by the representation, than he would feel in an immersive VE.

Gibson (1986) has described how a subject sees the environment in reality, not only with the eyes but with the help of a system consisting of the eyes, which are positioned in the head, which is positioned on the body, which is resting on the ground. An observer perceives the position of 'here' as being relative to the environment and also to the body which is 'here'. The occupied point of observation is constantly in motion, so observers always see their bodies moving relative to the ground or see that part of the environment toward which they are moving. These are all cases of visual kinesthesis (Gibson, 1986, p.205-208). Humans have evolved to perceive themselves as parts of the environment. Gibson (1986, p.183) has also argued that *"vision is kinesthetic in that it registers movements of the body just as much as it does the muscle-joint-skin system and the inner ear system. Vision picks up both movements of the whole body relative to the ground and movement of a member of the body relative to the whole. Visual kinesthesis goes along with muscular kinesthesis.... Vision obtains information about both the environment and the self."*

If the avatar is only a three-dimensional cursor or a glove, as is often the case, participants cannot perceive the 'here' and 'there' of the surrounding environment as relative to their body's position in the real environment, which is also kinesthetically perceived as 'here'. As a result they cannot experience the visual kinesthetic feedback needed for informing them of their own movements relative to the VE, which was described above by Gibson for a human within a real environment. Consequently the sense of presence of the participant is reduced.

Steed et al. (1994) define 'presence' as the sense that the participant has of being in an environment, other than the one that he really is. They conclude that increasing the quality of the visual and auditory channels is important, but is not sufficient for presence in the general sense. They argue that kinesthetic sense, which includes proprioception, is just as important and for this reason the representation of the body, as an avatar in the VE, is an essential feature of the system.

Slater and Usoh (1994) also argue that the aim of modern VE systems is to consummate the tightly coupled loop between:

- the movement of the body and head in three-dimensional space which determines the image generated on the display and
- the internally generated proprioceptive signals that inform the brain of this bodily movement.

However, today's systems can only approximate this coupling to a relatively poor degree. This is due to:

- the lack in detail, resolution and visual field of view
- the very limited tactile and kinesthetic information and
- the lag caused by communication and computation bottlenecks which results in a temporal mismatch between proprioceptive feedback and corresponding changes in the sensory feedback perceived by the participant.

Finally they too agree with the above suggestion that the most significant structure in the visual field is the representation of the perceiver's own body.

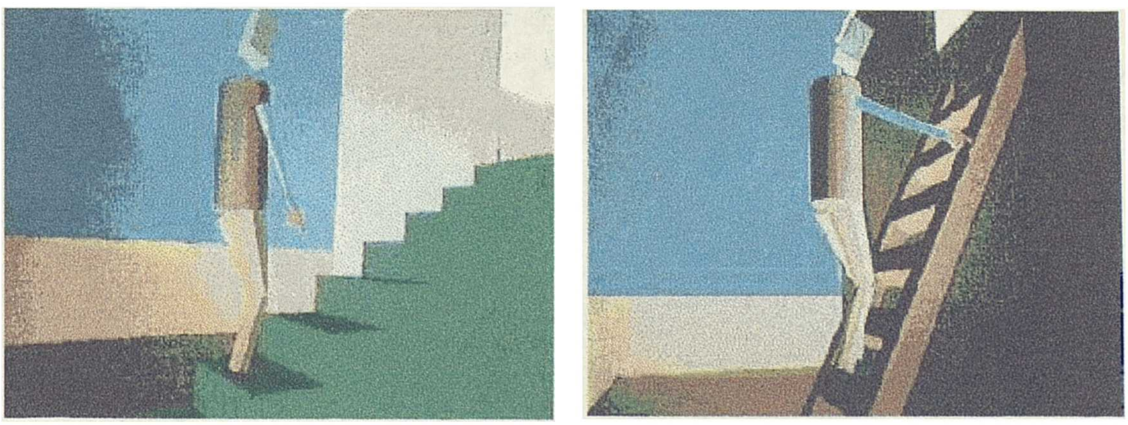

Figure 5.4: Views of a representation of a participant's body -avatar or Virtual Body - climbing stairs and ladders (Slater & Usoh, 1994b, colour plates 9.1, 9.2).

This suggestion is also in agreement with the arguments presented in (2.5), according to which we can only conceive of space, in the real world, in terms of the relation between our body and the environment. Merleau-Ponty (1962, p.250) had also introduced the concept of the 'virtual body' - presented in (2.2.1) - as a description of a phenomenological understanding of the potentiality of our real body for movement, within the constraints imposed by the environment which is unveiled upon us. Parallels may be drawn from this case of orientating in an unnatural situation which has been presented by Merleau-Ponty, when considering the case of a participant navigating in a desktop or immersive VE, while his body is located in the real world. We may argue that in a similar manner, the subject who is at first disorientated in the VE, gradually becomes conscious of a 'virtual body' which corresponds to his potentiality for moving within the space which is available in front of him within the VE. This could certainly be supported on the basis of the real body movements that participants may make when they interact with a VE. Depending on the design of the interface - input/output devices and desktop/immersive mode - the consciousness of a 'virtual body' may occasionally mask the stimuli perceived from the real world and thus prevail over the consciousness of the body which exists in the real world.

It can, however, be argued that the lack of an avatar in the VE, the movements of which are appropriately mapped to the real movements of the participant, results in the reception of incoherent information about the real body in relation to the avatar in the VE. This is due to the fact that the kinesthetic information which participants receive from their own body, acting in the RE, does not usually correspond with the action and events which are being displayed to them in the VE. Such discrepancies may break down the illusion, decrease the sense of presence within the VE and may also have distressing physical effects on the participant (Regan, 1994). Tactile and force feedback, tightly coupled with the auditory and visual output may provide proprioceptive information which may mask such a problem.

Bollnow (1963, p.166 as quoted in Norberg-Schulz, 1971, p.21) points out that man's active relationship to the world is characterized by his vertical position; he takes a 'stand'; to sleep means to return to the very 'point of departure'. But these differences cannot be experienced in a VE, since the body is not being adequately represented and there is not enough kinesthetic feedback to provide a sense of 'sitting' or 'laying down'.

A basic aspect of man's being in the world is movement along a path, by which we get from one place to another. The changing character of movement is related to pace and rhythm. We move because we want to 'take possession of the environment', according to Norberg-Schulz (1971, p.35), and we can achieve that by running, strolling, marching or dancing. In VEs we cannot move in these natural ways; instead we are limited to the forms of interaction, defined by the input/output devices, which determine the metaphor for movement in the specific VE; i.e. walking on a treadmill, flying where the virtual finger points, walking or rolling on floors or other surfaces, etc.

There is also experimental evidence (Smets, 1995) which suggests that the coupling between our own movements and shifts in the optic flow allows us to estimate where things are in space relative to ourselves and this coupling causes a sense of telepresence. The existence of an avatar, the movement of which is appropriately mapped to the participant's movement, is assumed to be necessary for such a phenomenon to occur.

It may then be argued that avatars, used as representations of the participants' bodies, are extremely important for providing a realistic sense of space and presence to the participant of a VE. However, most state of the art immersive VEs do not provide the visual kinesthetic feedback needed for informing them of their constantly changing position within the environment, through their avatar implementation. As a result, the sense of presence and the overall sense of space felt by the participants is limited. The situation is even more problematic in non-immersive VEs.

Indeed, Steed (1996, p.4) has distinguished between immersive and non-immersive virtual environments in terms of the interaction style and the representation of the self within the environment:

- In an immersive system, the rendering of the visual viewpoint is slaved to the head of the participant so that the graphical display is continuously updated and provides a realistic sense of 'being in the representation'; the viewpoint from which a non-immersive VE is rendered does not match the participant's body and is controlled indirectly through a certain input device.
- A cursor or a representation of the body of the participant is slaved to a sensor device in an immersive VE but controlled indirectly by some appropriate interaction metaphor in a non-immersive VE.
- Finally, in an immersive VE, if both the head and the hand are tracked then they may be modelled inside the VE in the correct relative positions so that the proprioceptive sense of where the head and hand are matches the display. In a non-imersive VE, the head of the participant may be tracked but this is rarely useful since the display, being a computer monitor, allows for very limited movements of the head.

It may then be concluded that the participant of a non-immersive VE feels an even more limited sense of space and presence than the participant of an immersive VE, since he receives very limited visual, auditory or tactile kinesthetic information from the representation of his body in the VE.

5.3.3 Characteristics of VEs

The differences between VEs and REs may also be seen as intrinsic characteristics of VEs which are essential in helping us understand the nature of VEs as a medium:

1) Space in a VE is non-contiguous (Bridges and Charitos, 1996). A participant is able to teleport from one position within a VE to another remote position

- within the same VE or
- among different VEs.

The positions from where one teleports and where one arrives are named 'portals'. However, if two VEs are connected in this manner, they are not spatially related to each other in terms of a three-dimensional, Cartesian context. They could be anywhere and indeed it becomes irrelevant where they are in relation to each other. In this sense, the structure of spaces within a VE is hypertextual in nature.

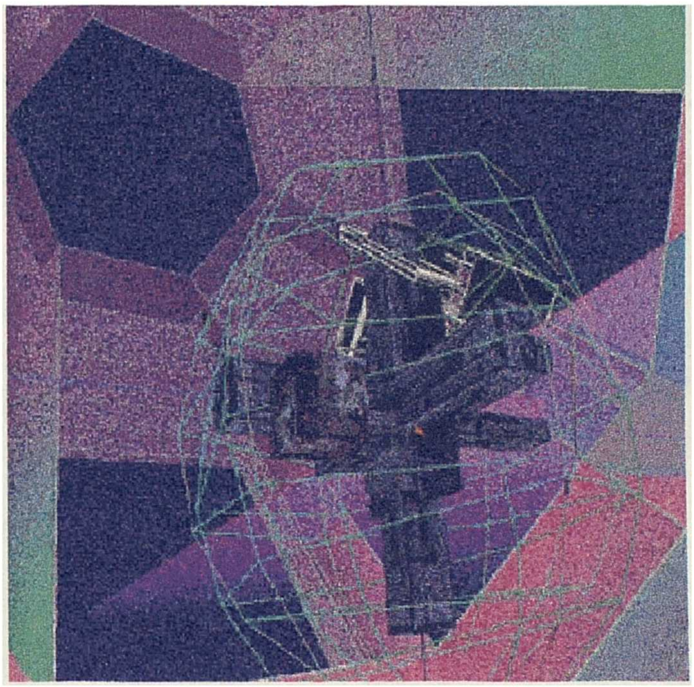

Figure 5.5: An attempt to visualise a four-dimensional cube in a VE by Marcos Novak: "Dancing with the virtual Dervish" (Moser & McLeod, 1996, colour plate 12).

2) Benedikt (1991) elaborates more on how the principles of real space may be violated in VEs. Accordingly, space may be seen as multidimensional; although all geometrical models of objects are designed in three-dimensional Cartesian space, we are not limited to three dimensions in a VE, because any surface or vertex may unfold to reveal other environments. This characteristic of VEs allows for the interactive visualisation of data sets represented by 4D (Figure 5.5) or higher-dimensional spaces, as witnessed in the work of Feiner & Beshers (1990) and Novak (1994).

3) There exist no physical constraints to dictate the dynamic, spatio-temporal nature of a VE; one cannot speak of physical laws like gravity or friction in a VE unless we design and implement them. Therefore it may be argued that such constraints are only determined by the specifications which define the VE and in accordance with the application task.

4) A VE does not necessarily have scale consistency. It is possible to alter the scale of the environment, in relation to the participant while he is in the VE. In this sense, we may transform our size in relation to each level of the environment - as environmental levels were defined in (3.7) and explained in Charitos (1996) - from a geographical level to the level of the smallest thing and in this manner experience all levels in a very direct way, as we can experience the level of things in REs.

5) Time is not necessarily continuous in a VE. When a participant is being teleported, a new environment is being downloaded to the system and the time that this downloading takes cannot be mapped to a certain translation of the participant's viewpoint in the space of the VE; in this sense there may be a certain temporal discontinuity in the experience of a VE. Moreover the pace of time may be altered - slowed-down or speeded up - according to the requirements of the application.

5.4 The spatial elements that the content of a virtual environment consists of

Taking account of these characteristics of VEs, it is possible to propose a hypothesis, in the form of taxonomy of the spatial elements that a VE consists of and an understanding of their structure. This hypothesis, is seen as a framework for informing the design of space in VEs. It is also based on the assumption that a human perceives and remembers space in a VE in the same manner and via the same processes as with space in an RE,.

When we navigate in real environments, we find our way by utilising environmental information which is directly or indirectly conveyed to us (Passini, 1992, p.90). Similarly in VEs, a participant may obtain:

- Primary environmental information, implied by the directly experienced arrangement of objects in the environment. The sense of space conveyed by this setting may indirectly help participants anticipate forthcoming events, or direct them towards spaces which are significant for the fulfillment of the application task.
- Secondary, indirectly perceived environmental information
  - from objects such as signs or symbols
  - via support systems which provide specific environmental cues; such support systems are described and hypotheses about their development are investigated in Charitos and Rutherford (1996) and Darken and Sibert (1993).

This thesis does not deal with such tools as support systems but focuses on direct ways of conveying environmental information and on signs and symbols, as these are considered more directly relevant to the architectural aspect of VE design.

If we want to design VEs, in which the arrangement of spaces aids the participants' spatial awareness, we firstly have to identify the possible elements that the content of a VE comprises. These elements are the types of objects that we may find in a VE and the types of spaces that these objects may define. Accordingly, the following framework will suggest:

- a taxonomy of the possible objects that a VE consists of,
- a taxonomy of the spatial elements that these objects may define,
- the characteristics and structure of these elements,
- how these elements affect human wayfinding behaviour.

5.5 The space-establishing elements in a virtual environment

The spatial design of a VE involves the composition of a set of visual and auditory objects which define space, by virtue of their formal qualities and their arrangement within the VE. It is understood that the objects of a VE may also be 'active' if they initiate certain interactions with other objects of the VE and such objects have been defined as actors in (5.1).

However, it has been explained in (5.2.5) that this thesis is concerned with static, as opposed to dynamic, VEs. Therefore this taxonomy does not consider dynamic objects such as actors, or even animated objects which may move within the virtual environment, exhibit a certain behaviour, or respond to an action of the user. It will be limited to static objects and the manner that these objects determine an environment as a background to human activities.

With respect to their form, objects in a VE could be classified as:

- surfaces or planar objects - faces, meshes, curves - which have zero thickness
- objects - solids, surface solids - when their form is clearly three-dimensional.

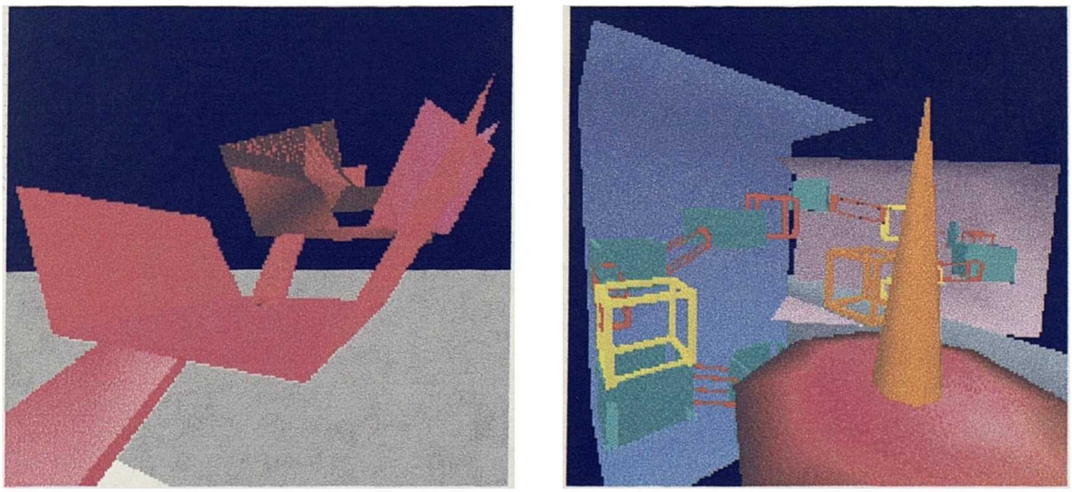

Figure 5.6: Two different types of space-establishing elements: Surfaces used as boundaries - left - and a cone object - right.

Their size and scale, relative to the participant and accordingly the way that they are being perceived may vary widely. A directly experienced surface may be a part of a much larger object, and this object may only be perceived as such only when in a different level of the environment, in terms of scale (Charitos, 1996). In the remaining sub-sections of (5.5), objects in a VE are classified in terms of their function.

5.5.1 Landmarks

When we navigate in a VE, we firstly recognise those objects which are predominant within the context of the environment as seen from our subjective point of view, according to our previous experiences, our goals for entering the environment and our action plans. These are the landmarks of the VE and the type of spatial knowledge that we acquire at this stage is landmark knowledge, as defined in (4.8.1). There is evidence to suggest that this knowledge is hierarchically organised.

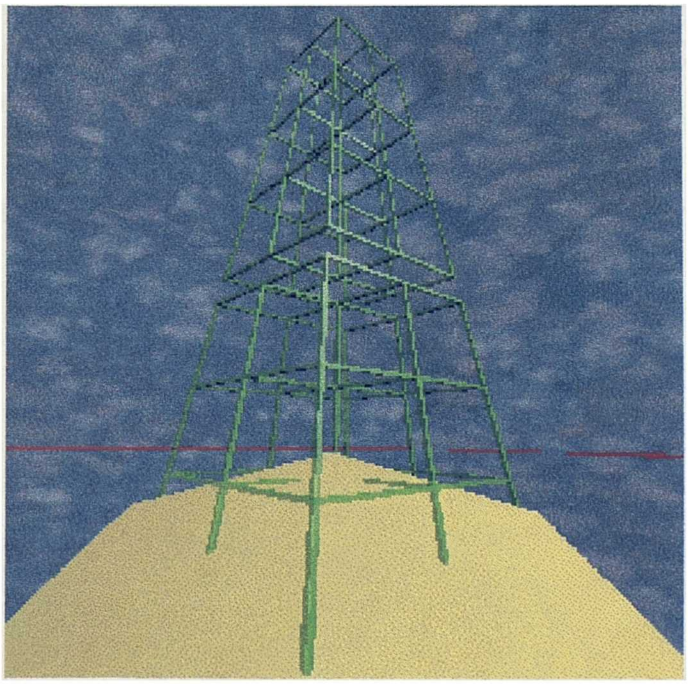

Figure 5.7: A landmark object on top of a sphere.

'Landmark objects', act as points of reference which are singled out from alternate possibilities available in the environment, by virtue of their form or function, for purposes of identification, structuring and orientation. They are space-establishing elements which are understood to be external to the participant who directly experiences them. They usually communicate some meaning to the participant and may vary widely in scale. Landmarks are mainly static but could also be mobile if their motion is sufficiently slow and regular. They are objective in the sense that they refer to all users that may navigate within the environment. However, it is understood that landmark objects become a part of landmark knowledge after having been experienced from a subjective point of view, which implies the influence of the participant's individual experiences, goals and plans. Burnette (1974, p.179) has also stressed the symbolic character of landmarks and has related them to the archetypal form of a tower.

Landmarks can function as:

- Strategic foci to and from which a subject travels, according to Siegel and White (1975);
- Internal foci which may emphasize the gathering function of a place, according to Norberg-Schulz (1996, p.418).

When distant they may symbolise a constant direction or be used as radial references. When local they may be used as clues of identity or structure. Landmarks are also very significant for the acquisition of spatial knowledge; they are, in fact, considered as a necessary condition for wayfinding to occur. Couclelis et al. (1987, p.99) have suggested that salient objects like landmarks are significant for:

- orientation
- recall and
- recognition of other cues.

In differentiated settings, subjects tend to utilise such salient environmental features for wayfinding. When landmarks are available at choice points, subjects will utilise them as guideposts for learning the necessary navigational decisions involving changing and maintaining course direction. (Heft, 1979, pp.172-4) On the other hand, in a relatively undifferentiated setting - which lacks environmental features - as is the case with most laboratory situations and as is often the case in VEs, subjects tend to rely on geographical orientation - to global features of the environment - for wayfinding.

The criteria which may influence the significance of a landmark within the context of a VE - as have been similarly described by Lynch (1960) and Appleyard (1969) for landmarks in REs - may inform the VE designer on how to design the various aspects of a landmark so that it contributes to the user's spatial awareness of the VE. Accordingly, a landmark would be easily identified if it is:

- An object with prominent physical features such as sharp contours, clear form, bright surfaces or there is a definite size disparity between the object and its context; in this case, the object is more easily singled out from the available possibilities in an environment.
- An object which is used frequently.
- An object which evokes symbolic meaning or may be associated with an activity, sign or history.
- An object located at the intersection of paths, which becomes a part of the organisational framework for the cognitive map produced by a user, because it is crossed by many routes; as such it is more likely to be seen as a landmark, especially in a smaller scale context.
- An object which is visible from many locations and which also contrasts with its background, due to its location in the context.

This 'figure-background' contrast does not necessarily refer to the physical characteristics of the landmark, but to any of its characteristics - meaning, style, etc.

However, the way that we functionally relate to a VE may become a more important parameter according to which participants will associate with an object and identify it as a landmark - according to Devlin (1976, p.66) - specifically in the case of:

- an environment with a lack of prominent objects which stand out as clear landmarks or
- when people move frequently and are not expected to stay long enough near an object so as to identify it by virtue of its form.

Apart from generally salient objects within a VE, landmarks may also be seen as:

- discriminable features of a route which signal navigational decisions,
- discriminable features of a region (district) which allow the subject to maintain a general geographical orientation (Appleyard, 1969),
- salient information in a memory task (Sadalla et al., 1980, p.516).

5.5.2 Boundaries

'Boundaries' or 'edges', in a more generic sense than the term used by Lynch (1960), define all spatial elements in a VE by suggesting a spatial form out of the void in varying degrees of explicitness. According to Ching (1979, p.108), space is *"inherently formless; its visual form, quality of light, dimensions and scale depend totally on its boundaries as defined by elements of form"*. Similarly, a VE consists of visual and/or auditory boundaries, which bind and subsequently define all spatial elements in the VE.

The form of boundaries does not need to imitate forms and characteristics of real world objects. This thesis argues, however, that it is important to implement 'collision detection' so that boundaries do not afford movement through themselves. Maintaining this real world constraint results in boundaries expressing a certain 'solidity' and thus defining spaces not only visually but also physically and functionally. If users were able to go through boundaries, these would loose their significance as space-establishing elements.

The appropriate design of boundaries may significantly aid navigation within a VE, in which collision detection is implemented. 'Solid' boundaries may prove a helpful constraint for guiding 'six-degree-of-freedom' movement within a VE. This principle may also become a starting point for designing functionally justified forms in VEs.

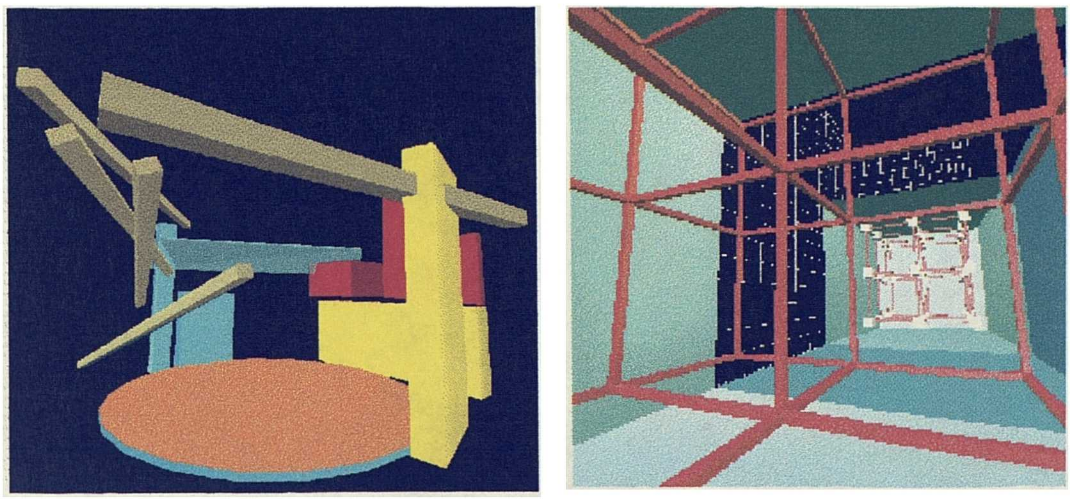

Figure 5.8: A space defined vaguely by its boundaries - left - and a more clearly established space - right.

Boundaries may define a space in varying degrees of explicitness. Thiel (1961) classifies spaces by their degree of spatial definition as

- 'Vagues': spaces vaguely defined by objects in a random or statistical distribution. Vagues are of an indefinite and ambiguous form.
- 'spaces': areas of intermediate degree of explicitness, more or less implicitly suggested and of a fluctuating quality.
- 'Volumes': explicit, completely defined spaces resulting from the use of complete and contiguous surfaces in all positions.

The quantity of boundaries is not necessarily an indication of the explicitness with which a space is defined; the form of the elements and the manner in which they are arranged in space is equally important. 'Spaces' and 'volumes' have a perceptible form and according to this form they may induce a particular response from the participant.

5.5.3 Thresholds

A third intermediate type of object is the 'threshold', which signifies the transition between spaces, while navigating in a VE. Since the 'solidity' of an object depends on whether collision detection is implemented on this object or not, a threshold does not have to be void to afford passage. Therefore, thresholds may be visible objects, similar to boundaries in that they may still define spaces by binding them. At the same time, they functionally differ from boundaries in that they afford movement through themselves, if collision detection is not implemented on them.

Carefully designed thresholds may efficiently signify:

- the transitional experience of passing from one space to the other
- the beginning and the end of a certain space.

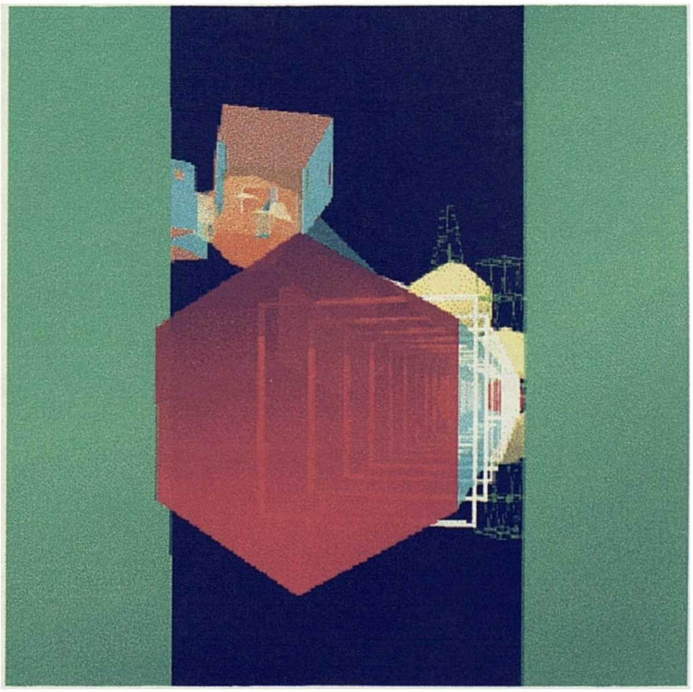

Figure 5.9: A threshold indicating the entrance to a path.

Norberg-Schulz (1971, p.26) mentions the basic dichotomy between the concepts of place and path which is experienced as the tension between centralisation and longitudinality in our environments. A threshold is often the locus of this tension.

5.5.4 Signs

The arrangement of objects in a VE provides the participant not only with a purely plastic experience but with a certain meaning as well. This spatial meaning may range from a philosophical to a purely practical level, where it may affect user orientation and wayfinding within the VE. As was explained in (4.11), such secondary environmental information is indirectly acquired, in relation to a setting, from vicarious information sources such as signs, maps or other types of environmental description.

Thiel (1961, pp. 45-46) has argued that meaning may be indirectly conveyed to the user in the real world by means of:

- signs, which indicate the past, present or future existence of a thing, event or condition and
- symbols, which are vehicles for the conception of things.

These visual and/or auditory signs and symbols convey meaning

- as a consequence of an object's feature - as in the case of landmark objects - or
- implicitly, through the spatial arrangement of the space-establishing objects.

It is essential that a correspondence between the outer form and the inner meaning exists, as without this isomorphism the intended message may be misunderstood.

While landmarks - as defined in (3.6.1) and (5.5.1) - are mainly symbolic objects which may inform a user for identification, structuring and orientation purposes, signs according to Passini (1992, pp.90-92) communicate specific environmental information needed to make wayfinding decisions; they tell the viewer what is where and they also specify when and how an event is likely to occur. Additionally, Passini presents the possible functions that a sign may perform:

- It may designate direction towards a place, an object or an event;
- It may identify an object, a place or a character in a VE; such signs are the most elementary state of description of a location, usually perceived when the destination is reached.
- It may reassure participants that they are on the right track when navigating in a VE; such signs act as checkpoints after a wayfinding decision is made.

Wayfinding signs are, in fact, more effective aids for subjects in an unknown, complex building than 'you-are-here' maps, as Butler et al. (1993) have suggested, due the fact that they provide local spatial information indicating which specific decisions and actions a subject should perform in order to find his way, with a minimal memory load.

A sequence of directional signs may be employed for the purpose of aiding participants in finding their way towards a particular destination within an unfamiliar VE. Such a sequence could be designed according to the following guidelines proposed by Passini (1992, pp.92-107) with respect to signs in REs:

- Signs need to present a brief, clear and visually structured message and indicate the decision needed to be taken by the participant, to effectively aid wayfinding in the VE.
- Signs which belong to such a directional system should be consistent in their graphic identity and also in the location that they are placed within the VE.
- The continuation of directional signs within a sequence should not be interrupted or discontinued as this may result in certain disorientation.
- The complexity and intensity of sensory stimulation provided by the surroundings should be controlled because it may directly affect the reception of information from the participant and the effectiveness of the sign system.

5.6 The elements of space that the content of a virtual environment consists of

There are four different types of void, spatial elements that the three-dimensional content of a VE may consist of. These are defined in this section of the thesis, in terms of their spatial qualities and significance for the navigating participant of the VE

5.6.1 Place - a space for action

When navigating within a VE, a participant may enter a desired destination in order to interact with certain objects which are found there. Such a destination, where certain relatively static actions 'take place' and which actions determine its character, is called 'place'.

Behaviour is place specific in the sense that *"people do different things in different places"* (Ward et al., 1988) A place elicits the behaviour (Barker, 1963 as quoted in Ward, 1988, p.5) and particularly the cognitive and affective responses of a subject to this specific place. However, planning for different goals measurable alters how a place is cognitively and affectively represented and consequently the way that a plan is cognitively and affectively represented presumably influences how a subject behaves in a place. Moreover, we may be influenced in how we experience a previously unknown place by our experiences of all places of similar function we have known (Brewer & Treyens, 1981).

A space is subjectively defined and remembered as a place and is thus tightly related to individual actions and intentions. Relph (1976, p.42-43) suggests that *"places are the contexts or backgrounds of intentionally defined objects or groups of objects or events, or they can be objects of intention in their own right....Those places are* *defined largely in terms of the objects and their meanings. As objects in their own right, places are essentially focuses of attention, usually having a fixed location and possessing features which persist in an identifiable form...They can be at almost any scale depending on the manner in which our intentions are directed and focused."*

For the participant of a VE:

- places may be seen as nodes or landmarks, if the participant is navigating within the VE, but
- we may refer to the node as a place, if the participant has just entered a node in order to involve himself in an activity within the boundaries of this node.

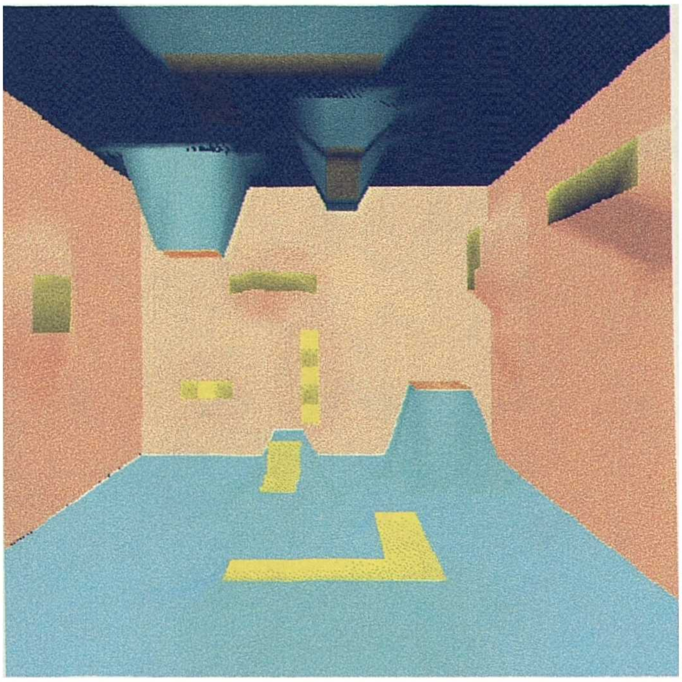

Figure 5.10: View of the interior of a place.

In terms of function, a place may:

- Play the role of a goal for a specific route within the VE, and in this sense it may serve many of the purposes of a landmark in the spatial knowledge acquisition process.

- Help structure the region and become a subgoal with important wayfinding implications (Devlin, 1976, p.66).

As a component of spatial knowledge, a place can be described as a spatial unit. In the context of a cognitive map, a place is assumed to be represented as information about its properties:

- name
- spatial scale
- function
- perceptual characteristics such as affective quality or affordances and
- psychological, affective attributes like pleasantness, aesthetic quality and complexity. (Bell et al., 1996, p.79) and (Garling et al., 1984, p.10)

A place is primarily an 'activity setting' (Burnette, 1974, p.180) of an egocentric character. The design of a place for a particular activity is only meaningful in terms of the user and his satisfaction and therefore may be related to the affective pursuit of the ideal of happiness for this user. The place concept may also be related to the archetypal concepts of the 'cave' and the 'home'.

A place may also be seen as a choice point - a position in a VE where navigational choices are made - which is a significant node within the system of routes in the cognitive map of a VE. Such a location - place - is recognised more quickly and more accurately if the participant is familiar with it as a result of previous exposure. (Golledge et al., 1985, p.149) Moreover, such a place, which may function as a choice point, may also influence the way that participants remember a route that is anchored to this place.

In (4.10) it has been suggested that knowledge about a system of places/nodes/landmarks is hierarchically organised:

- firstly there are primary nodes, such as the origin and destination for a route or task, a person's home or place of work;
- secondly there are interstitial nodes identifying key choice points or lower order nodes that help define expectations with respect to the location of choice points;
- finally there are miscellaneous cues that act as a general referent and provide 'security information' - because of familiarity - during wayfinding. (Golledge et al., 1985, pp.142-3)

It has also been argued in (3.3.1) that when the relations between the 'inside' and 'outside' of a place are clearly defined by the boundaries of the place, a subject can 'dwell' in a place, which implies that he can orientate and identify with the place, find the place meaningful and consequently feel secure in there. Humans need to feel secure and to identify with a certain space in order to engage in activity in the space. Therefore the concept of a place is strongly connected to a situation where these fundamental human needs are being satisfied. It may then be suggested that in a VE, as is the case in real environments, the degree of explicitness with which this place is defined by its boundaries determines the feeling of security or comfort with which we engage into an activity in this place and consequently affects the performance of a particular activity in there. As this hypothesis is considered crucial for the design of places, it is essential to test it by means of experimentation.

The form of a place, of course, affects the way that we experience it. A clearly defined place which is experienced as an 'inside' generates a spatial sense of proximity, centralisation and closure (Norberg-Schulz, 1971, p.20). Centralisation implies a sense of concentration and decreases the apparent size of a place. Geometrisation of a place's form may enhance this effect. The validity of this suggestion, as well, needs to be tested in VEs, as it may be particularly important for designing places.

A qualitative distinction between spaces, in terms of their formal configuration, has been made in (3.3.1). This distinction suggests that environments mainly consist of configurations which may be seen as:

- 'Centralised' characterised by a sense of completeness, closure, cohesion, a tendency towards a centre, symmetry and balance which are most likely to be places. Such spaces imply static action generally relating to a centre or the periphery of their spatial configuration and according to Norberg-Schulz (1971, p.26) they also symbolise the need for belonging to a place.
- 'Longitudinal' which imply a certain dynamism, a tendency towards mobility, freedom, expansion and change and which are likely to be paths.

In the composition of such spatial elements however, there will be spaces where both tendencies are combined and the character of such spaces is determined by the way that this combination is structured. The relevance of the above mentioned distinction and its impact on human wayfinding behaviour in VEs has to be studied by experimental methods of research.

Norberg-Schulz (Nesbitt, 1996, p.414) describes a place as "*a totality made up of concrete things having material substance, shape, texture and colour. Together these things determine an 'environmental character' (or atmosphere), which are the essence of place.*" We cannot reduce the totality of the qualitative phenomenon of place to any of its properties, such as spatial relationships, without loosing its concrete nature, therefore a place cannot be described by means of analytic, scientific concepts.

5.6.2 Route and path - spaces for movement

Burnette (1974, p.181) suggests that

- While the concept of a place is egocentric and refers to a relatively static activity which is limited within the boundaries that define the place,

- a path refers to movement which is a functional and dynamic activity and which is characterised by behavioural continuity.

He describes the path as a 'movement channel' and relates it to the archetypal concepts of the road and the river and to the ideal of efficiency as appropriate use of energy.

As is the case in the real world then, a path in a VE is a kind of space which implies movement and within which directions are always evident, due to the formal qualities of its spatial arrangement. When navigating in a VE, after identifying certain landmarks, we begin to think of the routes which connect these landmarks and as a result we acquire route knowledge. The physical expression of a route is the path.

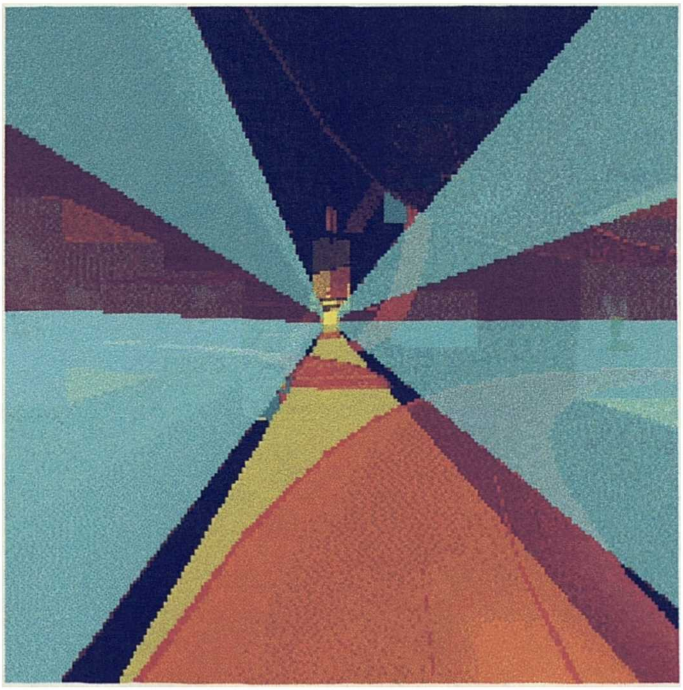

Figure 5.11: View along a path.

Considering spaces in terms of their formal configuration and consequent volumetric proportions, Thiel (1961, p.40) has introduced the concept of 'run' as a space or volume which has any one overall dimension - length, breadth or height - two or more times greater than any other dimension. A 'run' has an implicit directional character. Being inside such a space induces movement of the eye or the body along an implicit direction which coincides with the greater dimension of the space. This view is in agreement with Merleau-Ponty's 'virtual body' understanding of spatial potentiality for a navigating subject, which was explained in (2.2.1). Such a space in the real world is likely to be a path of some sort - horizontal or vertical. As such, it may be argued that the concept of the 'run' describes the physical requirements for a path in a VE as well. However, the hypothesis that a space which has the volumetric proportions of a 'run', in a VE, would induce movement towards the direction it implies, needs to be tested by means of experimentation.

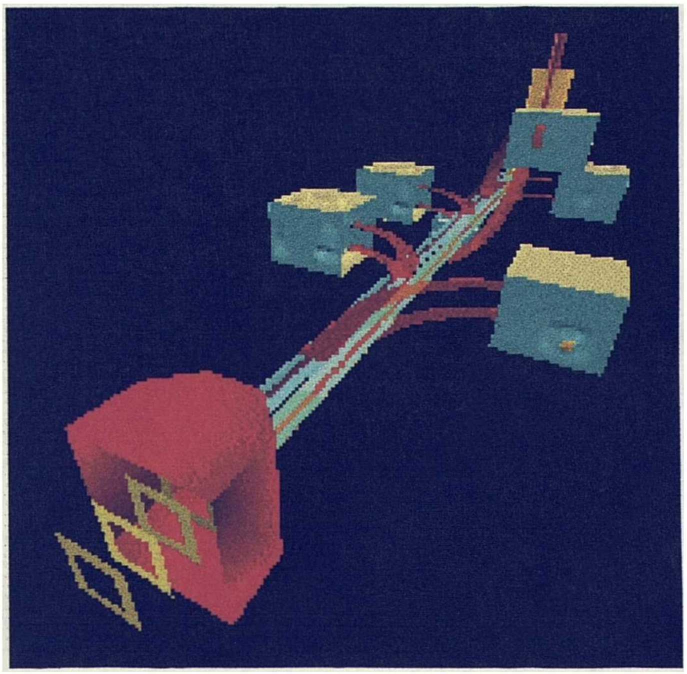

Figure 5.12: A path with a starting point, certain events along its direction and a final goal - destination.

Route knowledge comprises the knowledge of sequences of places, landmarks and the distance segments connecting them, a sense of time needed for navigating these sequences, a sense of direction relationships between these distance segments and a knowledge of barriers that might occur along a given route; it does not, however, comprise the knowledge of general interrelationships between these elements (Golledge, 1991, p.47). When designing a path, which is going to be experienced as a segment of route knowledge, it is essential to make its structure clear to users so that they easily 'read' the spatial configuration and consequently remember how to navigate this path. Accordingly, the generic parts that the path consists of:

- the starting point,
- the direction of movement and
- the final goal,

should be easily identified, so that users know where to start the movement from, which direction to follow and where the movement will end (Figure 5.12). It is also important to provide cues for informing participants of directional relationships between consequent paths.

According to Golledge (1991, p.48) and Gale et al. (1990, p.4), knowledge about routes may also contain:

- decision points, along with
- the knowledge and description of the appropriate actions to perform at those choice points.

At a more detailed level, route knowledge includes:

- information concerning less significant landmarks along the route,
- distances between landmarks
- relations of landmarks and route segments to a larger frame of reference
- the angle of turns between segments of the route. (Thorndyke and Hayes-Roth, 1980, p.5)

It may then be suggested that we may adequately enhance the legibility of a path in a VE, by improving the visual impact of places which are located at points along the path, where important navigational choices are more likely to take place. A landmark, which complies to the criteria set for landmark significance in (5.5.1), may be particularly effective in aiding the recall of a particular navigational decision, if it is positioned at a possible choice point.

Heft (1979, pp.172-4) has emphasised the significance of salient features such as landmarks and of other important characteristics of the setting - specific turns of routes for example - for the acquisition of spatial knowledge. In differentiated settings, subjects tend to utilise such environmental features for learning the necessary navigational decisions involving changing and maintaining course direction. In a relatively undifferentiated setting, which lacks environmental features - as is the case with most laboratory situations and as is often the case in VEs - subjects may

- resort to learning particular navigational choices - e.g. particular route turns - or
- rely on geographical orientation, aided by support systems which provide indirect secondary environmental information - explained in (5.4) - for wayfinding. (Heft, 1979, pp.172-4)

It may then be argued that VEs have to be somehow differentiated and complex enough to provide participants with environmental information which may help them remember their way along routes within these VEs. Moreover, they should include several salient features appropriately positioned so as to serve as guideposts for navigational decisions in the VE. In the case of a less differentiated VE, the route turns along a path should be visually enhanced so as to aid the recall of navigational decisions by the participant.

Knowledge of a route is focused on key loci representing such points where navigational choices are made (Golledge et al., 1985, p.144, 149) and is accordingly segmented by these choice points. Couclelis et al. (1987, p.99) have also identified a tendency towards route segmentation. The resulting segments are hierarchically remembered according to the significance of the choice points that they are anchored to (Golledge, 1991, p.47). It may then be suggested that we may influence the significance of paths within the context of a VEs, by appropriately enhancing the visual impact of the landmarks or places that these paths are anchored to.

When designing paths in VEs, it is useful to be aware of the fact that routes with more intersections may be seen as longer than routes with fewer intersections (Sadalla and Staplin, 1980) and similarly routes with more turns may be estimated to be longer than routes with fewer turns (Sadalla and Magel, 1980). Generally, the distance between two points along a route may be influenced by the amount of information stored in memory that must be processed to mentally traverse this section of the route between them (Golledge, 1991, p.49). In this sense, our conception of distance between two points in a RE or a VE, may be altered if a significant object or event is placed on route from the one point to the other.

Moreover in VEs, the lack of environmental complexity and the relativity of scale may further distort the temporal aspect of our spatial knowledge about traversed routes. It is then considered essential that some visual feedback is provided for informing users of the distance they have traversed along a path and of their velocity, at each moment in time. This could be achieved by arranging rhythmically repeated elements at equal intervals along the path.

Finally, it is important to mention that the level of user interaction with the environment is fundamental for the acquisition of route knowledge. In specific, active engagement in navigation enhances such knowledge, considerably more than passive viewing does. Learning 'about' may come by seeing, but apparently learning 'how to' comes only by knowing. We associate places with actions, kinesthetic feedback and with all other sensory input, in order to produce the knowledge necessary for informing navigation (Gale et al., 1990, p.21). It could therefore be argued that participants of immersive VEs may benefit more in terms of route knowledge acquisition, than participants of desktop VE, since they are involved in active navigation, in which bodily movements may contribute as well.

5.6.3 Intersections

Choice points along a path are likely to be intersections of paths. When we acquire route knowledge, more information is coded at intersections, where choices are made as opposed to between intersections and therefore it was suggested in (4.8.2) that intersections are the foci of route knowledge (Gale et al., 1990, pp.20-22). Scenes at intersections are selected and stored with the highest frequency because subjects have several actual or potential navigation choices to choose from and also because such scenes are usually visually richer and more complex. Additionally, the novelty of having fresh visual stimulus where new views are first seen may contribute significantly to focusing attention and encoding information at an intersection (Figure 5.13).

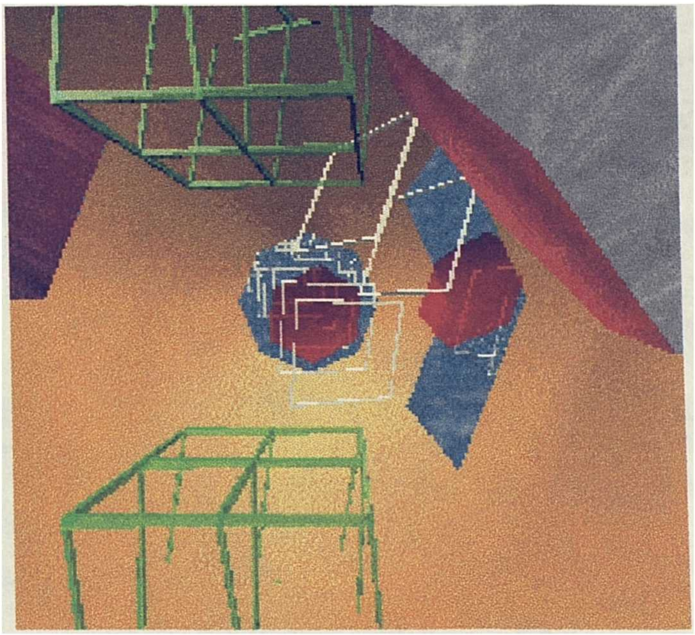

Figure 5.13: The interior of an intersection, where several paths merge. Each red threshold indicates the entrance to a path.

Similarly, both landmarks and scenes, which are anchored at choice points and located on routes that have to be navigated and learned, were significantly better recognised and recalled than those landmarks and scenes which are not important for the decision-making process of the navigation task (Golledge et al., 1985). Therefore, it can be argued that nodes or intersections of routes are particularly significant because they are the main decision points, when navigating in a real environment or a VE and therefore they need to be considered as a separate type of spatial element (Figure 5.14).

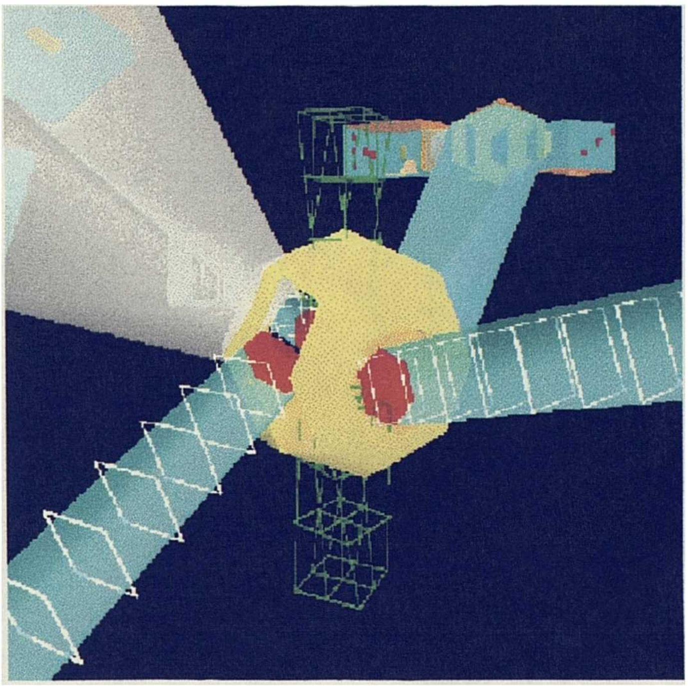

Figure 5.14: A yellow intersection positioned at a point where several paths merge. A landmark is integrated with this intersection.

'Intersections' thus are defined as the spaces of interaction between other spatial elements in a VE. Smyth et al. (1994, p.312) have concluded that landmarks become positioned in space when they are crossed by many routes, therefore becoming a major part of the organisational framework for our mental map of the environment. Accordingly, this thesis suggests that if an object is positioned at an intersection of paths within a VE, it is more likely to be identified as a landmark and integrated in the environmental image of a user who navigates within this VE. Additionally, if this object is located at an intersection, we may remember it as a landmark because of the navigational decisions which were made at this intersection. By being a part of the intersection, a landmark adds to the individual spatial character of this intersection thus making it memorable in association with this particular landmark. These hypotheses, however, are in need of experimental evaluation.

5.6.4 Domain or area or region - a subset of the VE

At the final stage of acquiring spatial knowledge when navigating in a real environment, we begin to think of the interrelationships of all the above mentioned elements by utilising the properties of distance and direction within three-dimensional space. This final type of spatial knowledge has been defined in (4.8.3) as configuration or survey knowledge and may be seen as corresponding with the spatial element that Norberg-Schulz named 'domain' (1971) and Lynch named 'district' (1960). It is then suggested that we may consider a domain as a subset of the whole VE, which consists of a system of paths and places.

The production of domains expresses man's general need for imagining his world as an *"ordered cosmos within an unordered chaos...By structuring the environment into domains by means of paths and places"* (Norberg-Schulz,1971, p.23). This need has also been identified in (4.9) by Couclelis et al. (1987, p.99) as a tendency towards regionalisation - the breakdown of space into discrete regions - in the generation of cognitive maps. They also identify the presence of a hierarchical organisation in the structure of such regions and put forward a model according to which landmarks or other primary nodes anchor distinct regions in cognitive maps of any given environment. In this sense, an RE or a VE may be seen as comprising known regions within which distances are better known, but between which distance knowledge is less precise. In each region, one particular element, which may be a landmark or a place, functions as a reference point which cognitively anchors the entire region (Bell et al., 1996, p.98). It may also be suggested that it is necessary to structure a VE by means of domains, in order to be able to conceptualise it as a whole.

We relate to landmarks in a direct, experiential manner by viewing and identifying them. Similarly, we relate to routes by moving along them. Domains, in the real world though, are mainly thought of rather than experienced, since we cannot directly experience them as a whole. However, if scale is not consistent, as has been explained in (5.3.3), then a domain may be experienced as a whole if its scale is decreased.

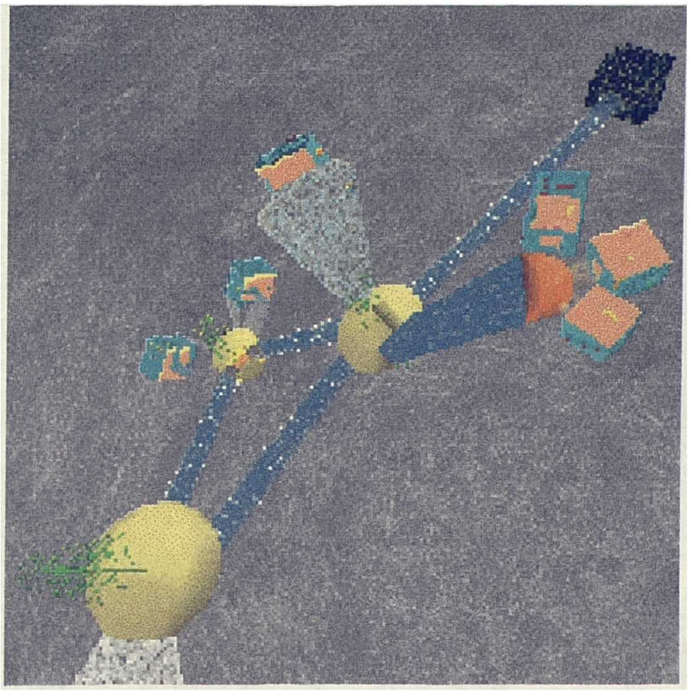

Figure 5.15: A domain comprising places, paths, their intersections and landmarks.

Moreover, as was suggested in (5.5.2), a participant may be able to fly without constraints within a VE and accordingly position his viewpoint quite far from a domain, so that he can directly experience the whole domain from this distance. The transition of procedural knowledge to survey knowledge is attributed to extensive navigation in a real environment (Thorndyke and Hayes-Roth, 1980 ,p.51-52). It is however understood that a participant may acquire survey knowledge about a domain by directly viewing the whole of this domain from a certain distance, as if viewing a map. It may then be argued that survey knowledge about domains in VEs does not need to involve extensive navigation but may be acquired by appropriately positioning one's viewpoint so as to view the whole of the domain.

Survey knowledge about segments of a VE may be directly provided to a participant by means of a map or any other analogical representation of this VE which he may experience within the display. The development of such aids for navigation has been covered in Darken and Sibert (1993) and Charitos and Rutherford (1996).

In the real world domains expand in two dimensions, due to physical constraints such as gravity. In VEs though, which are devoid of such constraints, domains may expand in three or more dimensions. Finally, it may be useful to mention that in REs, there is evidence which suggests that subjects comprehend path structures with parallel streets and perpendicular intersections more readily than intersections at smaller angles. (deJonge, 1962; Tzamir, 1975; as quoted in Evans, 1980, p.280)

5.6.5 Portals

A spatial element which is specific to synthetic environments is the 'portal'. This element may be seen as the physical expression of the characteristic of spatial discontinuity in VEs, as explained in (5.3.3).

Before explaining the concept of a portal however it is necessary to define the concept of the 'universe'. According to the World Up™ documentation (World Up User's Guide, 1996) every aspect of a simulation takes place in an area known as the 'universe'. The universe is the volume of space in which all graphical objects appear in a simulation. Any location in space can be described by its (x,y,z) coordinates relative to the origin. The origin is the center of the volume, which is located at (x,y,z) coordinates (0,0,0). Unlike real life, where the universe expands outward infinitely, a universe in World Up™ expands outward only to the floating point capacity of the computer.

From an architectural perspective, the universe is a three-dimensional Cartesian world which contains all objects within a representation. World Up^{TM}, however supports the linking of several such universes. This linking could be triggered through an event, initiated by the participant when he passes through the portal, which may start the loading of a new universe. As this new universe is loaded and displayed, the old universe can either continue to be displayed along with the new one or can be erased. In the former case, all universes may exist in the same Cartesian world sharing the same origin; this implementation is similar to a 'Level of Detail' implementation. In the latter case however, when a subject passes through a portal and the new universe is loaded, the old one disappears. This phenomenon implies that each of these universes belongs to its own Cartesian space and origin and it is not possible to conceptualise of the spatial relation between the two universes. This latter implementation describes the spatial discontinuity of VEs.

A portal which links two remote universes, therefore, is:

- a kind of threshold, in the sense that it signifies the passage from one spatial element to another but is also
- a kind of path, in that it affords movement within itself, between two remote positions within the VE.

Finally, a portal differs from both thresholds and paths, in that it does not necessarily comply to a Cartesian conception of space and therefore has to be considered as an individual type of spatial element. It is suggested that the form of a portal should be designed so as to signify its unique function; that it affords teleportation within a VE.

5.7 The organisation of spatial elements within a VE

The structure of space in real environments was discussed in (3.5), where ways of arranging the proposed elements of space into configurations were suggested. After proposing a taxonomy of space-establishing and spatial elements that a VE may consist of, it is necessary to suggest ways of structuring these elements within a VE.

The significance of a certain fixed point within space, from where a subject may orientate, was stressed by Eliade (1987, pp.20-22): *"nothing can begin, nothing can be done, without a previous orientation - and any orientation implies acquiring a fixed point".* Having established a centre within a VE, humans may begin to explore the rest of their environment. This centre may be used as a global reference point for orientation, for the purpose of aiding navigation and wayfinding. Moreover, the need for a sense of orientation to a vertical and horizontal direction, for a human in the real environment, has been explained in (3.3.2). Accordingly, it may be suggested that there should be cues which may inform a participant in a VE of the relation of their viewpoint to a global vertical - above and below - or horizontal direction at all times.

Places within a VE may be connected to other places by several paths, which may or may not intersect with each other. Intersections may accommodate the space where paths merge. It is necessary to suggest principles according to which these spatial elements could be arranged into systems of paths, intersections, places and domains for the purpose of structuring a VE.

Kaplan (as quoted in Evans, 1980, p.280) has suggested two criteria which make an environment preferable by individuals:

- Coherence is the degree to which a scene 'hangs together' or has organisation. Structural features that provide coherence include continuous texture gradients, thematic colour or graphic patterns and variable but identifiable physical forms.
- Moderate uncertainty is provided by variety, moderate complexity, moderate spaciousness and occasional structural irregularities.

Five possible generic categories of spatial organisation, which could be implemented for arranging spatial elements within a VE, were proposed in (3.5) according to Ching (1979, p.205):

1) In a centralised organisation, a number of spaces are arranged around a central dominant space in an introvert and geometrically regular composition. Such arrangements may be used for establishing a certain point in space or for terminating an axial composition in a VE (Ching, 1979, p.206-7).

2) A linear organisation may consist of a series of places, directly related to one another or linked through a path. The beginning, the end or the rhythm of repetition of spaces in the series along this organisation may be emphasised. The form of a linear organisation can relate to other forms by

- linking them along its length,
- serving as a barrier to separate them or
- surrounding and enclosing them within a field of space (Ching, 1979, pp.214-215).

3) A radial organisation consists of a dominant central space from which a number of linear organisations extend in a radial manner. Such an arrangement, combines the introvert character and regular form of a centralised arrangement with the dynamism of linear elements (Ching, 1979, p.224).

4) In a clustered organisation places do not have to be similar but may relate to each other by proximity or by another ordering device, such as symmetry or axis. Such an organisation is flexible and can accept change without significant change of its character (Ching, 1979, p.230).

5) A grid organisation consists of elements whose position in space and interrelationships are regulated by a two or three-dimensional grid pattern or field. The characteristics of this arrangement are the regularity and continuity of its pattern which are more powerful than the elements it organises. The identity of the structural pattern is not altered if any of the elements are changed, therefore the grid is flexible in changes, growth and expansion (Ching, 1979, pp.238-239).

5.8 Scale and levels of existential space in VEs

This thesis deals with large-scale VEs, as these have been defined in (5.2.2). Existential space was seen in (3.7) as structured in a horizontal and a vertical sense:

- The horizontal structure comprises the different types of spatial elements
- The vertical structure comprises the different levels of existential space or in other words, all possible categories of environments in terms of scale.

In a similar way, a VE may be structured in

- a horizontal manner, in terms of different types of spatial elements - paths, places, domains, intersections and portals - and
- in a vertical manner by all possible categories of environments in terms of scale.

The way in which a subject relates to his environment depends on the scale of this environment, as was assumed in (4.7). However, it has been suggested in (5.3.3), that scale is not necessarily consistent in a VE. Moreover, it was explained in (5.5.3) that we may experience larger parts of a VE, like a domain, in a more direct manner, due to the lack of navigational constraints in VEs. A vertical structuring of existential space in VEs in a manner similar to the one suggested by Norberg-Schulz for REs is therefore questionable.

We may argue, however, that the urban level of existential space in the real world, as defined by Norberg-Schulz, may be considered relevant to the problem of existential space in VEs:

- because of the significance of the urban level as the main context where man's sense of place is being developed,
- because of its scale relative to the human body, which could roughly be compared to a legible, large-scale VE.

With respect to a navigating participant, the sense of scale in a VE also depends on how easily can this participant sense their position along the length of the path or grasp the distance they have traversed or they have yet to go. Scaling, along a path, may be accomplished by a sequence of known landmarks, nodes or even repetitive objects. Features that may facilitate scaling may also give a sense of direction. These suggestions however, need to be evaluated by more objective methods of research.

5.9 The implications of dynamically evolving VEs

Humans develop spatial schemata at a very young age, through sensorimotor activity or through communication of experiences and cultural traditions; they continuously update a large part of these schemata through new experiences in the real world. It has been explained in (5.3) however, that space in REs differs significantly from space in VEs. It is assumed, therefore, that a participant of a VE has to develop new spatial schemata or to adapt the existing schemata which have been acquired as a result of his real world spatial experiences to the nature of space in a VE, in order to cope with experiencing such synthetic spaces.

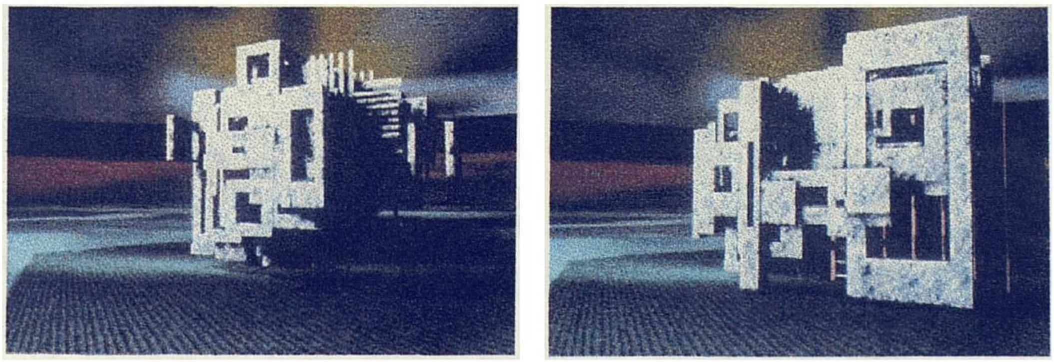

Figure 5.16: Two consecutive images from a dynamically evolving three-dimensional composition comprising a 'liquid architecture' (Novak, 1991, colour plates 24, 25).

The liquid intrinsic nature of VEs (Figure 5.16), as identified by Novak (1991, pp.248-251), may hinder the establishment of such schemata. The assumption that a mobile, wholly-changing environment can be disorientating is put forward by Norberg-Schulz (1971, p.35), who agrees with Piaget in that *"a mobile world would tie a man to an 'egocentric' stage, while a stable and structured world frees his intelligence".* The framework that has been suggested in this chapter aims at informing the design of such stable and structured VEs, which may function as the setting for efficient navigation, wayfinding and the performance of activities.

CHAPTER (6)

6. BACKGROUND TO THE EXPERIMENTAL STAGE - TWO EXPERIMENTS ABOUT FACTORS WHICH MAY AFFECT MOVEMENT IN A SPACE

6.1 Introduction

The following chapters present an evaluation of certain aspects of the framework, proposed in chapter (5). It soon became obvious that the evaluation of the whole framework was too complex and ambitious a scheme, far exceeding the objectives of this thesis, since this framework consists of a large number of suggestions and guidelines for the spatial design of VEs. What was thought to be more feasible within the time limits of this thesis was to:

1) Firstly, implement the framework by designing several pilot VEs which utilised the suggestions and guidelines of this framework;

2) Secondly, identify several significant design issues, which could correspond to specific claims made within the framework;

3) Finally, design a number of experiments to investigate these specific issues.

The aim of this evaluation phase of the thesis would then be to draw conclusions as to how the arrangement of spaces affects the spatial behaviour and performance of subjects, in different scenarios of navigation and interaction.

During the first stage of the evaluation, the author experimented with the design of several VEs by generally following the hypothesis proposed in chapter (5). The type of

VEs that this thesis refers to was more precisely defined in (1.7) and (5.2.5) and accordingly this definition dictated the kind of application which was deemed appropriate for the purpose of the evaluation. It was, however, necessary to loosely define a particular application to which the VEs could function as an interface. Defining such an application would constrain the design of experimental VEs on requirements relating to specific objectives and situations.

6.2 Defining a hypothetical application

It was clarified in (1.7) that the design concepts and ideas presented in the chapter (5) mainly refer to environments where abstract entities are metaphorically represented by audio/visual counterparts, in the context of an interactive VE. It is assumed that the main advantage of using a VE as an interface - as opposed to a two-dimensional interface - in such an application, is that the VE makes use of the participant's intuitive skills for orientation, wayfinding and manipulation of objects in the real world and thus enhances his interaction with large and complex information structures.

It was decided that the subject of the pilot design would consist of VEs which would function as a three-dimensional interfaces to a hypermedia database, for the purpose of enhancing navigation and information retrieval within this database's complex information structures. The hypothetical hypermedia database, on the basis of which the interface was designed, is supposed to be a container of art-related information of any format, which is available to any user for viewing and/or for downloading. It is necessary, however, to explain the background to the design of this particular application.

Tasks which were assumed to be performed by the possible users of such an interface would be:

- exploration of the spatial representation of the database,

- starting from a home-place and finding several specific objects situated in the database,
- finding a specific place within the database,
- finding specific 'data-objects' which are located within such places.

In terms of the conceptual design of the interface, after generally defining the design problem, a definition of the particular type of 'data-objects' which could be stored in such a database and appropriately visualised in the VE, was needed. Observing various relevant sites which exist on the World Wide Web proved helpful for this purpose. The recent emergence of the concept of MCF[10] and, in general, of a tendency towards visually representing the content existing on-line or on an individual workstation within one unified interface, provided this thesis with an indication of what could be the data input for the suggested representation. Accordingly, the three-dimensional interactive representation of the content of the hypermedia database could be generated on the basis of a level of information-on-information - as in the case of meta-content in the MCF format - existing on top of the actual content information.

This information might include the address of the object, its parents and children, a description, the author, the type of media and most importantly the topic, size, date and links to other addresses. Because of its smaller size, this information can be easily transferred between users and provide the input for generating the simulation. This implies that the actual data-objects which are represented do not need to exist on the desktop, where the simulation takes place; only the meta-content information is needed for generating the representation and the actual objects may be retrieved when needed.

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[10] 'MCF' is an abbreviation for 'meta-content format', a concept underlying the implementation of the HotSauce project - formerly Project X - developed by Apple. MCF is a scaled down knowledge representation language for describing knowledge about the web. MCF appears to still be in an early stage of development. More information about MCF can be found in the following web sites:

http://www.millennial.org/mail/talk/fmf-cyber/hyper/1206.html

http://www.macaddict.com/issues/1096/info.projectx.html

In terms of the physical design of the interface, the procedure was mainly dictated by the definition of the problem. What was needed was a three-dimensional interactive desktop VE, which would function as the desired interface. The intention underlying this design was that the interface should be as intuitive and as three-dimensional as possible, by avoiding two-dimensional elements, such as dialogue boxes or input through keyboard commands. It is also understood that the design of the hypothetical application did not deal with aspects of the problem relating to software architecture, on-line information retrieval or HCI design, as they were beyond the scope of this project.

The main design problem had the following aspects:

1) how to give form to abstract entities of information,
2) how to classify them and accordingly represent these sets of objects in the interface,
3) how to build legible and coherent environments which would function as the setting for these representations, so as to facilitate orientation and wayfinding within them.

The design of VEs at this stage of the thesis only dealt with the third aspect of the design problem as this was more relevant to the architectural aspect of VE design, which is the central concern of this thesis.

The first solution that is usually suggested, in the case of the spatial design of such VEs, is the identification of appropriate metaphors. However, a problem with employing metaphors is that they may prove limiting, because they carry with them associations which may impose unnecessary constraints to the design of a VE. This would be the case if an overall environment metaphor had been employed. It was suggested, therefore, that metaphors should only be employed at the levels of :

- information presentation and
- interaction.

The overall hypermedia database structure could consist of two parts:

- A repository space for art-related information - images, texture maps, material libraries or three-dimensional models of objects - which could be downloaded.
- An exhibition space where art works, which have hypothetically been uploaded to the database, are displayed; these works could be three-dimensional environments, three-dimensional objects, images, etc.

Alternatively, links to other such VEs could be appropriately placed in the designed VE although the serious operational and representational problems posed by such a 'hypertextual' structure should not be underestimated.

6.3 Designing several pilot VEs and identifying issues for investigation

On the basis of the above mentioned requirements for an interface, several VEs which followed the suggestions and guidelines presented in chapter (5) were designed as pilot design studies. Some images of these pilot VEs have already been used for the purpose of illustrating the taxonomy of spatial elements in a VE, in chapter (5). Other examples of VEs, which were designed by the author during this stage of the evaluation are presented below.

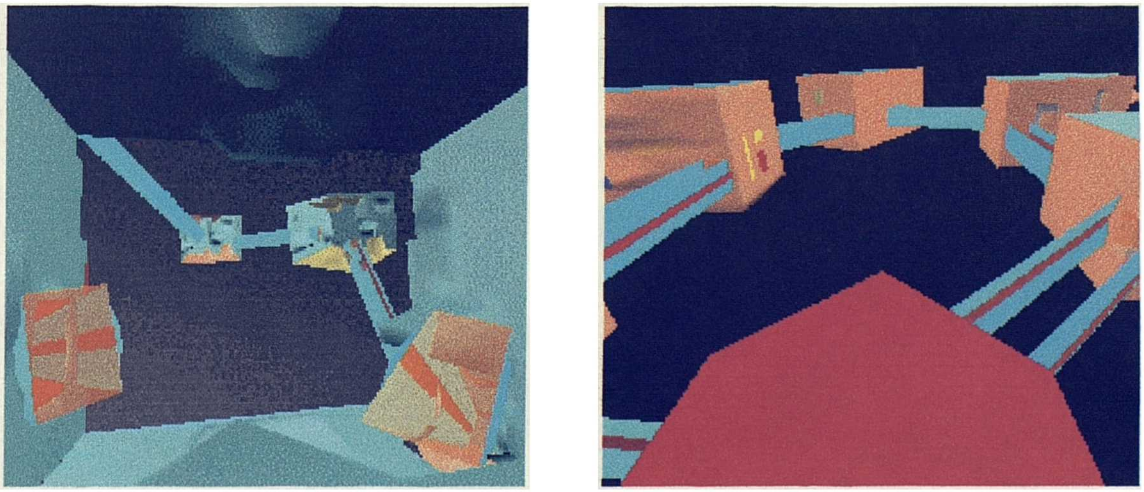

Figure 6.1: Two instances of a domain with a 'ring' configuration: view from inside a place - left - and view from the top of the domain - right.

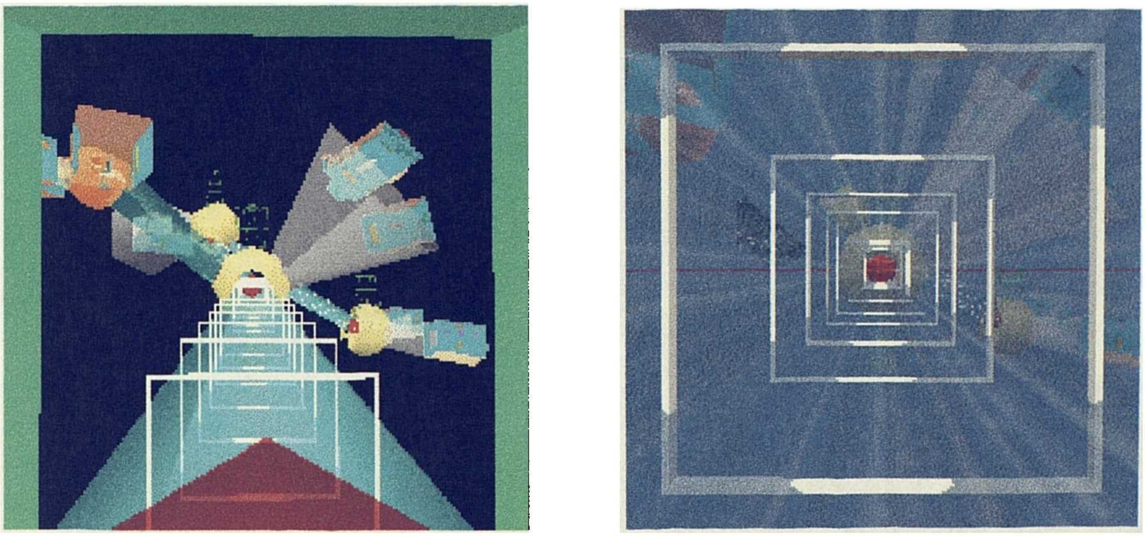

Figure 6.2: Two views from the entrance of a domain with a 'star network' configuration.

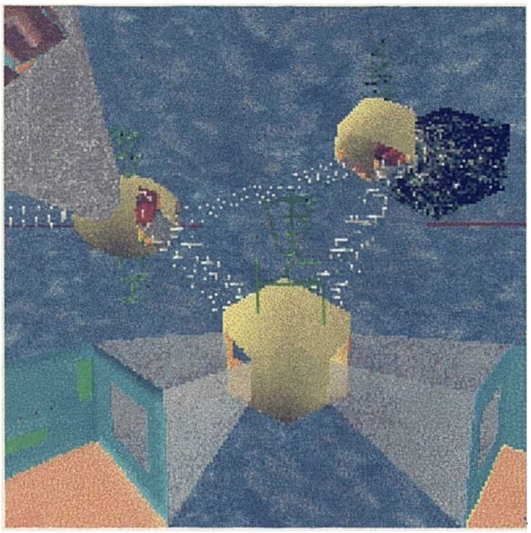

Figure 6.3: Three yellow intersections where paths merge within a domain

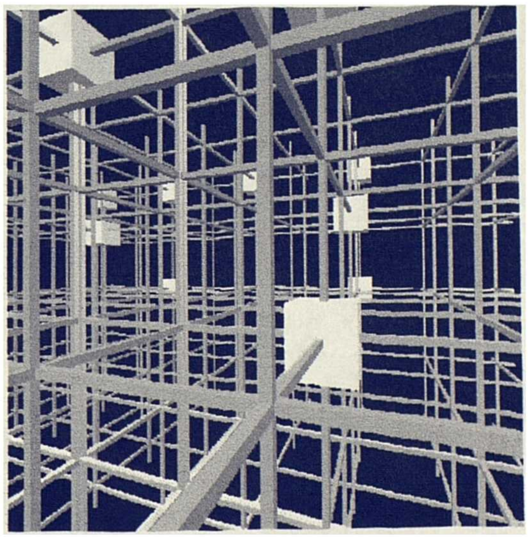

Figure 6.4: A three-dimensional grid configuration

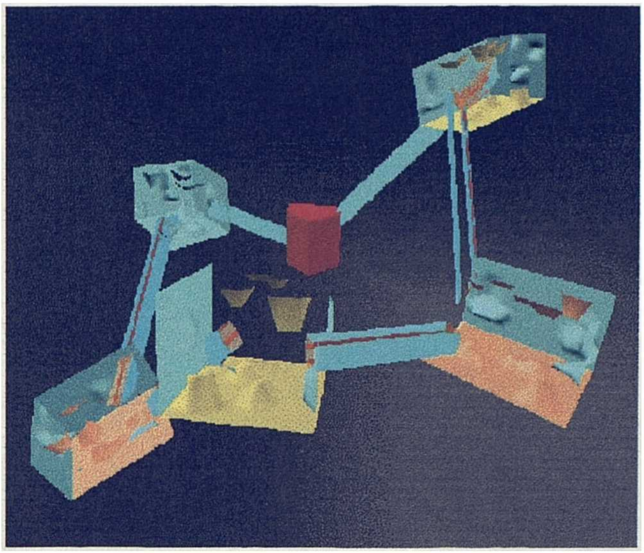

Figure 6.5: A view of a domain with a 'ring' configuration.

During the design process, several key issues were identified as being in need of further investigation through experimental methods of research. These issues mainly related to

- movement within spaces in VEs
- aspects of the design of places and paths
- the composition of these two elements within a domain of a VE.

It is understood, however, that these issues for evaluation have been identified in a somehow arbitrary manner. The main explanation for selecting these particular issues is that all of them corresponded to situations where the impact of an environmental parameter to the behaviour of a subject could not be predicted. Since doubts about this impact were very often felt by the author, who designed the pilot VEs, an investigation of these environmental parameters was considered very significant for informing the design of space in VEs.

The key design issues, identified during this stage, are the following:

1) What impact would texture maps and rhythmically repeated formal elements, applied on the surfaces of path boundaries, have on the sense of movement felt by subjects moving along a path. In (5.6.2), it has been suggested that rhythmically repeated formal elements could inform a subject moving along a path of his velocity of movement and of the distance that he has travelled at a moment in time. The awareness of these parameters was thought to be related to the sense of movement felt by a subject. In this sense, investigating the impact of rhythmically repeated elements along a path to a subject's sense of movement may be seen as evaluating the claim made in (5.6.2). Moreover, the impact of texture maps on surfaces of path boundaries was indeed felt by several subjects who used the pilot VEs. It was therefore considered appropriate to investigate this impact by experimental methods.

2) What impact would the volumetric proportions of a space have on the way that a subject moves within this space. In (5.6.2), paths were suggested to be corresponding to the volumetric proportions of a 'run', as this concept was defined by Thiel (1961, p.40). It has also been argued in (5.6.2) that being inside such a space induces movement of the eye or the body along an implicit direction which coincides with the greater dimension of the space. It was therefore thought appropriate to investigate whether the navigational behaviour of subjects was in accordance with this assumption.

3) What impact would the form of a place have on the behaviour of subjects. It was suggested in (5.6.1) that the form of a place affects the way that we experience the place. In specific, centralisation of a place's shape was assumed to decrease the apparent size of the place and this effect could be enhanced by geometrisation of this place's shape. Therefore, the impact of the shape of a place on the apparent size and the appropriateness of this place for performing a particular task were investigated.

4) What impact would the degree of explicitness, with which a place is defined, have on the behaviour of subjects performing a task in this place. In (5.6.1) it was suggested that the degree of explicitness, with which a place is defined by its boundaries, determines the feeling of security or comfort with which we engage into an activity in this place and consequently affects the performance of a

particular activity in there. The validity of this assumption is considered crucial for the design of places and was therefore investigated by experimental methods.

5) During the design of the pilot VEs, it became obvious that if a place was positioned at some particular angles in relation to a path, a subject who moved into or out of the place would become somehow disorientated. This phenomenon indicated an issue which was crucial for the composition of sets of places and paths within domains. Accordingly, the impact of the way, that a place was positioned in relation to a horizontal path, on the orientation of subjects who moved into or out of the place, was investigated by experimental methods.

6) During the design of pilot VEs, it became obvious that if a path was orientated in some particular ways in relation to the two places that this path was connecting, then subjects became disorientated when moving along these paths. This phenomenon indicated the need for investigating the impact of the way that a path is orientated in relation to the two places it connects, on the way that subjects orientate while entering, moving along and exiting this path, by experimental methods.

The six experiments which were conducted were designed to provide answers to these six significant design issues.

In accordance with the distinction made between a navigating and a static subject in (4.3), it is assumed that:

- The experiments that refer to paths or movement mainly investigate the navigational, dynamic behaviour of subjects and their sense of orientation while navigating along a path or while moving within a space in general.
- The experiments that refer to places mainly investigate the behaviour of subjects with respect to relatively static activities located in these places as well as their subjective impression emanating from the experience of these places.

Finally, it has to stressed that since the following chapters refer to experiments, involving the design of VEs, the operator of a VE will be referred to as a 'subject' and not as a 'participant'.

6.4 The experimental process

Before describing the six experiments, several significant issues that refer to the process of conducting these experiments have to be clarified. Firstly, it is essential to describe in which phases these experiments evolved:

1) Firstly, during the 'planning phase':

- The aim and further objectives of the experiment were clearly defined;
- The VE that would function as the environment to be tested was designed; space-establishing objects which defined all spaces were appropriately modelled and collision detection was implemented on all objects, apart from thresholds.

2) Secondly during the 'design phase':

- The process of the experiment was carefully designed and at the same time, possible statistical procedures for analysing the results were considered. Taking into account the limitations for the experiment in terms of available time and number of subjects, it was decided that all subjects would have to experience all possible options, within each experiment. However, the order of experiencing these spaces would be randomised for the purpose of avoiding learning or other unpredictable effects. In each option, the setting comprised a series of paths or places, the position or form of which differed in one respect among all options; the aspect of the setting which was different in all options was the independent variable of the experiment and the effect of this variable on several dependent variables was investigated. The method of statistical analysis appropriate for such data was a repeated measures general linear model AVOVA procedure, which would identify contrasts among within-subjects factors - different kinds of experienced spaces - on several different kinds of measurements - dependent variables[11]. In the case of dependent variables which were not quantifiable, tables of frequencies and graphs would be used for the analysis of data.

- A questionnaire was designed and a video camera and stop watch were prepared in order to record the experiments.
- A 'pilot experimental study' which involved 3 subjects took place; this study evaluated the experimental design by:
  - identifying any general problems in the process,
  - finalising the questionnaire,
  - making necessary changes in the three-dimensional model of the VE and
  - 'fine-tuning' the procedure for the purpose of avoiding unpredictable effects and for decreasing its duration, as much as possible.
- Finally, the six experiments were conducted. 47 subjects participated and most of them did 3-6 of the experiments, so that at least 30 subjects had participated in each of the six experiments. At least a third of the subjects were female. Most subjects were architects - 12 students, 16 graduates, 9 postgraduates - but at least 1/5 of them - 10 subjects - were not architects. It was essential to have a majority of architects as subjects in this experiment, due to the nature of the questions and the issues that were investigated. In other words, it was generally easier to talk about spatial qualities with architects. However, the feedback of non-architects should not be underestimated in any way, as they provided very useful observations relating to the nature of their spatial experience within these VEs.

3) Finally, the 'analysis phase' involved:

[11] This procedure is explained in the on-line help of the statistical software package SPSS release 7.5.1.

- The statistical analysis of the data collected during the previous phase.
- The collection of observations which were made by subjects or by the author himself; a selection of the most relevant or most frequent of these observations will be presented.
- An attempt to explain the results of the analysis by further hypotheses, partly based on these observations; quite often the observations seemed to be supporting the results, but whenever this was not the case, it will be made clear.
- A series of conclusions was compiled, on the basis of the results of all experiments. These conclusions have been mainly based on evidence provided by the analysis of the results and not on observations. Additionally, a series of speculations was made on the basis of these observations. These speculations may be seen as explanations for the conclusions or as the basis for further experimental work on these issues.

In general, the observations, made during the experiment, were not recorded as an answer to a question and were not prompted. Whatever is referred to as an observation:

- has been spontaneously reported by subjects, while doing the experiment or while being questioned or
- has been observed by the author whilst the subjects were doing the experiment.

Whenever the quotes of subjects are being used, they are thought to be essential in illustrating a certain observation or result or it is because they describe the spatial experience of a subject in a successful or interesting way.

Finally, it has to be mentioned that the order with which each subject experienced all possible options in each experiment was randomised. More specifically:

- in experiments (1) and (3) where there were 3 spaces to be experienced there were 6 possible combinations,
- in experiments (2) and (4) where there were 4 spaces there were 24 possible combinations and

- in experiments (5) and (6) where there were 5 spaces there were 120 possible combinations.

Since 47 subjects took part in all experiments, in categories (1) and (2) all possible combinations were utilised more than once. In category (3), the order of experiencing the spaces was randomly chosen amongst the 120 possible ones.

6.5 Description of the VE system

A desktop VE system has been used for this experiment. The decision to use such a system was made upon

- the constraints of the resources available for the experiment and
- the fact that an immersive system would impose further complexity on controlling the parameters that would affect the specific variables that were to be investigated.

The 'six-degree-of-freedom' input device[12] named "Magellan"[13] was used for controlling navigation during this experiment. This device:

- Provided a much more intuitive way of navigating in three dimensional space than a mouse or a joystick would;
- Minimised the time for learning how to use the interface of the system; indeed most subjects took 10-15 minutes of navigating in a pilot VE in order to feel comfortable with using the device. If a 2 degree-of-freedom device like a mouse had been used, it would have taken much longer for them to learn how to navigate in three dimensional space, by learning how each combination of pressing one or two buttons and moving the cursor affected the movement of their viewpoint.

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[12] A 'six-degree-of-freedom' input device is capable of translating and rotating the viewpoint of a VE along all three axes of the Cartesian space in all possible ways.

[13] The "Magellan" or "Space Mouse" is a 3D input device and a registered European trademark of the Space Control GmbH, Company of 3D Systems, Germany.

Navigation with this device was left completely unconstrained; in other words, no constraints were imposed on translation along or rotation around one of the (x,y,z) axes. This decision may have made it more difficult for some of the subjects to control their viewpoint at times but was thought to provide a more intuitive interface.

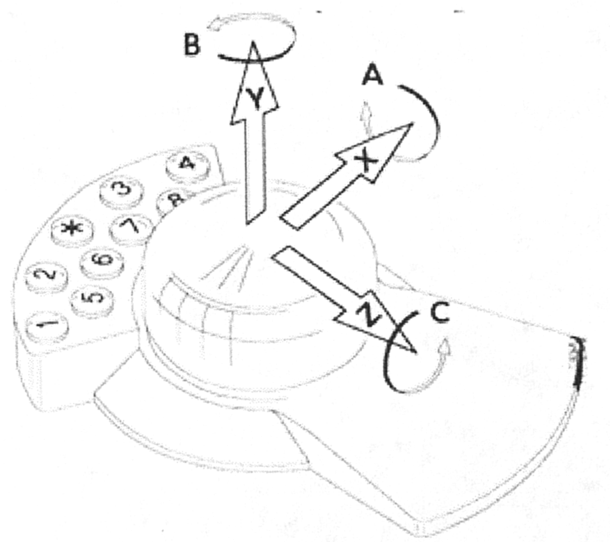


Figure 6.6: The 'Magellan' 6-degree of freedom input device (Magellan, 1996, p.9). In specific, if x and y are the axes which define the viewpoint of the participant, and z is the axis of his direction of view, then a rotation around the x axis is defined as pitch rotation, around the z axis, is defined as roll rotation and rotation around the y axis is defined as yaw rotation.

It was considered necessary for subjects to accustom themselves with the use of the input device for navigation, before they took part in the experiment, so that their performance would not be influenced by their effort to learn how to use the device while taking part in the experiments. Accordingly, at the beginning of the experimental process, each subject was asked to spend as much time as they wanted in a VE, the navigation of which required translation and rotation of the viewpoint in all possible ways. By experiencing this VE, each of the subjects familiarised themselves with navigating in three-dimensional space with the use of the "Magellan" device. Collision detection had not been implemented in this training VE for the purpose of allowing the subjects to navigate without any constraints and to concentrate on controlling of the device.

In the case of all six experimental VEs however, collision detection was implemented. This constraint was assumed to:

- Provide a more realistic sense of space, by not permitting movement through most objects and thus giving those objects a solid quality which makes them define space not only visually but functionally as well;
- Aid the subjects in navigating within the boundaries of places, paths and domains.

Finally, the simulation software used for designing and running the simulation was WorldUp release 3, by Sense8 Corporation.

6.6 EXPERIMENT (1)

In the remaining sections of chapter (6), two experiments will be presented. These experiments attempt to investigate the impact of certain formal characteristics of spaces:

- on a subject's impression of movement - experiment (1) - and
- on the way that a subject wants to move within these spaces - experiment (2).

6.6.1 Planning phase

The aim of this experiment was to investigate what impact certain formal elements, applied on the surfaces of path boundaries, have on the impression of movement experienced by subjects who navigate along these paths. Such elements are:

- Texture maps with a certain 'dynamic' kind of pattern, mapped on the surfaces of a path. The dynamic pattern on this texture was considered to simulate the impression of flow perspective - as defined by Gibson (1986, p.227) - that a subject experiences while moving in a real environment. Moreover, the perspective correction of the texture was thought to be contributing to the sense of movement in three-dimensional space.

- A series of three-dimensional objects with the form of a 'frame', positioned at equal intervals along the path. These frames were rectangular in shape and their dimensions were slightly larger than those of the section of the path so that the sequence of frames enveloped the form of the path. This frame sequence created a rhythmically repetitive pattern, which according to the suggestions made in (5.6.2) may inform subjects of their velocity of movement along the path and of the distance covered at a moment in time.

These formal elements were assumed to have an impact on parameters which contribute to the sense of movement, felt by a subject navigating along a path.

During the design of pilot VEs, various different types of paths were modelled. It was observed that certain paths, which had the above-mentioned elements integrated in their form, gave an improved impression of movement, which was accompanied, at times, by a sense of enjoyment or excitement. This phenomenon indicated the possibility for developing a useful guideline, to inform the design of functional and enjoyable paths. However, evaluation by means of experimental methods was necessary. Therefore an experiment was designed for the purpose of evaluating the hypothesis that "the use of texture maps and rhythmically repeated 'frame' objects improves the perceived sense of movement while moving along a path". The evaluation of this hypothesis could also be seen as an evaluation of similar claims, with respect to the use of rhythmically repeated elements on paths, which were made in (5.6.2).

6.6.2 Design phase

For the needs of this experiment, a VE comprising

- a central hall,
- three different numbered paths and
- three small 'target places' at the end of each path,

was built. Collision detection was implemented, since it is considered to be a constraint that would help subjects navigate within the limits of the spatial boundaries and consequently enhance the realistic character of the VE. Additionally, transparency has been applied to materials of the surfaces which define the paths and the places at their end. The use of such transparencies aimed at providing subjects with certain views to the exterior of the VE and consequently with cues informing them of where they are in relation to the context, while navigating in this VE.

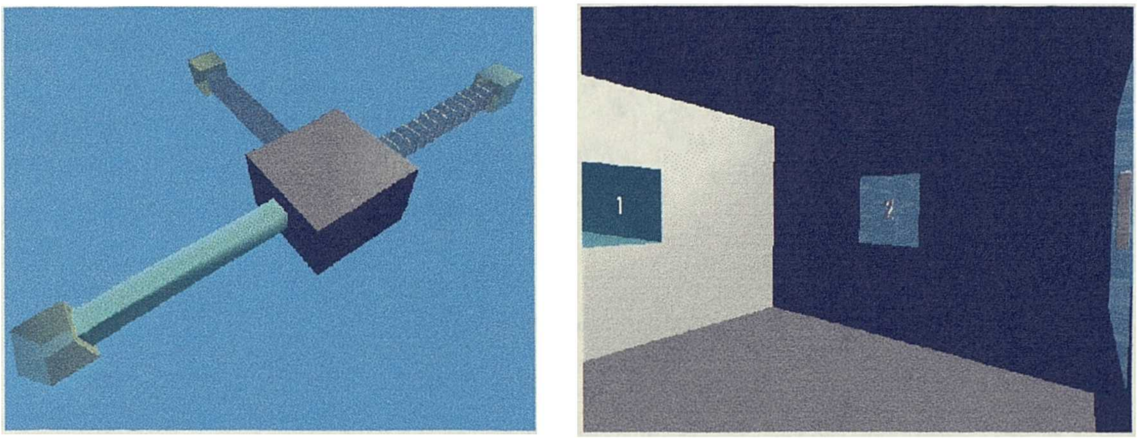


Figure 6.7: External view of the whole VE in experiment (1) - left - and internal view from the central hall looking at the numbered entrances of the three paths - right.

Several independent variables may have affected the impression of movement along paths:

1) The material or the other formal elements applied on the surfaces of each path; this qualitative factor was set at specific levels of interest and its effect on the dependent variable was studied.

2) The form of each path and target place - dependant upon factors such as length, width, height, shape of sections, etc.; this factor was rigidly controlled so accordingly all three paths and target places in the experimental VE were identical in terms of their form.

3) The order with which the subjects would experience one path after the other; this factor was randomised, as explained in (6.4).

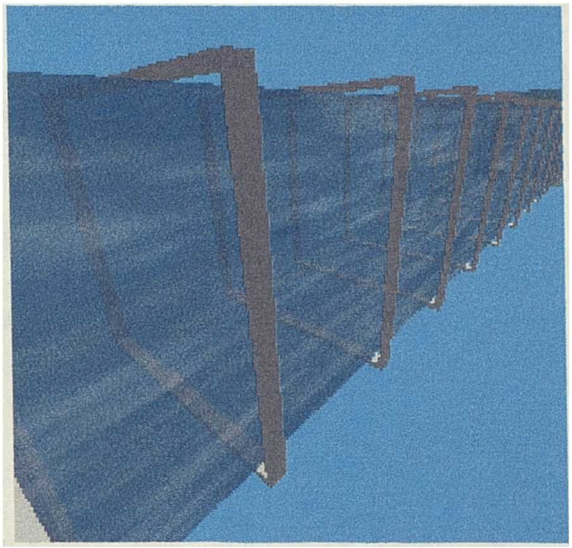


Figure 6.8: The sequence of 'frame' objects applied along the path.

Therefore, all three paths had exactly the same length, the same rectangular section and the same place attached to their end. They differed, however, in the type of material or formal element applied to the boundaries which defined the path:

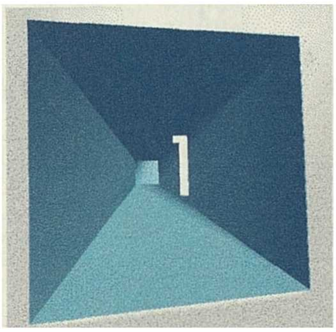
1) The first path was defined by semi-transparent shaded boundaries;
2) In the second path, a certain dynamic semi-transparent texture was applied on its boundaries;
3) In the third path the same semi-transparent texture was applied on its boundaries and additionally, a series of rhythmically repeated frames were positioned along its length.

Each subject was asked to move along each one of the three paths, to the place at its end and back through the path to the entrance hall. The dependent variable which was investigated in this experiment is the subjective 'impression of movement' that a subject experienced, while navigating along each of the three paths. The response values for this dependent variable were given as an answer to the following question, which was asked when subjects returned to the central hall after navigating each path:

"Did you feel as though you were moving in this path ? Give an indication of the impression of movement that you had when moving along this path, as a result of the boundaries that surrounded you". Give response in marks out of 100 where:

0 means that you thought you were not moving at all and

100 corresponds to a very clear impression of movement.



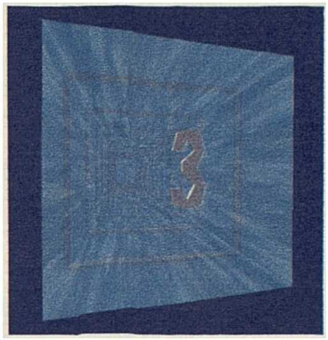


Figure 6.9: View from the entrance along the main axis of each path; path (1), (2), and (3) - from left to right.

Another possible dependent variable was the 'time' that each subject spent while navigating through each path. On the basis of observation during the experiment it can be suggested that time largely depended on:

- Each subject's individual navigation skills, mainly determined by how well they have adapted to using the particular input device;
- Whether the surfaces of a path were shaded or textured; the frame rate of the system slowed down when the majority of pixels that were being displayed were textured.

It is therefore argued that the variable of time could not be controlled and although recorded, is not considered relevant and will not be used in the analysis of the results.

34 subjects - 12 female and 22 male - took part in this experiment.

6.6.3 Analysis phase - Statistical analysis of results

Since all subjects who took part in the experiment, experienced all three paths, three measurements of the dependent variable were taken for each subject and each of these measurements corresponded to each of the paths. Accordingly, a repeated measures General Linear Model procedure was followed for the analysis of the results. The within-subjects factor was named 'path' and had three levels, each level corresponding to each of the paths and the measure recorded for each level was the 'sense of movement'. The null hypothesis to be rejected is that: "all three paths give the same impression of movement to the subjects that tested them."

The test of sphericity for the measure of 'sense of movement' showed that there was a need for adjusting the degrees of freedom in order to perform the within-subjects effects test; this test is presented in appendix (A.1.1). The results of the corrected tests showed that:

- the F statistic for the within-subjects effects was significant ($F = 38.313$, $df=1.701$, $p<0.05$).
- The within-subjects tests showed significance for all contrasts:
  - path (1) - path (2) ($F=25.628$, $df=1$, $p<0.05$)
  - path (2) - path (3) ($F=16.183$, $df=1$, $p<0.05$) and
  - path (1) - path (3) ($F=61.626$, $df=1$, $p<0.05$.

An explanation of the above mentioned procedure along with tables of the tests of sphericity, within-subjects effects and within-subjects contrasts can be found in appendix (A.1.1). The above mentioned results for the variable of 'sense of movement' is illustrated by the following error bar graph.

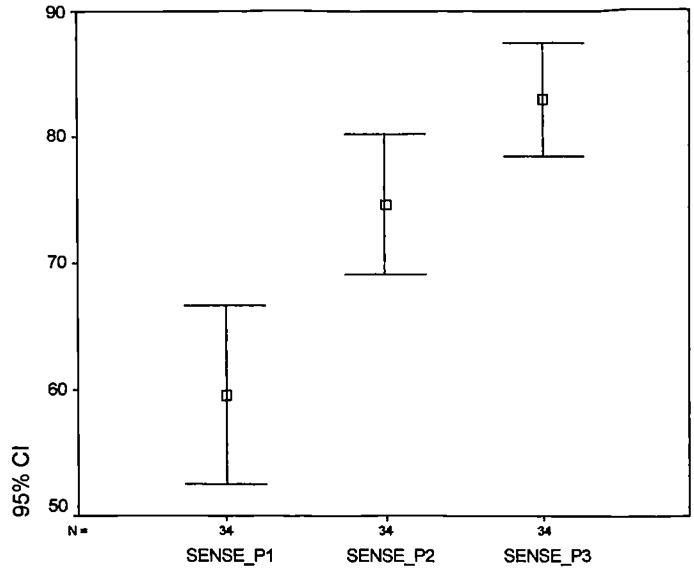


Chart 6.1: Error Bar Graph for the 'sense of movement' dependent variable.

The results of the analysis provide evidence for the rejection of the null hypothesis for the variable of the 'sense of movement'. In specific, from the above mentioned contrasts and graph, it can be concluded that:

- subjects felt significantly more that they were moving in path (3) than path (2),
- subjects felt significantly more that they were moving in path (2) than path (1) and consequently that
- subjects felt significantly more that they were moving in path (3) than path (1).

In other words, the impression of movement:

- was significantly enhanced for subjects who navigated in a path, on the boundaries of which a dynamic texture had been applied and
- was even more enhanced for subjects who navigated in another path, on the boundaries of which a series of rhythmically repeated formal elements - frames - was also applied along its length, in addition to the dynamic texture.

6.6.4 Analysis phase - Observations during experiment (1)

Many (13) subjects reported that they felt an enhanced impression of movement in path (2) and an even more enhanced impression in path (3) and they attributed this to:

- the existence of a texture mapped on the surface of path (2): *"this texture map gave you the impression that you were drawn towards the direction of movement"*;
- the existence of rhythmically repeated frames in path (3), which provided an indication for the velocity of each subject's movement, by how quickly these frames passed by the subject - on the understanding that these frames were seen as positioned at equal intervals.

The frames were also seen as enhancing the sense of perspective and consequently the sense of depth. One subject reported that: *"texture offered a sense of scale and frames gave a sense of measure"*.

However, path (1) also gave a strong impression of movement to some of the subjects, who attributed this phenomenon to:

- the clearly visible goal at the end of the path, which was approaching as they were moving towards it;
- the simple rendered surfaces that made the path seem like a real corridor and enhanced the effect achieved by the perspective and
- the shading effect.

Generally, the subjects who reported that they found the impression of movement in path (1) to be higher than in paths (2) and (3), felt that the texture made the environment unrealistic and they did not like that; on the other hand they thought that the impression of movement was clearer in the simplest path (1), where due to the lack of texture the shading effect was stronger resulting in a stronger sense of depth and perspective. The fact that a clearly visible goal approaching or receding gave a strong impression of movement was confirmed in all three paths.

More details about these observations are presented in appendix (A.1.2).

6.7 EXPERIMENT (2)

In (6.6), experiment (1) has investigated how the application of certain formal elements on the boundaries of a path may affect the impression of movement experienced by subjects who navigate such a space. Experiment (2), which is presented in the rest of this chapter, aimed at investigating how spaces of different volumetric proportions affect the way that a subject moves in them.

6.7.1 Planning phase

In (5.6.2), paths have been defined as spaces, which have the volumetric proportions of a 'run' - following Thiel's definition (1961, p.40) of the 'run' concept. The original intention, underlying this experiment, was to investigate the suggestion that "being inside a space of the volumetric proportions of a 'run' induces movement along an implicit direction which coincides with the greater dimension - main axis - of the space". This experiment, therefore, aimed at investigating whether the navigational behaviour of subjects in paths was in accordance with the above made assumption. On the other hand, it was considered essential to study the navigational behaviour induced by a non-directional space, like a place, as well.

The distinction between a path and a place has been described by in (3.3.1) as the dichotomy between spaces of a longitudinal and a centralised character. A similar distinction, in terms of spatial form quality, has been made by Kepes (1956, as quoted in Thiel, 1961, p.41) between dynamic, expansive spaces which induce movement and those of a centralised, ordered character. This distinction can be made on the basis of considering an implicit spatial quality of these spaces, pertaining to the intrinsic dynamics of a space. This implicit quality, along with all other qualities of the space, which are also determined by the properties of the enclosure (Ching, 1979, p.175), affects the spatial experience.

The difference between the spatial form of a path and a place can be described in terms of their formal configuration and consequent volumetric proportions. Accordingly, the hypothesis that this experiment attempted to evaluate was that: "the volumetric proportions of a space may affect the behaviour of a subject within the boundaries of this space, by inducing a certain kind of movement:

- Being inside a path induces movement along the path's main axis.
- A place is a space which is mainly defined in terms of a centre and its boundaries. As a result, it was speculated that being inside a place would induce movement which focuses on the centre or the boundaries of the space."

Since this last speculation was somehow arbitrary, it would be wrong to consider the two above mentioned kinds of navigational behaviour as the only possible ways of moving within these spaces. It was therefore essential to identify the possible ways that subjects would move within the experimental spaces, during the pilot experimental study. Three subjects took part in this study and the ways that they navigated in each type of space were recorded. According to this study, subjects either moved to centre of a space and looked around from there, or moved along the main axis of the space towards its extends or moved along the boundaries of the space and observed space from there.

6.7.2 Design phase

The independent variables that may have affected the way that subjects moved within the experimental spaces were:

1) The three-dimensional shape of each space, which is described by its volumetric proportions and is accordingly determined by the length, width and height of its boundaries. This qualitative factor was set at specific levels of interest and its effect on the dependent variables was studied. Each of this factor's levels corresponded to each of the differently shaped spaces, which are described below.

2) The material assigned on the boundaries of each space; this factor was rigidly controlled so that if all vertical boundaries were considered as 'walls' and all horizontal boundaries as 'floors' then:

- all 'walls' were assigned a khaki colour and
- all 'floors' are assigned a dark green colour.

Differentiating between 'walls' and 'floors' was thought to be essential for aiding subjects in maintaining a sense of orientation. The validity of this suggestion was evaluated by the experiment. Although the above mentioned way of assigning materials on surfaces does not make all spaces look identical, it was consistent in that 'walls' and 'floors' were assigned the same material in all spaces.

3) The order with which the subjects experienced one place after the other; this factor was randomised.

To achieve the objectives of this experiment, a VE comprising

- a central hall
- 4 differently shaped spaces and
- 4 identical small paths, which connected the central hall with each space,

was build. The 4 spaces, which corresponded to the 4 levels of interest at which the independent variable was set, were two instances of a path and two instances of a place; they were all parallelepiped and had equal width but they differed in their length/height ratio:

- space (1) had the form of a vertical path, similar to a 'lift shaft' and had a length/height ratio of 1/10,
- space (2) looked more like a 'normal room' and had a length/height ratio of 2,
- space (3) had the form of a horizontal path and a length/height ratio of 10 and
- space (4) had a cubic form and a length/height ratio of 1.

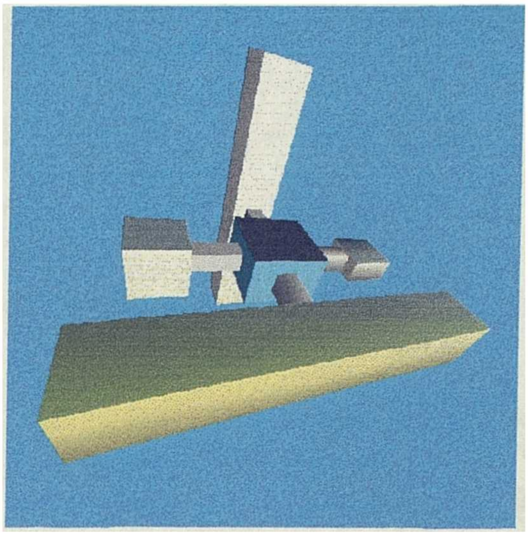


Figure 6.10: The experimental domain comprising the central hall and the 4 spaces in experiment (2).

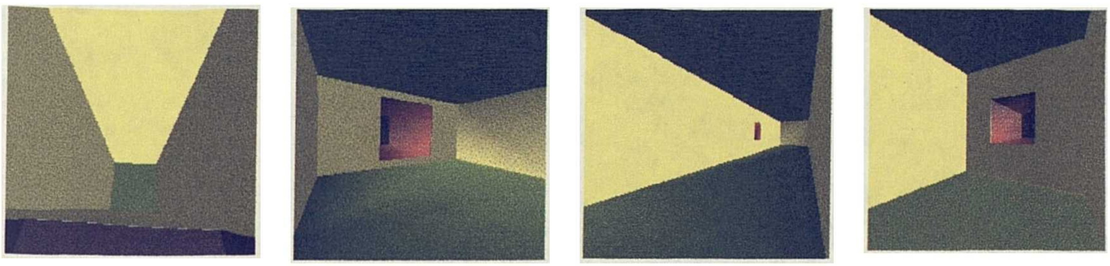


Figure 6.11: Interior views of the 4 experimental spaces. From left to right: looking down from the entrance towards the floor in space (1), view form the corner towards the entrance in space (2), view from on end towards the other in space (3) and view from corner towards the entrance in space (4).

The fact that the independent variable was quantifiable, in terms of the length/height ratio of each space, was not taken into account in the analysis of the results. This was due to the fact that the experiment merely aimed at investigating the kind of movement which was induced in each of the places, individually and not at identifying a specific correlation between the length/height ratio of a space and the movement induced by this space.

The first dependent variable which was investigated in this experiment was the response of subjects in terms of how they moved within each of the spaces. The values for this variable were measured at a nominal level. According to the pilot experimental study explained in (6.7.1), subjects behaved in one of the following ways, within each of the spaces:

1) moved to the centre and looked around from there,

2) moved along the main axis of the space towards its extends or

3) moved along the boundaries of the space and observed space from there.

However, from the pilot study it also became evident that each subject did not necessarily respond in only one way but may have responded in two of these ways, while being in each of the spaces. Both responses, along with the order that they had happened, were recorded and consequently taken into account in the analysis. In the case of two subsequent responses, both have been recorded in the data file in the form of a sequence of two numbers separated by a '/' character, each of them corresponding to the type of response. For example, 1 was recorded if the subject did only response 1 and 1/3 was recorded if he first did response 1 and then response 3.

The second dependent variable which was studied in this experiment, was the 'time' that each subject spent in each of these spaces.

32 subjects - 11 female and 21 male - were asked to enter each one of the 4 spaces and after staying there for as long as the they wanted, they were asked to exit the space and wait for the next prompt. No restrictions were given to subjects in terms of how they would move within each space; they were only requested not to exit immediately. During the pilot study the following observation was made: if subjects were asked whether they preferred to respond in one of the above mentioned three specific ways of movement - and thus were told which are the three possible responses - their behaviour in the following spaces might have been biased. Therefore, it was decided that the their

navigational behaviour would merely be interpreted and recorded by the author after each trial, and no questions would be asked.

During the pilot study, the possibility of a set of objects positioned in the centre of each space was investigated. These objects were thought to provide a better sense of scale when being in these spaces and to motivate subjects to enter the space and stay there for a certain time. It was, however, subsequently understood that these objects would affect how subjects moved, in ways that could not be controlled and which may have not been related to the volumetric proportions of the spaces. Therefore, it was decided that all 4 experimental places were left empty, so that the response would only be attributed to the volumetric proportions of each place. It is however understood that the lack of cues inside the experimental spaces, attributed to the fact that there were no objects inside these spaces and no transparencies to relate to spaces nearby, resulted in a definite lack of sense of scale and orientation.

6.7.3 Analysis phase - Statistical analysis of results

6.7.3.1 The way of movement in each space

The aim of this experiment was to identify how subjects wanted to move in each of the 4 types of experimental spaces. No comparison between responses in these spaces was desired, so tables of frequencies for each type of response in each space were adequate for the needs of this analysis. Consequently, the results for the second dependent variable of 'time' spent in each space were also analysed, in order to identify whether they supported the results for the way of movement in each space.

	Response in space 1	Response in space 2	Response in space 3	Response in space 4
	%	%	%	%
1	6.3%	6.3%	3.1%	
1/2	43.8%		37.5%	
1/3	3.1%	25.0%		28.1%
2	46.9%		50.0%	
2/1			3.1%	
2/3			3.1%	3.1%
3		62.5%	3.1%	65.6%
3/1		6.3%		3.1%

Table 6.1: Table of frequencies for responses in all spaces of experiment (2).

The results will be investigated for each individual space; firstly for the two longitudinal spaces and secondly for the two centralised spaces. The tables of frequencies for the ways of movement within these spaces are included in appendix (A.2.1).

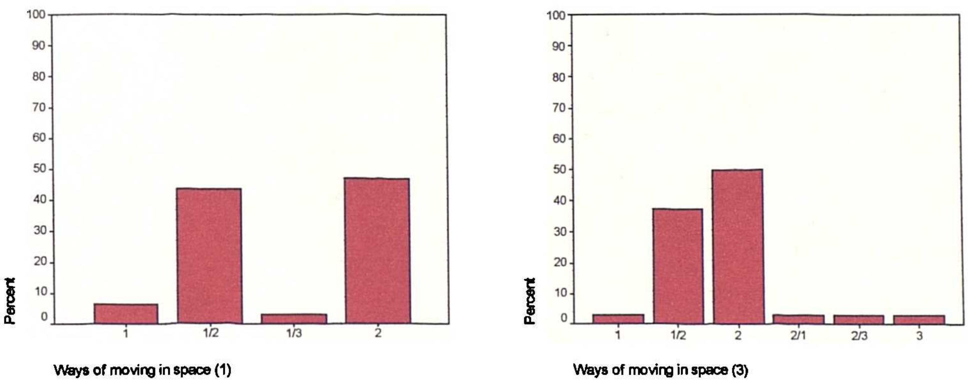


Chart 6.2: Bar graphs of frequencies for the way of movement in spaces (1) and (3).

The results for the vertical, longitudinal space (1) show that:

- 15 subjects (46.9%) moved along the space's axis towards its extends and
- 14 subjects (43.8%) first moved to the centre of the space and looked around and then moved towards its extends;
- only 3 subjects did something else.

Therefore, all but 3 of the subjects moved to the extends of the space but less than half of them moved to the centre of the space first and then to the extends.

The results for the horizontal, longitudinal space (3) show that:

- 16 subjects (50%) moved along the space's axis towards its extends,
- 12 subjects (37.5%) moved to the centre and looked around first and then moved along the space's axis towards its extends,
- 2 subjects moved along the space's axis towards its extends first and then to the centre or to the boundaries of the space and
- 2 subjects did something else.

Therefore, all but 2 of the subjects moved along the main axis of the space towards its extends; less than half of them though, moved to the centre of the space and looked around, either before or after moving towards the extends.

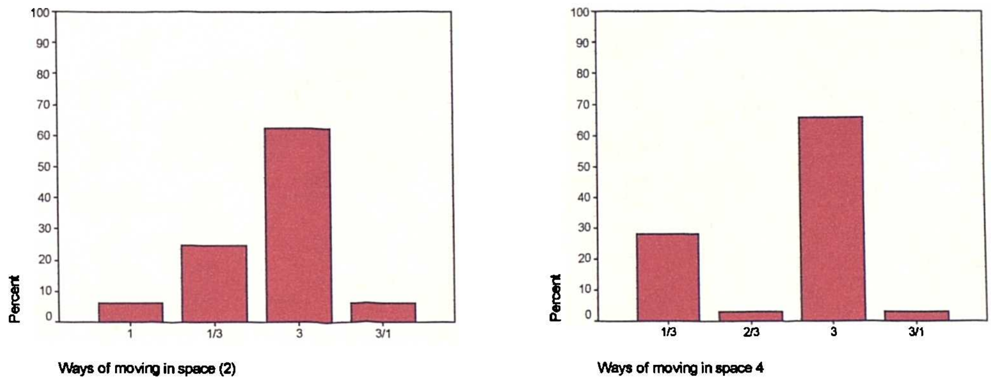


Chart 6.3: Bar graphs of frequencies for the way of movement in spaces (2) and (4).

The results for space (2) which had the volumetric proportions of a real room show that:

- 20 subjects (62.5%) moved to the boundaries of the place and kept moving along those boundaries in order to observe the space from there,
- 8 subjects (25%) moved to the centre and looked around first and then moved to the boundaries of the place in order to observe the space from there,

- 2 subjects moved to the boundaries first and observed the space from there and then moved to the centre and looked around from there and
- only 2 subjects did something else.

Therefore, all but 2 of the subjects moved to the boundaries of the space and observed the space from there; a third of them though moved to the centre and looked around as well, either before or after moving to the boundaries of the space.

Finally, the results for the cubic space (4) show that:

- 21 subjects (65.6%) moved along the boundaries of the space and observed the space from there,
- 9 subjects (28.1%) moved to the centre first and then moved towards and along the boundaries of the space and observed the space from there,
- 1 subject move along the boundaries of the space and observe space from there and then moved to the centre and looked around and
- only 1 subject move along the space and then moved along the boundaries of the space and observe space from there.

All but 1 of the subjects moved along the boundaries of the space and observed the space from there; almost a third of them though, moved to the centre of the space and looked around as well, either before or after moving along the boundaries.

As a result, it can be concluded that:

- In both the horizontal and vertical longitudinal spaces, almost all subjects moved along the main axis of the space towards its extends; less than half of them though, moved to the centre of the space and looked around, either before or after moving towards the extends.
- In both centralised spaces, almost all of the subjects moved along the boundaries of the space and observed the space from there; a third of them though, moved to the centre of the space and looked around as well, either before or after moving along the boundaries.

6.7.3.2 The variable of time

As in the case of experiment (1), a repeated measures general linear model procedure was performed for the purpose of identifying whether the times spent inside the places were significantly different. The null hypothesis to be rejected was that: "subjects spent the same amount of time in all four spaces". The within-subjects factor was 'space' and had four levels, one for each space; the measure recorded was named 'time' and it represented the time that each subject spent in each of the places.

The test of sphericity for the measure of 'time' showed that there was a need for adjusting the degrees of freedom for performing the within-subjects effects test; this test is presented in appendix (A.2.1). The results of the corrected tests showed that:

- the F statistic for the within-subjects effects was significant ($F=7.280$, $df=2.142$, $p<0.05$).
- The within-subjects tests showed significance in the contrasts between:
  - space (1) - space (2) ($F=11.064$, $df=1$, $p<0.05$)
  - space (2) - space (3) ($F=12.894$, $df=1$, $p<0.05$)
  - space (3) - space (4) ($F=14.634$, $df=1$, $p<0.05$)
  - space (1) - space (4) ($F=9.839$, $df=1$, $p<0.05$)
- while differences between: space (1) - space (3) and space (2) - space (4) are not significant.

An explanation of the above mentioned procedure along with tables of the tests of sphericity, within-subjects effects and within-subjects contrasts can be found in appendix (A.2.1). These results for the variable of 'the way of movement' are illustrated by the following error bar graph.

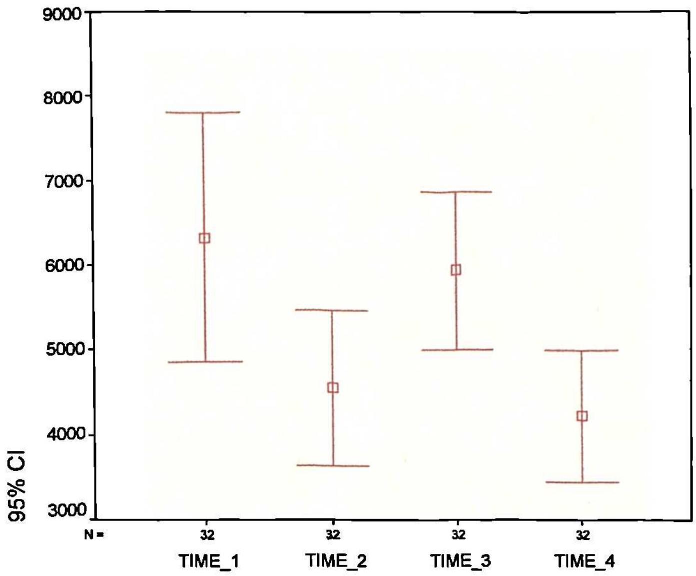


Chart 6.4: Error bar graph for the 'time' dependent variable.

The results of the analysis provide evidence for the rejection of the null hypothesis for the variable of the 'time'. From the above mentioned descriptive statistics and contrasts for this variable, it can be concluded that:

- subjects spent significantly more time in space (1) than in space (2) or space (4)
- subjects spent significantly more time in space (3) than in space (2) or space (4)
- times spent in space (1) and space (3) did not differ significantly
- times spent in space (2) and space (4) did not differ significantly.

Although this phenomenon could also be due to differences in the volumetric proportions of the spaces, it is mainly attributed to:

- the fact that the sizes of four spaces in this experiment differ significantly and to
- each subject's individual navigation skills.

Therefore, it can be argued that the above mentioned results about 'time' do not contradict the conclusions of the analysis, for the navigational behaviour of subjects in each space; however, they are not necessarily in support of these conclusions. Indeed, subjects may have spent more time in spaces (1) and (3) mainly because there was more space to move towards and explore than there was in spaces (2) and (4).

6.7.4 Analysis phase - Observations during the experiment

On entering space (1), many subjects positioned themselves so that they experienced this vertical place as if it were horizontal - like space (3). Although, some of them may have done this because it seemed easier, 8 subjects reported that they did not realise that space (1) was vertically positioned. This phenomenon could be attributed to the fact that:

- there were no cues for orientation inside this space;
- due to navigational difficulties with the input device, some subjects may have approached the threshold of the space in a rolled position at a certain angle and therefore accidentally entered in a way that the space seemed horizontal.

The only cues for differentiating between space (1) and space (3) would be by the material of their surfaces and the number at the entrance from the central hall; once you are inside the space, however, it is difficult to tell whether you are vertical or horizontal. It is also interesting to mention that the 8 subjects who saw space (1) as being vertical, felt quite strong positive or negative feelings about being in this place; on the other hand, subjects who saw this place as being horizontal felt more neutral about being inside it.

In spaces (1) and (3), subjects may have moved towards the extends in anticipation of something being hidden behind these surfaces; this feeling was stronger in space (1) where 7 subjects explained their willingness to move towards the extends of this place, because the surfaces at both extends were of a darker colour and this made them suspect that they were thresholds that may have lead to other spaces.

In space (3), few subjects thought that the dark green surfaces were the 'floor' and 'ceiling' of the space and assumed that the space was horizontal because of this. They could not, however, understand whether they were oriented upright or upside/down because:

- of the lack of cues for orientation within each place;
- all surfaces were opaque so there was no information of the relation to the context;
- the entrance to each place was positioned at equal distances from the 'floor' and 'ceiling' so there was no way of telling up from down; since no gravity was implemented in this VE, subjects would not navigate, while in constant contact with the 'floor' of the VE and therefore it was not necessary to position the entrance of this space very close to the 'floor', as is the case in a real room.

The only cue for vertical orientation seemed to be the numbers positioned in the entrance to each space from the central hall. As these were consistently positioned upright, one could have assumed that this was the global upright orientation.

Three subjects reported that when entering a space they:

- first felt like finding out the shape of the space and then
- they had to define the relationship of the extends of the space with the exit; the orientation did not seem important to them as long as they knew where the exit was.

Three other subjects though, reported that after establishing the limits of the space they were in, they tried to move in ways that they cannot in the real world.

In spaces (2) and (4) most subjects moved first towards the centre and turned their viewpoint around to observe the place; soon they realised that this space was small and they would not be able to get an overall view from there, so they moved backwards towards one of the corners, edges or boundaries. Upon understanding that they get the best possible view from there, they seemed to move along the boundaries in order to observe the place, by focusing on the centre from several possible viewpoints. Once they had tried this strategy and had found it successful, they seemed to employ it on a similar space.

Although space (4) was twice the size of space (2), the latter actually seemed bigger than the former to many of the subjects; indeed three subjects reported that they felt more comfortable moving around in space (2) rather than in (4). The apparent size of space (4) felt smaller and 4 subjects felt more claustrophobic and less comfortable to be in there and wanted to come out quickly. If this phenomenon is attributed to the cubic shape of the space then it may be considered as an indication that the sense of scale in a place is more related to the place's volumetric proportions than to its actual size. A possible explanation could be given, if we consider the absence of a human body representation which would help a subject to compare his avatar with the perceived space at all times.

Finally, it may be argued that people seem to explore an unknown space by moving to a corner of this space and then trying to orientate from there and to observe the space. Moving to a corner may be attributed to

- the fact that it provides the best possible view in an enclosed space and to
- a certain sense of security that the subject may feel there, because his back feels protected and since a corner may be still seen as a place within the space, defined by only two boundaries.

A detailed account of all relevant observations is presented in appendix (A.2.2).

CHAPTER 7

7. TWO EXPERIMENTS ABOUT PLACES

This chapter deals with the impact of certain spatial properties of places on the spatial behaviour of subjects who enter these places in order to perform a certain activity there.

In (3.3.1), it was suggested that a place is "*a totality made up of concrete things having material substance, shape, texture and colour. Together these things determine an 'environmental character'* (or atmosphere), *which are the essence of place.*" (Norberg-Schulz, 1996, p.414) It has to be understood that we cannot reduce the totality of the qualitative phenomenon of a place and of its atmosphere for the purpose of measuring any of its properties, without loosing its concrete nature. Therefore, these experiments merely attempt to understand the impact of certain characteristics of a place on certain aspects of the environmental character of this place and on the spatial behaviour of subjects. By no means is it suggested that an analysis of these aspects can describe the overall character of a place.

7.1 EXPERIMENT (3)

7.1.1 Planning phase

This experiment aimed at investigating the impact of the shape of a place on the behaviour of subjects who perform a certain activity in this place; in specific, the apparent size and the appropriateness of this place for performing a particular task were studied.

It was argued in (5.6.1) and (3.3.1) that the form of a place affects the way that we experience this place. In particular, centralisation as a fundamental notion relating to the definition of the concept of place was strongly related to the notion of concentration. Consequently, a centralised form was seen as a clearly defined place. It was also suggested that the sense of concentation implied by a centralised space, may result in the decrease of the apparent size of this space; giving a certain geometrical shape to a centralised place, might also enhance the effect of size decrease. In this sense, a round shape was considered as a maximally closed form and this has been attributed to the geometrisation of its shape. Finally, spaces were classified in terms of their formal configuration along a continuum,

- at the one end of which are centralised spaces and
- at the other end of which are longitudinal spaces.

On the basis of these suggestions, it may be argued that by making the shape of a place in a VE more centralised or more geometrical, we increase the sense of concentration and closure and decrease the apparent size. On the other hand, it may also be suggested that by introducing a certain direction in the shape of a place and thereby making the spatial form less centralised and more longitudinal, we may decrease the sense of closure and concentration and increase the apparent size of the place.

According to these suggestions, the more centralised the shape of a place is, the more enclosed and concentrated the space will feel and consequently this space will be clearly defined as a place for the subject who is inside it. If we then hypothesise that the more clearly defined a place is, the better it may function as the set for the execution of a task, then we might also suggest that the more centralised the shape of a place is, the better it may function as a context for the execution of a task.

The validity of these speculations needed to be tested in VEs, as they may be particularly important for designing places in such environments. Therefore, this experiment aimed at investigating the impact of the degree of the 'centralisation/ directionality' attribute, which characterises the shape of a place:

- on the easiness with which a subject would perform a task within this place and
- on the apparent size of the place.

7.1.2 Design phase

For the purpose of the experiment, a VE which consists of:

- a central hall,
- 3 places and
- 3 short paths which connect the central hall with each place,

was designed. The spatial form of these three places differed in terms of the degree of centralisation of each place's shape. Subjects were asked to enter each place and perform a task in there. The task was mainly considered essential for motivating subjects into moving within each place and viewing it from different viewpoints and not for assessing the subjects' ability in performing this particular activity. It was also significant for assessing the usability of each place as the context for the execution of a task, of a visual and three dimensional character, in this place.

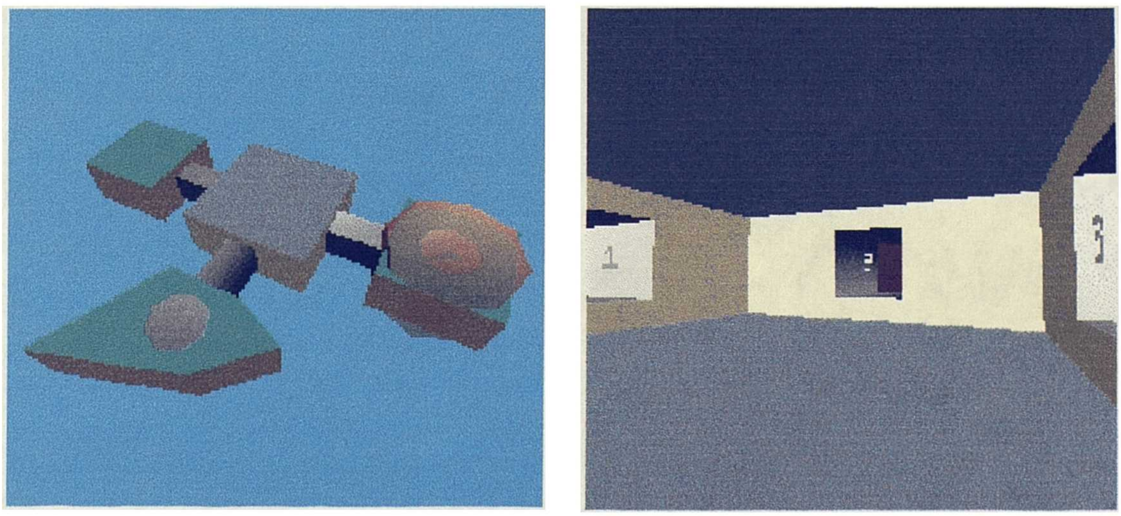


Figure 7.1: External view of the VE - one the left - and interior view of the entrances towards the three places from a corner of the central hall - on the right.

Ten three-dimensional numbers were scattered around near the centre of each place, positioned above a large round 'podium'. The flat cylinders that this podium comprised were positioned on the boundaries of the place, which could be considered as a 'floor' and 'ceiling', were immediately visible on entrance to each place and were also concentric to the shape of this floor. This way the two identical cylinder objects defined the space between them, where the numbers were lying. Each subject was asked to enter the place and to identify which of the ten numbers was the biggest, in value.

The dependent variables in this experiment were:

- The easiness with which subjects performed the task in each place and
- The apparent size of the place.

For the first variable, the response was an interval measurement, given as an answer to the question:

> *"How easy was it for you to perform the task, as a consequence of being and moving within this place ? Give answer as a marks out of 100 where:*
>
> *0 it was very difficult*
>
> *100 it was very easy."*

Subjects were requested to take into account only the enclosure that surrounded them, as a factor which affected their response, and to ignore the particularities of the task itself.

Similarly, for the second variable the response was an interval measurement which was given as an answer to the following question:

> *"When being in this place did you feel that the size of the place was adequate for you to perform the task in ? Give answer as a marks out of 100 where:*
>
> *0 it was too small*
>
> *100 it was too large"*

This question was asked in the first instance of a place that each subject experienced; in the following two places the subject was asked to compare the apparent size of the place that he experienced to the first one. This way the responses provided a comparison among the apparent sizes of the three different places and additionally an indication of the appropriateness of the size for the specific task.

Time of task execution and the answer to the task were also recorded and these could be considered as other dependent variables. However, both variables were not seen as relevant for the purpose of evaluating the above mentioned hypotheses.

There are several independent variables that may have affected the 'easiness of task execution' and the 'apparent size' dependent variables in these three places:

1) The spatial form of each place, determined by the shape of the place, which varied in terms of how centralised or how directional it was. This qualitative factor has been set at specific levels of interest, each level corresponding to one of the experimental places, and its effect on the dependent variable was studied.
2) The area and volume of each place; as this factor would directly affect the apparent size response, it was rigidly controlled so all three places in the VE had approximately the same area and volume.
3) The materials assigned on the boundaries of each place; this factor was also rigidly controlled so that all places had the same materials assigned to the corresponding boundaries within them. Accordingly, all 'floors' and 'ceilings' were given a dark green colour and all 'walls' were given a khaki colour.
4) The order with which the subjects experienced one place after the other; this factor was randomised.
5) The task performed in each place might have affected the response on the easiness of task execution, although subjects were requested not to take into account the specificities of the task itself in their response. Accordingly, this parameter had to be rigidly controlled and therefore the task was the same in all three places. It is understood that there might have been learning effects which

affected the easiness with which subjects performed the task. However, it was considered that these effects did not significantly influence the result of this experiment, due to the randomisation of the order with which subjects experienced these places.

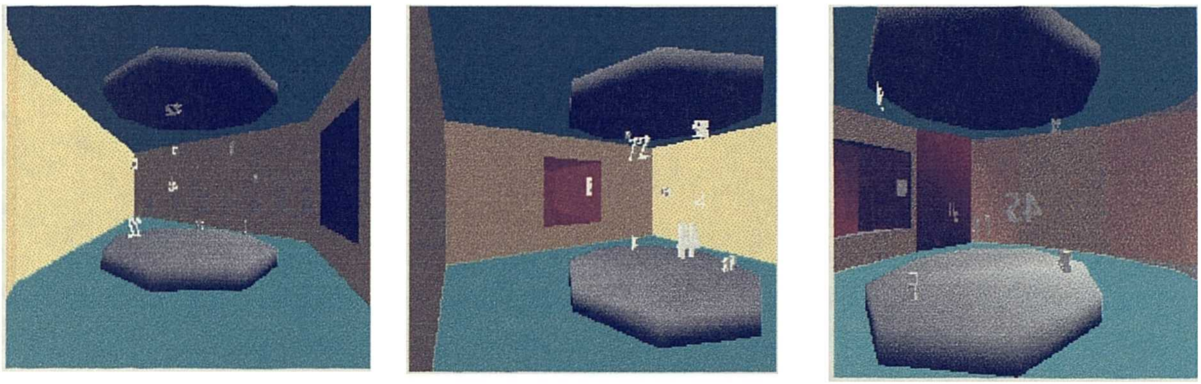


Figure 7.2: Interior views from a corner towards the entrance of each of the three places; from left to right: view inside place (1), view inside place (2) and view inside place (3).

Accordingly, all three places had the same area, volume and material scheme. They differed, however, in their shape in that:

1) place (1) is the least centralised one, since its oblique shape introduces a direction, which competes with the effect of the centre,

2) place (2) is slightly more centralised than the first, as it is rectangular in shape, and

3) place (3) is the most centralised one, due to the combination of a rectangular and a concentric octagonal shape, which further accentuates the effect of the centre on the whole space.

The three places (1), (2) and (3) are therefore ranked in ascending order, in terms of the degree of centralisation of their plan and consequently of their three-dimensional shape.

38 subjects - 14 female and 24 male - took part in this experiment.

7.1.3 Analysis phase - Statistical analysis of results

As mentioned above, the aim of this experiment was to investigate the impact of the degree of centralisation in the shape of a place to the easiness of executing a task in this place and to the apparent size of the place. Therefore, the null hypothesis for both dependent variables was that: "the easiness of executing the task and the apparent size are the same in all three places". The analysis of the results aims at rejecting this hypothesis.

As in the case of both previous experiments, since all subjects had experienced all three places, a repeated measures general linear model procedure was chosen for the analysis of the results. The within-subjects factor was named 'place' and had three levels, for each of the three places that each subject experienced; the measures recorded in each place were the 'easiness' of task execution and the apparent 'size' of the place.

The test of sphericity for the measure of 'easiness' of task execution showed that there was no need for adjusting the degrees of freedom for performing the within-subjects effects test. On the assumption of sphericity, the F statistic for the within-subjects effects was clearly not significant ($F=0.827$, $df=2$, $p<0.05$). Accordingly the null hypothesis was not rejected for the measure of easiness of task execution.

Similarly, the test of sphericity for the measure of 'size' of place showed that there was no need for adjusting the degrees of freedom for performing the within-subjects effects test. On the assumption of sphericity, the F statistic for the within-subjects effects was clearly not significant ($F=1.143$, $df=2$, $p<0.05$). Accordingly the null hypothesis was not rejected for the measure of the apparent size of a place as well. The tables of tests for sphericity and within-subject effects along with the descriptive statistics can be found in the appendix.

All tests of sphericity and within-subjects, along with the error bar graphs for the measures of 'easiness' of task execution and 'size' are presented in appendix (A.3.1).
It is, therefore, concluded that the impact of the degree of centralisation of the shape of a place did not significantly affect :

- the easiness with which a task was performed in this place and
- the apparent size of the place.

In other words, subjects did not differentiate between their responses about their experiences in the three places in a consistent way that could support the originally defined hypothesis. It can finally be concluded that this experiment found no evidence to suggest that in VEs:

- the more centralised the shape of a place is, the better it may function as a context for the execution of a task and that
- the more centralised a place is, the more its apparent size will decrease.

7.1.4 Observations during the experiment

Although the statistical analysis did not reject the null hypothesis, some useful suggestions can be made on the basis of observations, which were made during the experiment. Although these observations do not constitute evidence, such suggestions may still provide directions for future experimental research.

It became evident that some subjects - especially the ones who had difficulties with navigation and who rolled a lot - concentrated mainly on the task itself and ignored the enclosure. Additionally, improvement of performance is some cases had more to do with learning the task rather than with the enclosures themselves, despite of the randomisation of the order of presentation. As a result, some subjects found it difficult to differentiate between the task itself and the enclosure as factors for their responses. It seemed difficult to explain this difference to some subjects, which makes their feedback questionable.

Whilst taking these problems into account, it is concluded that the responses from the sample used in the experiment were contradictory; they did not show a pattern that would suggest a tendency for a population towards a particular response for 'easiness of task execution' and 'size' about these places.

It is interesting to mention that certain elements informed subjects of their vertical relation to the context:

- the podium - on the floor and the ceiling - and
- the upright vertical direction given by the numbers.

In general, the podium and the way that these numbers were positioned induced a certain circular movement around the podium. This phenomenon was intensified in place (3), where the circular shape was enhanced by the introduction of an octagonal volume.

7.1.4.1 Place (1)

The reports of subjects on the size of place (1) were rather contradictory. For some of them the place felt smaller, tighter, narrower or generally constrained, mainly because they got easily stuck in corners or because the shape of the place did not allow for unconstrained movement around the podium. For others though, the place felt bigger but even they felt constrained in moving within the place and at times even claustrophobic or panicked because of these constraints. It may then be suggested that, in general:

- most subjects felt that the shape of this place constrained their movement,
- more subjects felt negative than positive, about moving within this place in order to do the specific task.

This phenomena could be attributed to the acute angle of corners in this place and the lack of space between the podium and the 'walls' to allow for comfortable circular movement around the objects. These problems induced feelings of discomfort and constraint.

7.1.4.2 Place (2)

Subjects seemed more neutral about place (2). Very few expressed an opinion but most of them merely responded to what they were asked. The few who felt like saying something, generally gave contradictory observations.

7.1.4.3 Place (3)

Although the sizes of all three places were considered to be the same, in place (3) subjects felt that it was more difficult, than in the other two places, to move back into its corners in order to observe all numbers at the same time. Despite these difficulties, 17 subjects felt positive about being in place (3). The chamfered corners enhanced the circular shape of the place and along with the shape of the podium, induced circular movement, in this place. In general, these chamfered corners were favoured by subjects because they created *"a nicer ambience"* and the made the place feel a *"smoother",* safer and more aesthetically pleasing space. Fewer (9) subjects reported negative feelings of distraction, disorientation or confusion about this place.

In general, it could be argued that more subjects seemed to prefer being and moving in place (3) and less found it disturbing. This phenomenon may be attributed to

- the obtuse angles of all corners in this place
- the more complex and interesting enclosure and colour scheme.

A detailed account of all relevant observations is presented in appendix (A.3.2).

7.2 EXPERIMENT (4)

7.2.1 Planning phase

It was argued in (3.3.1) that a place represents to man what is known in contrast to the unknown and uncertain world around. A place is a space where particular activities are carried out and these activities are only meaningful in relation to particular places, and are coloured by the character of the place; this character is understood as a result of the interaction of the place with its surroundings. (Norberg-Schulz, 1971, p.19) Indeed behaviour is place specific; a place may elicit certain behaviour but on the other hand, a certain plan or goal alters the way that a place may be perceived and remembered. It is also important to stress that we subjectively perceive and know places.

We need places where 'here' is clearly distinguished from 'there', in order to realise our possibilities within our world. This distinction between 'here' and 'there' or 'inside' and 'outside' is also made by Norberg-Schulz (1971, p.20) who clearly suggested that "*for its definition, the place needs a pronounced limit or border*". Thiel (1961, p.19) has classified spaces according to their vagueness or explicitness in suggesting or defining a given space-form out of the void. Accordingly, it has been argued in (3.3.1) that when relations between the 'inside' and 'outside' of a place are clearly defined by such borders or boundaries and consequently a place is explicitly defined out of the void, then a subject can 'dwell' in this place; this situation implies that he can orientate in the place, identify with the place, find the place meaningful and consequently feel secure in there.

Humans in real environments need to feel secure and to identify with a certain space, which is clearly defined by boundaries as a place, in order to engage into activity in this space. In (5.5.1), it was argued that this hypothesis may be valid in VEs as well. Accordingly, it may be suggested that in a VE, when the 'inside' and 'outside' of a place are clearly defined and consequently this place is explicitly established as a spatial element out of the void by its boundaries, then

- a subject may feel secure and comfortable enough to engage into an activity in this place and
- accordingly, his performance of a particular activity in there is also positively affected.

This experiment attempted to investigate the validity of this hypothesis which has been considered crucial for the design of places in VEs. Additionally, the impact of the degree of explicitness of space establishment was studied on the distraction that subjects felt, while performing a task in this place.

7.2.2 Design phase

For the objectives of the experiment, a VE was designed, which comprised a certain domain, where the experiment mainly took place and its surroundings. The experimental domain consisted of:

- a central hall
- 4 places
- 4 paths connecting the central hall with the places and
- complex surroundings comprising several objects.

These four places were ranked in terms of how explicitly their inside was defined in relation to their outside, by their boundaries.

There are several independent variables that may have an impact on the spatial behaviour of a subject within each place:

1) The form and arrangement of the boundaries defining each place, which determine the degree of explicitness for the establishment of the place. This qualitative factor is set at specific levels of interest and its effect on the dependent variables is studied.

2) The shape and volume of each place; since this factor could have affected the response for the dependent variables in unpredictable ways, it was rigidly controlled and therefore all places in the experimental domain had the same area and volume. However, it is understood that subjects were free to move outside the boundaries of each place and when this happened, the overall space that they experienced also entailed the surrounding context of the domain. The impact of this situation could not be controlled:

- In the case of places (1), (2) and (3), where subjects could move out of the boundaries, the effect of this behaviour was randomised by the different order of presentation.
- Subjects could not move out of place (4) and this fact determined the value of the first independent variable for this place.

3) The order with which the subjects experienced one place after the other; this factor was randomised.

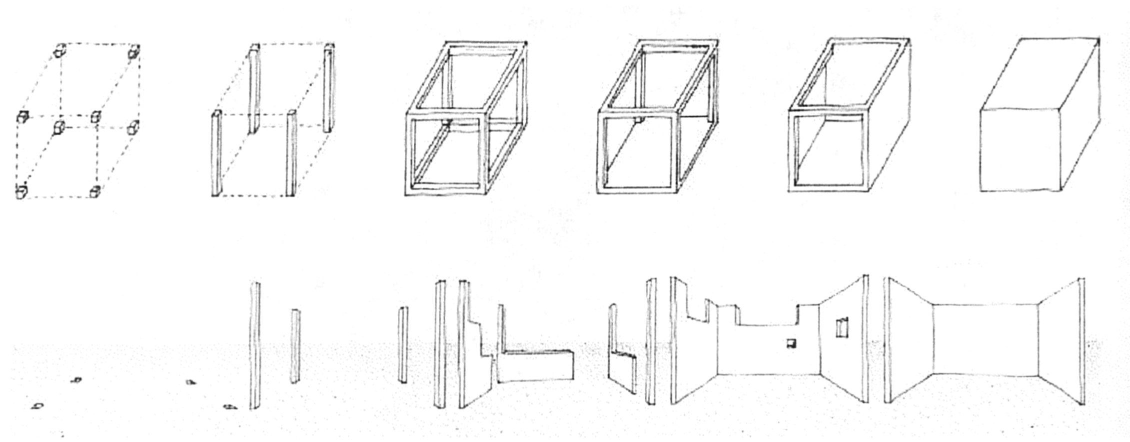


Figure 7.3: Series of spaces illustrating the continuum from an implicit to an explicit space (Meiss, 1991, p.102).

Thiel (1961, p.19) has classified spaces according to how vaguely or explicitly they define a given space-form out of the void, in terms of a quality which he names 'the explicitness of establishment' along a continuum:

- on the one end of which are vaguely defined spaces and
- on the other are very clearly defined and well enclosed spaces.

Similarly, Meiss (1991, p.102) has presented a series of places which illustrate this continuum, on the one end of which is a place defined only by its corners, whilst on the other end is a completely enclosed cubic place (Figure 7.3).

The three-dimensional shape of the four places of the experimental domain was a rectangular parallelepiped and their volume was identical. Following Meiss' (1991) series of places,

- Place (1) was the less explicitly established of the four; it was only defined by four small cubes positioned at the corners of its rectangular shape.
- Place (2) was slightly more explicitly established than (1); the edges of its parallelepiped volume were emphasised by three-dimensional objects of rectangular section, which created screens - or frames - in the place of each of the six planes of the parallelepiped.
- Place (3) was similar with (2) with the addition of two opaque planes as boundaries in the place of a 'floor' and a 'wall'; the wall boundary was positioned so as to obstruct direct view towards the place adjacent to place (3).
- Place (4) was the most explicitly established of the four; it was similar to (2) with its edges being emphasised by screen-like objects, but was completely enclosed by opaque boundaries, thus not affording views to the surroundings of the experimental domain (Figure 7.4).

Each subject was asked to enter each of the experimental places, to execute a task and on exit to provide feedback about his spatial experience. The tasks which were performed in each place involved identification of groups of solid objects, by their colour and decision-making. Each composition of the objects, involved in the tasks, had exactly the same number of solids and these were positioned in a similar way and in the same central position within each place. The tasks which were executed in each place were similar but not identical for the purpose of avoiding learning effects.

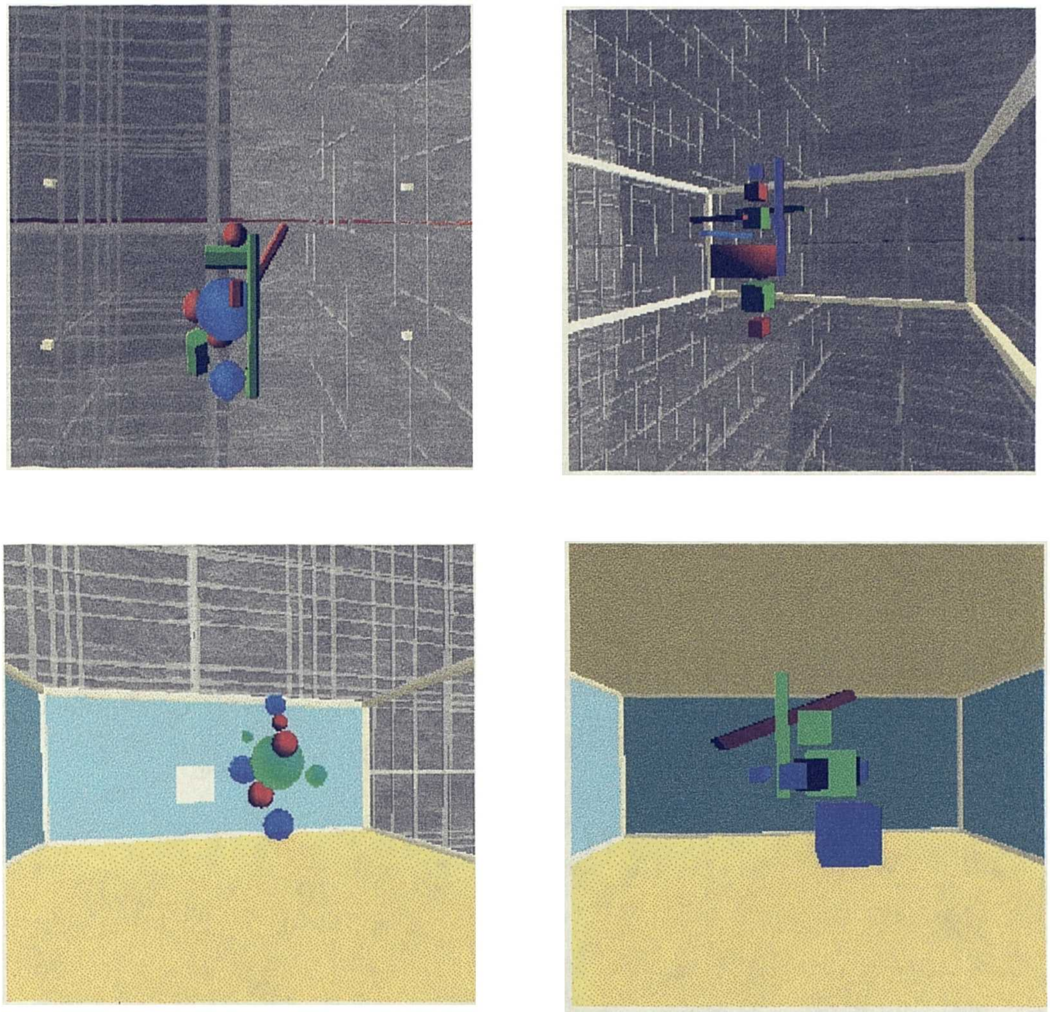


Figure 7.4: Views from within each of the places; place(1) - top left; place (2) - top right; place (3) - bottom left; place (4) - bottom right.

Subjects were not prompted to stay within or move outside the boundaries of each place; they were told that they were free to move anyway they wanted to, as long as they did the task as well. This was considered necessary in order to identify whether or not they felt like moving out of these places. It was also considered necessary because of the behaviour of subjects who took part in the pilot experimental study and who were not prompted at all: they seemed to think that they were not allowed to move out of the places, but that they ought to have stayed within the boundaries and to have concentrated solely on the task.

Since most experimental places were not completely enclosed by their boundaries, subjects were able to view the surroundings around the experimental domain. It was considered essential that certain complexity was added to this context for the purpose of aiding orientation and for providing subjects with certain surroundings that they could move within and explore if they wished to do so. This context (Figure 7.5) consisted of:

- A textured spherical surface which was used as an overall environmental enclosure.
- A red coloured vertical cylinder of a very small height, the diameter of its base being equal to the diameter of the environmental enclosure, which signified a 'horizon'. This spatial element, which may also be seen as a landmark, would inform subjects of their orientation in relation to a certain global frame of reference - as defined in (4.7) - at all times.
- Several three dimensional grid-like structures were designed around the experimental domain; these structures provided a background that informed subjects for their direction of movement and orientation and enhanced the impression of depth within the VE.

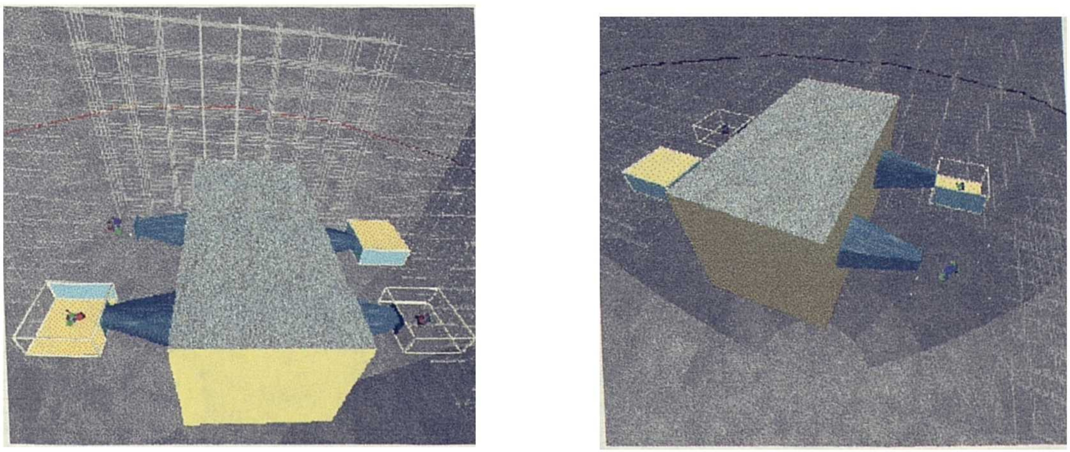


Figure 7.5: Views of the experimental domain from above; the spherical environmental enclosure, the horizon and the grid-like structures can be seen in the background.

It had been expected that subjects would move out of the boundaries of a place and would drift away within the surroundings of the domain, at times. Although this may have entailed the possibility of viewing a place that was to be viewed later in the course of the experiment, it was thought that the impact of such a phenomenon on the results of this experiment would be randomised by the different order of presentation used by each subject for experiencing the series of places. This impact was also considered as a necessary compromise when compared against the advantage of investigating the unconstrained and unbiased behaviour of subjects in such a situation.

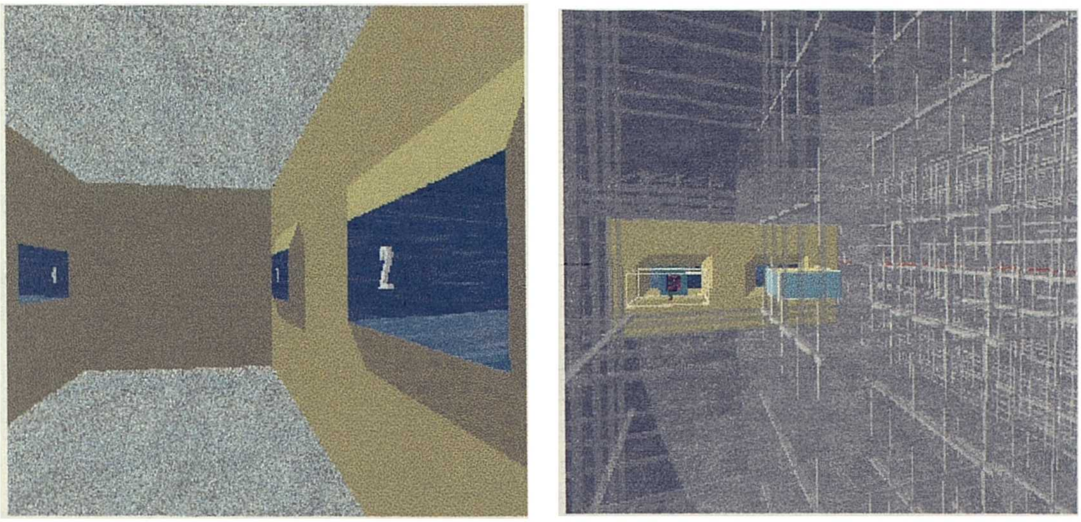


Figure 7.6: View within the central hall towards the entrances to the places - on the left. Outside view of the domain from the three-dimensional grid-structures - on the right.

As was argued in (5.6.1), a place can be described by its name, spatial scale, function, aesthetic qualities, complexity and by certain affective qualities and attributes. This experiment has attempted to investigate the impact of the spatial arrangement defining each place on affective and functional attributes of this place. The following attributes of a place, which are directly related to spatial behaviour within this place, were the dependent variables of the experiment:

1) 'comfort' felt by the subject,

2) 'easiness' of performing an activity in this place,

3) 'security' felt by the subject and

4) 'distraction' of the subject while performing the activity.

After exiting each place subjects were asked the following questions, the answers to which provided the values for the corresponding four dependent variables:

1) *"While being in this place how comfortable did you feel ?*
Answer with marks out of 100 where:

0. I did not feel comfortable at all

100. I felt very comfortable indeed "

2) *"While being in this place how secure did you feel ?*
Answer with marks out of 100 where:

0. I did not feel secure at all

100. I felt very secure indeed"

3) *"While being in this place and performing the task, did you feel distracted by your surroundings ? Answer with marks out of 100 for the degree of distraction you felt.*

0. I did not feel distracted at all

100. I felt very distracted indeed"

4) Finally, after experiencing all places, subjects were asked to rate all four of them, in terms of how easy it was to execute the task, as a result of the enclosure that surrounded them in each case. Accordingly, subjects had to rank the four places by order of easiness for task execution along a continuum, where the value of:

1. corresponded to the place where the task was more difficult to perform in,
2. ....
3. ....
4. corresponded to the place where the task was easiest to perform in.

Time of task execution was also recorded and could be considered as another dependent variable. However, this variable was not considered relevant for the purpose of evaluating the above mentioned hypotheses, since:

- the duration of task execution may have largely depended on the ability of the subject to navigate in three-dimensional space, by using the particular input device;
- some subjects may have spent more time in a place because they were very interested in exploring this space or excited about their spatial experience.

Therefore time measurements were not taken into account in the analysis of the results. The answer to the task which was performed in each place was also recorded but was not taken into account in the analysis since:

- the primary function of the task was to motivate the subject to enter the place and to move within it;
- very few subjects did not find the correct answer with their first response.

38 subjects - 17 female and 21 male - took part in this experiment.

7.2.3 Analysis phase - Statistical analysis of results

The aim of the experiment was to investigate the impact of the explicitness with which space was established in a place to the functional and affective qualities of comfort, security, distraction and easiness of executing a task within this place. The null hypothesis for the four dependent variables, was that "the comfort, security, distraction and easiness of task execution which was experienced by subjects were the same in all four places". The analysis of the results aims at rejecting this hypothesis. With reference to the fourth variable of easiness of task execution, tables and bar charts of frequencies were also investigated for the purpose of studying the responses of subjects.

As in all previous experiments and since all subjects had experienced all four places, a repeated measures General Linear Model ANOVA procedure was used for the analysis of the results. The within-subjects factor was named 'place' and had 4 levels, each level corresponding to each of the four places that each subject experienced; the measures recorded in each place were the degree of 'comfort', 'security' and 'distraction' along with the 'easiness' of task execution experienced by each subject.

7.2.3.1 The variable of comfort

The test of sphericity for the measure of 'comfort' showed that there was a need for adjusting the degrees of freedom for performing the within-subjects effects test; this test is presented in appendix (A.4.1). The results of the corrected tests showed that:

- the F statistic for the within-subjects effects test was not significant enough for $p<0.05$ but was close to being significant for $p<0.1$ ($F=2.211$, $df=2.154$).
- The within-subjects tests showed significance in the contrasts between
  - Place (2) - place (3) ($F=4.093$, $df=1$, $p<0.05$) and
  - Place (3) - place (4) ($F=5.301$, $df=1$, $p<0.05$) but
  - the place (1) - place (2) contrast was close to being significant ($F= 3.696$, $df=1$, $p<0.1$).
- All other contrasts between places were not significant.

An explanation of the above mentioned procedure along with tables for the tests of sphericity, within-subject effects and within-subjects contrasts can be found in appendix (A.4.1). It is understood that the significance of the within-subjects effects is not enough to indicate evidence for the rejection of the hypothesis and therefore the above mentioned significant contrasts may be taken into account, but should be interpreted with caution.

Since the contrasts between place (2) - place (3) and place (3) - place (4) were found to be significant and the result for the place (1) - place (2) contrast was very close to being significant as well, it may be suggested that:

- subjects felt slightly more comfortable in place (3) than in place (2) or place (4) and
- subjects felt slightly more comfortable in place (1) than in place (2)
- places (2) and (4) seem to be the less comfortable of the four.

These suggestions are also supported by the following error bar graph and by the observations which are presented in (7.2.4).

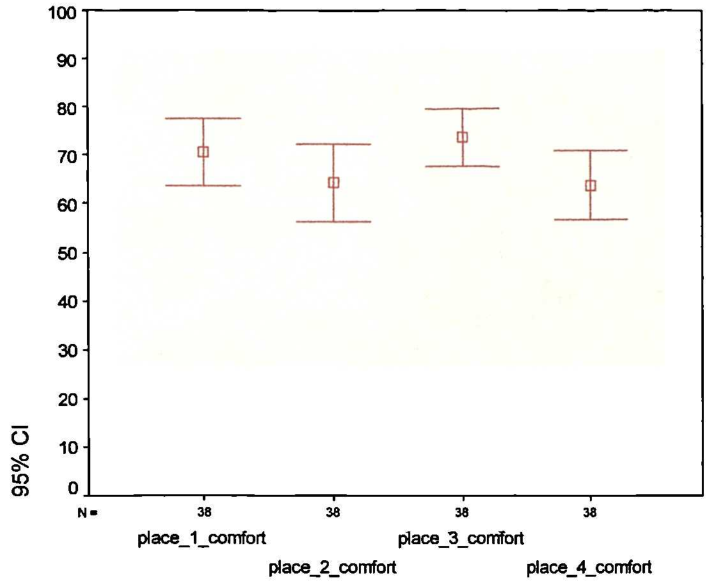


Chart 7.1: Error bar graph for the variable of 'comfort'.

7.2.3.2 The variable of easiness of task execution

The test of sphericity for the measure of 'easiness' with which subjects executed the task in each place, showed that there was no need for adjusting the degrees of freedom in order to perform the within-subjects effects test; this test is presented in appendix (A.4.2). Assuming sphericity, the within-subjects tests showed that:

- the F statistic for the within-subjects effects was significant ($F=4.771$, $df=3$, $p<0.05$);
- the within-subjects tests showed significance for the contrasts between:

- place (1) - place (4) ($F=6.323$, $df=1$, $p<0.05$)
- place (3) - place (4) ($F=15.573$, $df=1$, $p<0.05$) and also that
- the contrast between place (2) - place (4) was significant enough for ($F=3.324$, $df=1$, $p<0.1$);

- the contrast between place (2) - place (3) ($F=2.519$, $df=1$, $p<0.05$) was not significant enough but still not too small. The other contrasts were not significant.

These results provide evidence for the rejection of the null hypothesis for the variable of 'easiness' of task execution. Accordingly, it can be concluded that:

- subjects found it significantly more difficult to do the task in place (4) than in places (1) and (3);
- subjects found it slightly more difficult to do the task in place (4) than in place (2);
- easiness of task execution for places (1), (2) , (3) was not significantly different but doing the task seemed slightly more difficult in place (2) than in place (3).

An explanation of the above mentioned analysis procedure, along with tables for the tests of sphericity, within-subject effects and within-subjects contrasts can be found in appendix (A.4.2). It was also considered useful to study the tables of frequencies and the relevant bar charts for the variable of 'easiness' of task execution, in order to further interpret the subjects' responses. These are also included in the appendix. It was expected that the study of the frequencies of responses, along with the observations made during the experiment, may provide explanations for the behaviour of subjects in a more complete manner.

The results for the variable of 'easiness' of task execution are also supported by the following error bar graph.

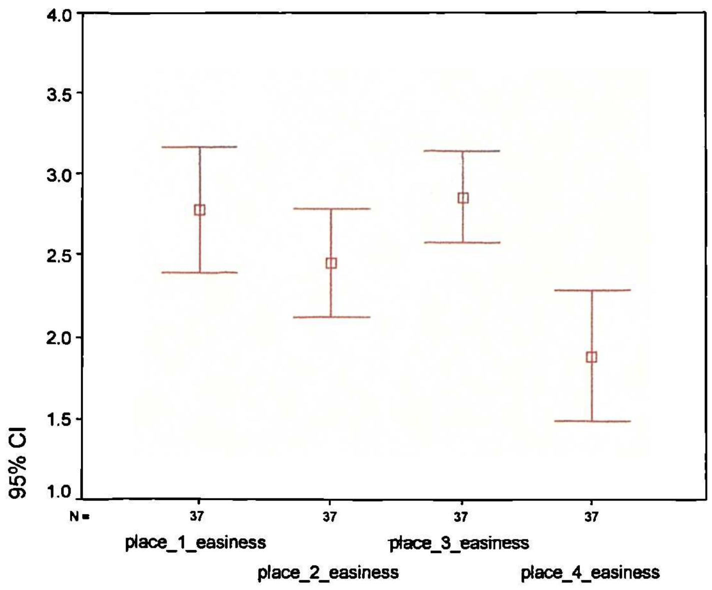


Chart 7.2: Error bar graph for the variable of 'easiness' of task execution.

7.2.3.3 The variable of security

The test of sphericity for the measure of 'security' that subjects felt in each place, showed that there was a need for adjusting the degrees of freedom for performing the within-subjects effects test; this test is presented in appendix (A.4.3). The corrected tests showed that:

- the F statistic for the within-subjects effects was significant ($F=16.633$, $df=2.078$, $p<0.05$);
- the within-subjects tests showed significance for the contrasts between:
  - place (2) - place (3) ($F=15.786$, $df=1$, $p<0.05$),
  - place (3) - place (4) ($F=10.950$, $df=1$, $p<0.05$),
  - place (1) - place (3) ($F=10.509$, $df=1$, $p<0.05$)
  - place (1) - place (4) ($F=20.317$, $df=1$, $p<0.05$) and
  - place (2) - place (4) ($F=25.466$, $df=1$, $p<0.05$)
- but the contrast between place (1) - place (2) was not significant.

These results provide evidence for the rejection of the null hypothesis for the variable of 'security'. Accordingly, it can be concluded that:

- subjects felt a similarly low degree of security in places (1) and (2), which were less explicitly established by their boundaries;
- subjects felt significantly more secure in places (3) and (4) than in (1) and (2)
- as the degree of explicitness with which these places were established increased, from place (2) to place (3) and from place (3) to place (4), so did the sense of security that subjects felt when being in these places.

An explanation of the above mentioned analysis procedure, along with tables for the tests of sphericity, within-subject effects and within-subjects contrasts can be found in appendix (A.4.3). The results for the variable of 'security' are also supported by the following error bar graph.

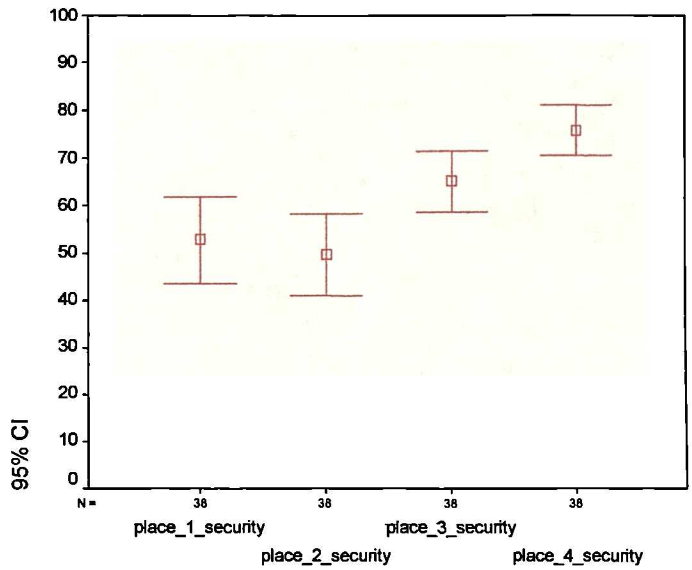


Chart 7.3: Error bar graph for the variable of 'security'.

7.2.3.4 The variable of distraction

The test of sphericity for the measure of 'distraction' from the surroundings that subjects felt in each place, also showed that there was a need for adjusting the degrees of freedom for performing the within-subjects effects test; this test is presented in appendix (A.4.4). The corrected tests showed that:

- the F statistic for the within-subjects effects was significant ($F=18.681$, $df=2.423$, $p<0.05$);
- the within-subjects tests showed significance for the contrasts between
  - place (3) - place (4) ($F=31.146$, $df=1$, $p<0.05$)
  - place (1) - place (4) ($F=24.319$, $df=1$, $p<0.05$) and
  - place (2) - place (4) ($F=37.610$, $df=1$, $p<0.05$)
  - but the contrasts between all other places were not significant.

These results provide evidence for rejecting the null hypothesis for the variable of 'distraction' by the surroundings. Accordingly, it may be concluded that:

- subjects felt significantly less distracted in place (4), which was the most explicitly established and enclosed of all four places, than in any other of the places
- the degree of distraction in places (1), (2) and (3) was similar;
- The higher the degree of explicitness with which a space is established, the lower the sense of distraction from the enclosure.

This result is very reasonable if we consider that:

- the degree of visual complexity that a subject experienced when in place (4) was significantly lower than in all other places, in which there were many more chances of visual contact with the surroundings outside the experimental domain;
- the chances of being interested in and therefore distracted by a set of objects from the surroundings was much smaller for a subject in place (4), as there was no way to come out of this place.

An explanation of the above mentioned analysis procedure, along with tables for the tests of sphericity, within-subject effects and within-subjects contrasts can be found in appendix (A.4.4). The results for the variable of 'distraction' are also supported by the following error bar graph.

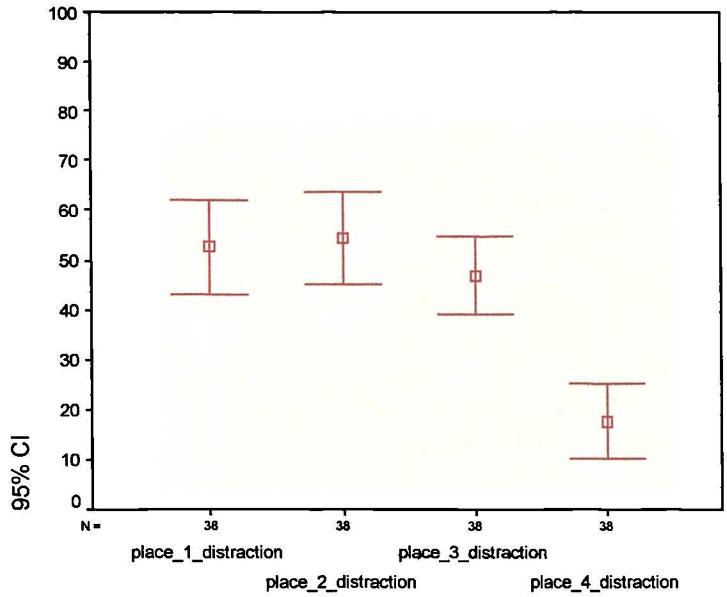


Chart 7.4: Error bar graph for the variable of 'distraction' by surroundings.

7.2.4 Observations during the experiment

This section includes a summary of the observations made by subjects and by the author during the experiment. A detailed account of these observations is presented in appendix (A.4.5).

7.2.4.1 Place (1)

The space in this place was the least explicitly established of the four places. Almost all of the 35 subjects moved out of the vary vaguely defined boundaries of this place. The three ones who did not move out had either not realised that they could or they were not confident enough to move around an open space, due to their low navigational skills.

A significant number of subjects (14) felt no sense of place at all in place (1); in fact, they thought that place (1) was the whole space they experienced when coming out of the threshold, including the surroundings. They believed that objects were merely positioned in this open space and the only visible boundaries were the grid-like structures at the background. Only four subjects reported very little sense of place, whereas not even one subject reported a clear sense of place defined by any elements:
"I had no feeling of enclosure at all, only sense of space and distance" or
"the spheres (objects of the task) were floating in the larger space but I saw the rest as a background".

It could then be concluded that the cubes which were positioned so as to define the place by indicating its corners, were not successful at that. Indeed, less than a third of the subjects saw the cubes as clearly defining a place; the others either were not sure what the cubes defined or thought that they did not define a space at all; few subjects also did not see the cubes at all.

Despite the lack of a sense of enclosure which would define a local space around the objects of the task, most subjects were positive about experiencing this place and felt very comfortable in navigating, without being constrained by any boundaries. These observations are in support of the results for the variables of comfort and easiness of task execution; most subjects seemed to feel very comfortable and thought that it was very easy to do the task in this place. Indeed, more than half of the subjects felt positive about being free to move around space without being obstructed by any boundaries.

These positive feelings were either expressed as feelings of comfort, excitement, interest, or mere enjoyment. Some subjects also reported positive feelings about the grid structures in the background, as they seemed to provide a sense of direction and orientation.

However, on the basis of the statistical analysis, it can be argued that the majority of subjects felt very insecure and distracted by their surroundings, when being in place (1). In support of this suggestions, many of the subjects reported negative feelings associated with insecurity or distraction, as a result of the existence of the cubes, the openness of space, the lack of boundaries and most importantly the lack of a floor. Awkwardly enough, some subjects who reported such negative feelings, had also reported positive feelings about the sense of comfort and easiness of task execution in this place.

7.2.4.2 Place (2)

This place was slightly more explicitly defined than place (1), since its edges were emphasised by solid beam-like objects. Most subjects (33) came out of the limits of this place and only 4 of them did not do so. Unlike place (1) though, almost all subjects felt the presence of these beam-like objects, which were defining the limits of place (2).

Some subjects reported positive feelings about the screen-like structure which defined this place. Few subjects also referred to the grid-like structures and the surroundings, which were beyond the experimental domain, as helpful for orientation.

On the other hand, the analysis of the results leads to the suggestion that the majority of subjects felt mostly insecure and distracted by their surroundings in place (2). This suggestion is supported by the numerous negative observations that subjects made about being in this place. These observations were associated with several aspects of this place:

- Firstly, the lack of floor and boundaries induced insecurity, fear or even shock. It is interesting that most of these subjects did not report the same negative feelings about place (1), or when they did they thought that place1 was preferable to place (2). One subject explained this phenomenon: *"the enclosing structure makes the lack of floor more prominent; I distinctly see where the floor should be and I feel I'm falling through the floor much more than in place (1)."*
- Secondly, the enclosing screen-like structure which defined the limits of this place induced feelings of distraction, disturbance, obstructed the task or constrained the movement of subjects.
- The openness of the place and the complexity of the surroundings induced distraction, fear of 'lostness' and confusion.

Finally, some subjects compared place (1) and place (2) and specifically reported that place (2) was more distracting or uncomfortable than place (1), but not necessarily in a negative way.

7.2.4.3 Place (3)

This place had clearly defined limits by its boundaries, a floor and a wall; on the other hand, it still was relatively open to the exterior thus affording viewing and moving out towards the surroundings. Fewer subjects (27) came out of the limits of this place and moved within the surroundings beyond the experimental domain, than did in places (1) and (2). Some subjects (11) did not come out at all; some of them may have thought that they shouldn't and this was more likely to happen when place (3) was the first place they experienced. In fact, three subjects thought that the screen structures were supporting glass panes and were not sure whether they could come out. Almost half (17) of the subjects reported a clear sense of place.

The analysis of the results indicates that this place could be seen as 'optimum', since it has been considered quite comfortable and relatively easy for task execution while at the same time it was not too insecure and not too distractive. These results are supported by the majority of observations reported by subjects, who were generally positive about this place.

More than half of the subjects (20) reported that they thought place (3) was comfortable and optimum. Some of them (12) thought that this was so because this place combined a clearly defined enclosure and at the same time the freedom to view or move towards the surroundings, which aided orientation. As one subject explained:
"A sense of enclosure as a point of reference and open space in the distance gave me more of a feeling of control of where I wanted to go" or another also said:
"Being able to see the open space surrounding the place in relation to the place itself made the experience more comforting".

Few subjects also thought that their sense of comfort in place (3) was due the boundaries acting as a background for the objects of the task at all times. Additionally, the view to the outside helps one to compare the local place to the global surroundings and to inform orientation within the context.

The existence of a floor was also significant for a number of subjects; some of them felt more secure and comfortable because of the floor whereas some others felt that the floor made them more aware of the drop outside the place and this made them feel more insecure. This phenomenon showed that even when subjects knew that they were free to navigate by flying in any direction, gravity still affected the way that they experienced a space. It can then be argued that when a space that we enter seems more *'like a real space'* then our expectations about spatial behaviour in this space are also more realistic and we may feel affected by gravity. On the other hand, when entering a space where it is clear that real world constraints are not applicable - like places (1) and (2), we may adapt our spatial behaviour to the lack of constraints and feel freer to navigate without gravity.

More than a third of the subjects reported that they felt distracted by their surroundings. Some of them found this distraction pleasant, interesting or in any case not too significant, while others were bothered by it.

7.2.4.4 Place (4)

This place was completely enclosed by opaque boundaries. As a result, several subjects thought that being in this place felt like being in *"a private space-room", or "an everyday space".* The analysis of the results clearly showed that place (4) was the most secure and caused the least distraction for the task; on the other hand it was mostly uncomfortable and also made it difficult for subjects to execute the task. The following observations support these results.

Less than a third of the subjects (11) felt more comfortable in this place than in the other places, even though they acknowledged that there was less room to move about. It is important to take into account however, that all those subjects, had either

- felt negative about the lack of floor in places (1) and (2) or
- had low navigation skills; these subjects preferred a completely enclosed place and were happy to be constrained from moving out of the domain, as these limitations helped them avoid the confusion and distress of moving within the open surroundings.

Most subjects, however, reported negative observations about this place. Most of these observations were due to the fact that place (4) was completely enclosed and this obstructed movement within the place and made subjects feel restricted, confined, distracted by the walls close to them, uncomfortable and even claustrophobic. Certainly, many subjects felt that the tight enclosure of the place obstructed the execution of the task. Some subjects reported that this place felt smaller than the other three places, others that they were bothered because they were not able to view the surroundings of the place and finally few subjects found this place boring.

One of the subjects explained her negative feelings about this place:
"(This place was) as secure as a prison might be because you cannot fall off but you are not comfortable"; she went on to explain this feeling: *"I like to have a sense of the space beyond me while in a space"* or *"you know that there is something out there but you do not know what it is ?"*.

7.2.4.5 General observations

Subjects who took part in this experiment, can be classified in two groups according to their overall responses and spatial behaviour in the four places:

1) the ones who enjoyed moving freely in space and preferred being in open spaces like place (1),
2) the ones who were more influenced by gravity and preferred more enclosed spaces with a floor, like place (3) and place (4).

Most subjects seemed to belong to the first group and fewer in the second group.

The majority of subjects who could not navigate well, got easily disorientated when they tried to rotate in an open space - especially when they were positioned facing the surroundings and could not view the experimental domain. These subjects seemed to feel afraid of open spaces and insecure to move out too far from the defined place because they might get lost. These subjects belonged to the second category and clearly preferred being in place (4).

Generally, one third of the subjects - even the ones who were good at navigating - rolled around a lot while moving in these places. They seemed to be rolling:

- more when they were in an open space, like in the case of places (1) and (2) or place (3) when they came out of the place's limits and
- less in the more enclosed place (4) or in place (3) when they remained within its limits.

This may have happened because:

- there were very few constraints for movement in the open space and this fact induced a 'flying around' mode of navigation and
- in the open spaces there were very few cues for informing subjects of the relation of their viewpoint to a global vertical direction, which was necessary for maintaining an upright posture, if they felt like doing so. One subject who was in place (1) explained this: *"I do not mind moving around and rolling at an 90^0 angle, because there is no space defined here. Had it been an enclosed space I would want to position myself vertical to the floor. The only elements that give me this sense of verticality are the numbers and the floor in the central hall".*

Some subjects who entered one of the open places - (1) or (2) - for the first time seemed shocked or excited, in a positive or negative way. This could be attributed to the abrupt change of scale and complexity of the setting surrounding them, which had an impact on the visual and kinaesthetic aspects of their spatial experience. This change occurred when they moved from a simple and more realistic, local space - the path leading to the place - through the threshold and into a relatively vast and complex global space, where there was little definition of any local space and where real world constraints were more significantly violated. However, when they experienced this phenomenon for a second time, the feeling of excitement and surprise was less significant. For example, at least 5 subjects who firstly experienced place (2), found it difficult to get used to the idea of an enclosure and the freedom of moving out, along with the lack of boundaries; they were more comfortable when they later experienced place (1) or place (3) though. This phenomenon may have influenced the subjects' response on the sense of security and distraction in those places; it is however assumed that this effect has been randomised by the different order of presentation for each subject.

The vocabulary used by most subjects for describing their experience showed a strong dependency on a gravity-related understanding of space; they could only explain or describe situations by bringing gravity into the context, although they were very much aware of the fact that it did not apply.

7.2.4.6 Some observations about the dependent variables

In two cases where the statistical analysis did not show a significant contrast between measurements of a variable in places (1) and (2), observations have provided indication of certain differences in the responses of subjects:

- The analysis for the variable of security did not show significance for the place (1) - place (2) contrast. From observations it became evident that more than half of the subjects (21) reported feelings of insecurity in place (2), whilst on the other hand much fewer subjects (9) reported such feelings in place (1). It may therefore be suggested that subjects felt generally less secure in place (2) than in place (1).
- Although the statistical analysis for the variable of distraction did not show any significance in the contrasts between responses in places (1), (2) and (3), through observations it became evident that many subjects felt a bit more distracted in place (2) than in place (1). Indeed,
  - 11 of the 38 subjects specifically reported that they felt place (2) was more distracting or uncomfortable than place (1), but not necessarily in a negative way;
  - The number of subjects (17) who reported that they felt very distracted in place (2) was double than the number of the ones (9) who reported the same in place (1).

The responses that subjects gave, however, differed by a very small degree and so the difference was not detected in the contrast tests.

With respect to the easiness of task execution, the analysis did not show significance for the place (1) - place (2) and place (2) - place (3) contrasts. Nevertheless, many subjects reported that they found place (2) a bit more problematic than places (1) and (3). It is not clear however, whether this response was influenced by the fact that they found the task with spheres in place (1) and place (3) relatively easier than then task with the boxes in place (2). The possibility of the task objects having an impact on the easiness of task execution should not cast doubt upon the contrast between place (4) and the other three places, since it became clear from subjects' observations that place (4) was the most difficult to do the task in, because it was completely enclosed.

It can be argued that the level of distraction that subjects felt in a place, was affected by:

- The order of presentation; when a subject experienced one of the open places for the first time, they were more distracted by their surroundings since it was a novel experience and they may have felt the need to explore them, which certainly distracted them from the task. It seems that the level of how much they ended up exploring the world may be related to their personality; in other words to whether they conformed to rules -even if they were not told not to go out - how anxious or how risky they were as characters. Indeed very few subjects moved to the very extends of the VE and tried out all possible experiences like moving in strange ways or looking into the other places of the experimental domain, before being asked to do so.
- The navigation skill of a subject.
- Finally, their concentration on the task; if they had a difficulty with the task, they seemed to be concentrating on it, thus ignoring the surroundings and avoiding distraction. In the case of place (1) and (2), at least 6 subjects strongly focused on the task and as a result ignored their surroundings and consequently felt much less distraction. It seemed that subjects allowed themselves to be distracted when they had the execution of the task under control.

Some subjects seemed to be influenced by how unsafe or fascinated they felt in a place in their response relating to easiness or comfort. In some cases also, the sense of comfort experienced by a subject might have affected the sense of security. These interactions, however, could not be controlled since these concepts may be interpreted in a very subjective way by each individual.

The lack of boundaries in places (1) and (2) helped subjects to move freely around the objects in order to execute the task. On the other hand, many subjects also felt distracted and were motivated to move out and explore the surroundings, in which case the freedom afforded by places (1), (2), (3) may have obstructed the task and resulted in decreased response for easiness. However, not all subjects took these factors into account when they responded for the easiness of task execution. The researcher avoided stressing such possibilities of interaction between factors to subjects, as this might have influenced their response in other unpredictable ways. Instead, it was decided that spontaneous observations of subjects should be taken into account. It is however, understood that there might be subjects who would have said something against the above mentioned observations but for some reason refrained from doing so.

One subject reported that she understood easiness as being determined by both comfort and security in a place. She certainly thought she had to relate variables in this way, when she needed to differentiate between place (1) and place (2), where difference of functionality was not clear for her. Although this observation is very interesting for considering future related experiments, such a relation cannot be established from this particular experiment.

Finally, five subjects mentioned that it was easier to do the task with spheres rather than with boxes as objects, having planes as backgrounds - in the case of place (1) - or enclosed within rectangular forms - in the case of place (2). This might have happened because:

- boxes hide each other more as you move around them to identify them or because
- the background should be different - in terms of form - from the foreground objects, for aiding object recognition.

CHAPTER 8

8. TWO EXPERIMENTS ABOUT THE SPATIAL ARRANGEMENT OF PLACES AND PATHS

8.1 Introduction

During the design of several pilot VEs, for the evaluation of the framework, which has been presented in chapter (5), it became evident that the implementation of this framework involved the development of solutions to the problem of structuring domains by arranging places and paths in three-dimensional space. In an attempt to analyse this very complex problem into several simpler problems which would be easier to resolve, two key issues were identified:

- How do places have to be positioned in relation to a path in three-dimensional space, in order to aid orientation when navigating into the place and performing a certain activity inside this place;
- How do paths have to be positioned in order to connect two places in three-dimensional space, for the purpose of easing orientation when entering the path and navigating through this path towards the other place.

The experiments (5) and (6) which are presented in this chapter have dealt with these two issues respectively.

Both of these key issues investigate the impact of certain settings in VEs on the sense of orientation experienced by a subject, who navigates within these VEs in order to perform a task there. As explained in (3.3.1), a subject has to feel orientated within a space in order to belong to this place: "*It is ... important that our environment has a spatial structure which facilitates orientation*" (Norberg-Schulz, Nesbitt, 1996, p.423-4).

As suggested in (4.3), a subject has a 'sense of orientation' within an environment when he is able to maintain a direction while moving, or to point to a direction, independently of his location in space and independently of cues originating from the environment (Passini, 1992, pp.27-28). Spatial orientation and wayfinding could both be defined as *"a person's ability to mentally determine his position within a representation of the environment made possible by cognitive maps."* (Passini, 1992, p.35).

8.2 EXPERIMENT (5)

8.2.1 Planning phase

During the design of pilot VEs, it became evident that if a place was positioned in certain ways in relation to a path, a subject who moved into or out of the place would become somehow disorientated. This phenomenon indicated an issue which was crucial for the composition of sets of places and paths within domains. Accordingly, the impact that the position of a place, in relation to a horizontal path, had on the way that subjects orientated while moving into or out of this place, was investigated by this experimental methods.

The aim of this experiment is, therefore, to identify how should places be positioned in relation to a path in a VE, for the purpose of aiding orientation whilst :

- entering the place,
- performing a task in the place,
- exiting the place.

This aim will be achieved by investigating the way that subjects respond to several cases of places, differently positioned in relation to the same path.

A second objective of the experiment is to investigate how subjects position their viewpoint in relation to a place, when they try to orientate and perform a task in this place, dependent upon how this place is positioned in relation to the path.

8.2.2 Design phase

Since there was no precedent for predicting the behaviour of subjects in such a situation, it has not been possible to develop a hypothesis about the possible outcome of the above mentioned objectives. Therefore, a VE was designed for the purpose of identifying how should places be positioned in relation to a path in order to ease orientation. This VE consisted of 5 rectangular parallelepiped places which were positioned in different ways in relation to the same horizontal path. Consequently the impact of the way that these places were positioned on the criteria:

1) how easily do subjects orientate while performing an activity,
2) the way that subjects position their viewpoint in relation to a place

was studied. The impact of the first criterion would identify which ways of positioning a place in relation to a path were preferable and which were problematic, for a subject who navigates in a domain comprising places and paths, which affords navigation in its interior space. The null hypothesis to be rejected in this experiment is that "all differently positioned places are equally easy for subjects to orientate into, while entering, doing the task and exiting the place".

Accordingly, the first dependent variable, investigated by this experiment, was the 'easiness' with which subjects orientated while moving and performing the task in each place. The value for this variable was given as an answer to the following question:

"How easy was it for you to orientate yourself while:

- *Entering the place*
- *Moving within the place in order to perform the task and*

- *Exiting the place.*

Answer with marks out of 100 where:

0. it was very difficult

100. it was very easy.

Time of task execution was also recorded and was used as the second dependent variable for this experiment.

The third dependent variable of the experiment was the way that subjects positioned their viewpoints in relation to the place. The author observed the way that subjects moved in each place, and attempted to find out how they wanted to position their viewpoints when they tried to orientate inside each place in order to do the task. The volumetric proportions of each place do not imply a specific direction but still one dimension is significantly smaller than the other two. This fact is likely to constrain movement along this direction and to induce movement perpendicularly to the axis of this direction. Four different possible options for positioning a viewpoint within such a place, were identified after the pilot experimental study - explained in (6.4). These four options corresponded to the four possible values that the second dependent variable took. If we consider the (x,y) coordinate system of the subject's viewpoint - where x is the horizontal and y is the vertical axis - then the four options were:

1) the y axis of the viewpoint was parallel to the small dimension and perpendicular to the surface that one could refer to as a 'floor';
2) the y axis was parallel to this 'floor';
3) the viewpoint was positioned randomly;
4) subjects tried to keep a global vertical orientation, following the external cues visible to them.

The independent variables which may have affected the behaviour of subjects in each place are:

1) The way that each place was positioned in relation to the path, which is described by the axis and angle of rotation of the place in relation to the path. This qualitative factor is set at specific levels of interest and its effect on the dependent variable will be studied.

2) The way that each path was spatially arranged was rigidly controlled. All paths, therefore, were positioned in a similar way, so that they could function as a reference against which places were positioned in different ways.

3) The physical characteristics of each place and path - form, volume, surface material; since this factor would affect the behaviour and response of subjects, it was rigidly controlled so all five places and paths in the VE are identical.

4) The order with which the subjects experienced one place after the other; this factor was randomised.

Therefore all places had an orthogonal parallelepiped form, with equal length and width, the height of which was a third of its length. The bigger two surfaces of the place were not intended to be seen as a 'floor' and a 'ceiling' respectively. Instead, the intention behind investigating the way that subjects positioned their viewpoint inside each place was to identify whether subjects did indeed tend to see these bigger surfaces as floor and ceiling or not.

The experimental domain of the VE consisted of:

- A central hall on the one surface of which 5 entrances to 5 paths were positioned;
- 5 identical and similarly positioned paths that lead to
- 5 identical places, differently positioned in relation to each path.

Each of the 5 places was rotated in a different way in relation to the path. By no means do these five cases exhaust every possible option of rotating a place in relation to a path. However, for the purposes of this experiment it would not be practical to use more cases, as the number of subjects needed for getting a useful result would exceed the scale of this project. Five numbers, which were positioned at the entrance of each path from within the central hall, signified the way towards each of the places.

Figure 8.1: External view of the experimental domain, from the top of place (1) - on the left - and front view of all 5 places - on the right.

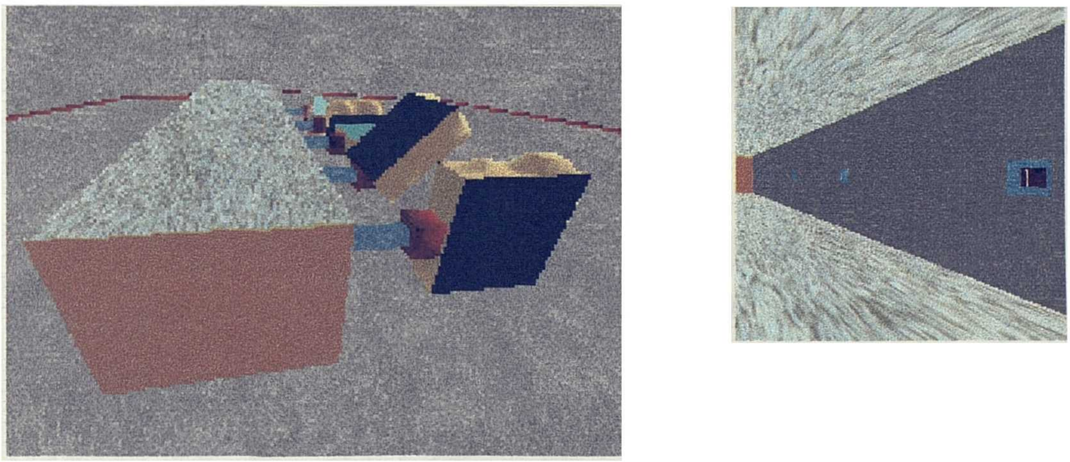


Figure 8.2: External view of the experimental domain from the side, place (1) is seen at the front - on the left. Interior view of entrances and their numbers from within the central hall - on the right.

The way that these places have been positioned can be described if we consider one of them as the 'control place', to which no rotation has been applied; this place would have its bigger surfaces parallel to the bigger horizontal surfaces of the central hall and to the direction of the path. If we consider an (x,y,z) coordinate system as a reference, where z is the main axis of the path, y is the vertical main axis of the numbers in the paths' entrances and x is the axis parallel to the longer direction of the central hall, then:

1) Place (1) is rolled 90^0 around the z axis
2) Place (2) is tilted 45^0 around the x axis
3) Place (3) is not rotated at all and in seen as the control place
4) Place (4) is rolled at a -60^0 angle to the z axis
5) Place (5) is rolled at 30^0 to the z axis and tilted at -45^0 to the x axis.

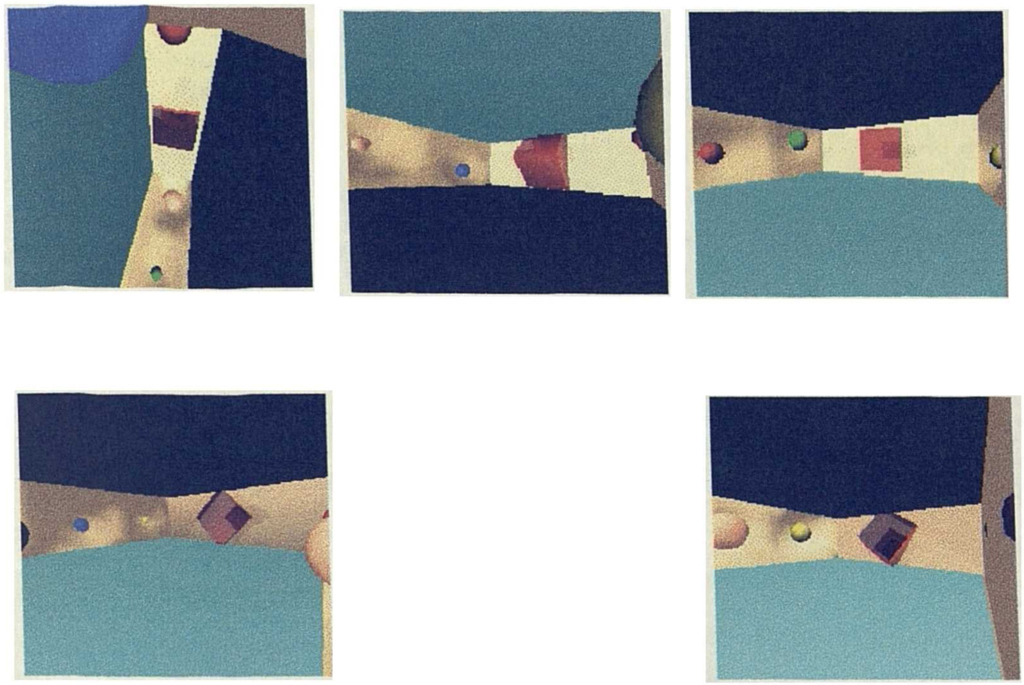


Figure 8.3: View of the interior of each place from the same corner towards the threshold at the entrance; top left is place (1), top in the middle is place (2), top right is place (3), bottom left is place (4) and bottom right is place (5).

There was a certain difficulty in designing the form of the threshold which would join each place with the horizontal path. Since this element would have to function as a link between these spatial elements it would have to:

- introduce the place to the subject as he entered from the path and to
- signify the exit and inform the subject of the orientation of the path, before he exited the place to re-enter this path.

These functional requirements dictated the need for a three-dimensional element, which would function as a threshold between each path and place. The form of this threshold was cubic and its surfaces were assigned the same transparent red material which had been assigned on thresholds in all other experiments.

The surfaces of the threshold were parallel to the corresponding surfaces of the path. Since the threshold could be seen from within the place, its orientation was expected to inform subjects of the orientation of the path in relation to the place they are in. Consequently, the subject would know how to position his viewpoint in order to manoeuvre from the place, through the threshold into the path, for the purpose of exiting the place.

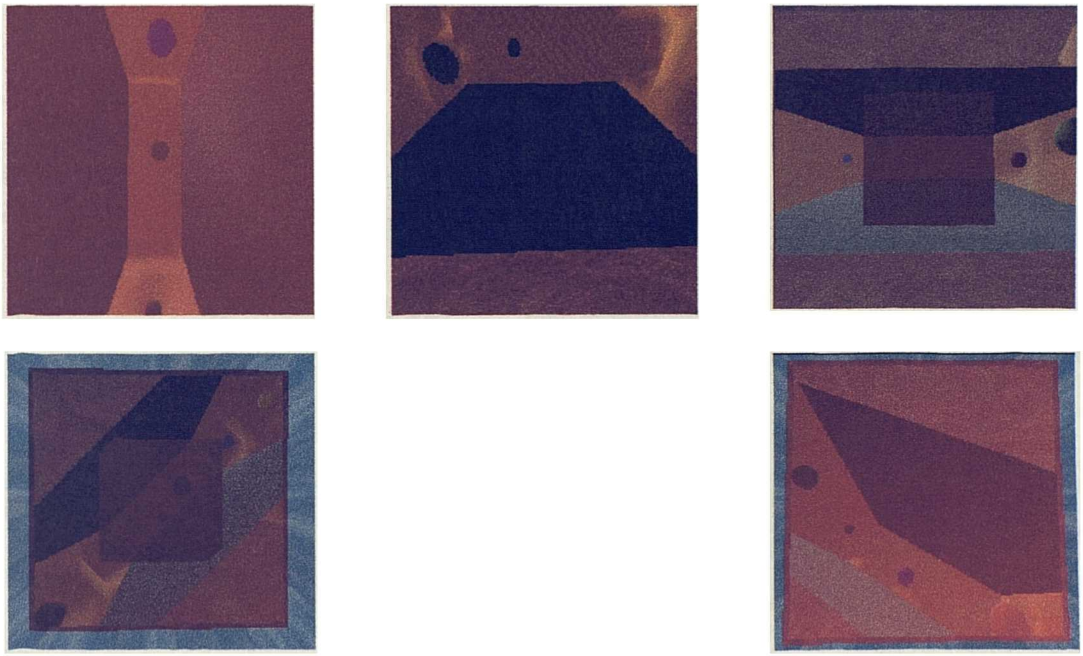


Figure 8.4: View of each of the interior of the five places while inside the threshold, just before entering each place; tope left is place (1), top in the middle is place (2), top right is place (3), bottom left is place (4) and bottom right is place (5).

Subjects were generally constrained into navigating within the limits of the experimental domain, so the surroundings of this domain only existed as a background to the experienced interior setting. These surroundings consisted of the same spherical environmental map and horizon, which were also used in experiment (4) - as explained in 7.2.2. Although the experimental domain was largely opaque and therefore these elements were rarely seen, they still aimed at aiding the subject in terms of orientation to a global context.

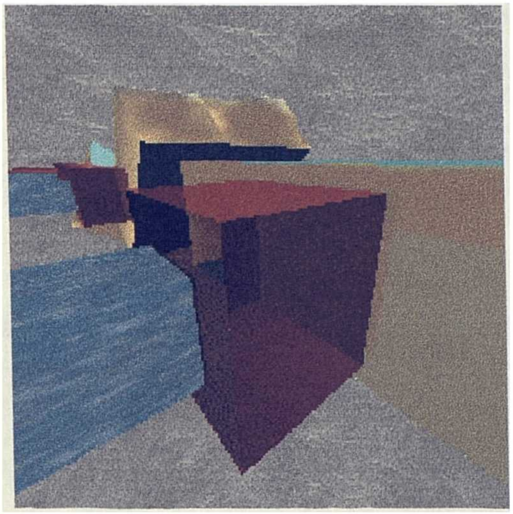


Figure 8.5: External view of the threshold and the context of the experimental domain.

The task which was executed in each of the places was not supposed to have an impact on the response of subjects in terms of how easily they orientated. The only aim of the task was to motivate the subjects to enter the place, move around and perform a certain activity there, so that their spatial behaviour, while doing something in this place, was investigated. Therefore it was not necessary to assign a different task in each place in order to avoid learning effects on the dependent variables. Accordingly, the tasks in each place were similar. Five spheres were positioned inside certain concavities on the surfaces of each place, at similar positions. These concavities did not have a shape which implied any direction but were circular and their shape was made even less obvious by assigning a smoothed material on these surfaces. The reason for selecting a shape of no implicit direction for the objects and the concavities was the need for avoiding any formal element which would influence the way that subjects orientated and positioned themselves within each place. Each sphere had a different colour - the same five colours were used in all places - and the size of each sphere also differed. The task was to identify which was the colour of either:

- the largest or
- the smallest sphere in each place.

The different order of presentation was expected to randomise any other unpredictable effects that the task may have had on the responses.

31 subjects - 11 female and 20 male - took part in this experiment.

8.2.3 Analysis phase - Statistical analysis of results

The aim of this experiment was to investigate the impact of the way that a place is positioned in relation to a path:

- to the easiness for orientation in the place and
- to the way that subjects position their viewpoint while moving within this place.

As in all previous experiments and since all subjects experienced all five places, a repeated measures general linear model ANOVA procedure was used for the analysis of the results for the two variables of 'easiness of orientation' and 'time'. The within-subjects factor was named 'place' and had 5 levels, each of them corresponding to each of the 5 places of the experimental domain. The measures recorded at each level corresponded to the two dependent variables - 'easiness of orientation' and 'time' respectively.

With respect to the third dependent variable, tables and bar charts of frequencies, for the four different values of the response, are investigated in order to study the spatial behaviour of subjects in each place. Any relationships among behaviour in different places are established on the basis of these tables and charts.

8.2.3.1 The variable of easiness of orientation

For the first dependent variable, the analysis of the results aims at rejecting the null hypothesis that: "in all five places, subjects found it equally easy to orientate within the place in order to do the task". The test of sphericity for the measure of 'easiness' of orientation showed that there was a need for adjusting the degrees of freedom for performing the within-subjects effects test; this test is presented in appendix (A.5.1). The results of the corrected tests showed that:

- the F statistic for the within-subjects effects was significant ($F=14.923$, $df=2.685$, $p<0.05$).
- The within-subjects tests showed significance in the contrasts between:
  - place (1) - place (2) ($F=4.654$, $df=1$, $p<0.05$)
  - place (2) - place (3) ($F=48.322$, $df=1$, $p<0.05$)
  - place (3) - place (4) ($F=29.279$, $df=1$, $p<0.05$)
  - place (1) - place (3) ($F=28.944$, $df=1$, $p<0.05$)
  - place (3) - place (5) ($F=56.844$, $df=1$, $p<0.05$)
  - it is also likely that the place (2) - place(4) contrast was significant
- whilst the contrast between place (2) - place (5) was close to being significant ($F=2.774$, $df=1$, $p<0.1$)
- the contrasts between the other places were not significant.

An explanation of the above mentioned procedure along with tables of the tests of sphericity, within-subjects effects and within-subjects contrasts can be found in appendix (A.5.1). The above mentioned results for the variable of 'easiness' of orientation are also illustrated by the following error bar graph.

The results of the analysis provide evidence for the rejection of the null hypothesis for the variable of the 'easiness' of orientation. In specific, it can be concluded that:

- The control place (3) - which was not rotated at all - was clearly the easiest to orientate in, compared to the other four places.
- Place (2) - the floor of which was tilted 45^0 around the x axis of the reference coordinate system - was clearly worst than places (1), (3) and (4) but it is not clear whether it was worst than place (5) as well, in terms of easiness of orientation.
- All other contrasts were not significant enough to be considered; this implies that it is difficult to differentiate between the easiness of orientation in places (1), (4) and (5) and also between place (2) and place (5).

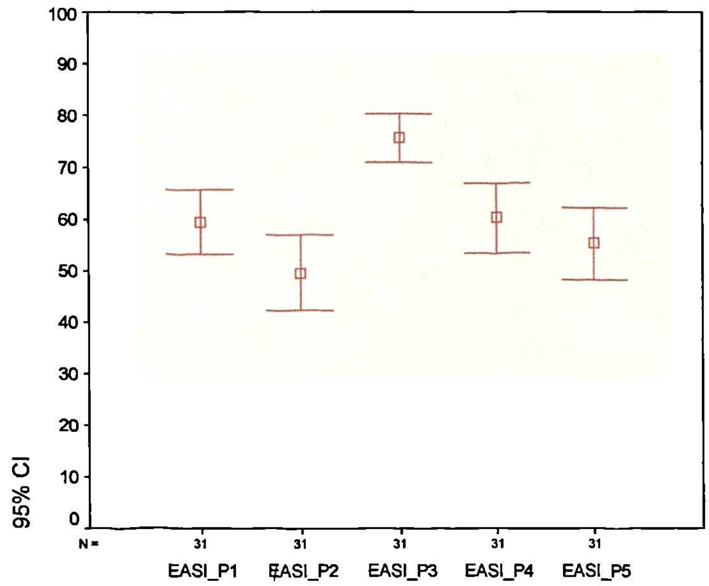


Chart 8.1: Error bar graph for the variable of 'easiness' of orientation.

8.2.3.2 The variable of time

For the second dependent variable, the analysis aims at rejecting the null hypothesis that: "subjects spent an equal amount of time in all five places". The test of sphericity for the measure of 'time' showed that there was a need for adjusting the degrees of freedom for performing the within-subjects effects test; this test is presented in appendix (A.5.2). The results for the corrected tests showed that:

- The F statistic for the within-subjects effects test was significant ($F=6.668$, $df=3.156$, $p<0.05$);
- The within-subjects tests showed significance for the contrasts between:
  - place (2) - place (3) ($F=31.125$, $df=1$, $p<0.05$)
  - place (1) - place (3) ($F=4.525$, $df=1$, $p<0.05$)
  - place (2) - place (5) ($F=13.568$, $df=1$, $p<0.05$).
- It is also very likely that the contrast between place (2) - place (4) is also significant.
- Additionally, the contrasts between:
  - place (1) - place (2) ($F=3.312$, $df=1$, $p<0.1$) and
  - place (1) - place (5) ($F=3.248$, $df=1$, $p<0.1$)

  were significant for $a<0.1$ whilst the contrast between
  - place (3) - place (4) ($F=2.063$, $df=1$, $p<0.05$)

  was not significant enough to provide evidence but was not too small to be ignored.
- All other contrasts were not significant.

An explanation of the above mentioned procedure along with tables of the tests of sphericity, within-subjects effects and within-subjects contrasts can be found in appendix (A.5.2). The above mentioned results for the variable of 'time' are also illustrated by the following error bar graph.

These results provide evidence for rejecting the null hypothesis for the variable of 'time'. Accordingly it may be concluded that:

- Subjects spend significantly more time in place (2) than in places (3), (4) or (5) and slightly more time in place (2) than in place (1).
- Subjects spend significantly less time in place (3) than in place (1) and (2) and slightly less time in place (3) than in place (4).
- Subjects spent slightly more time in place (1) than in place (5).

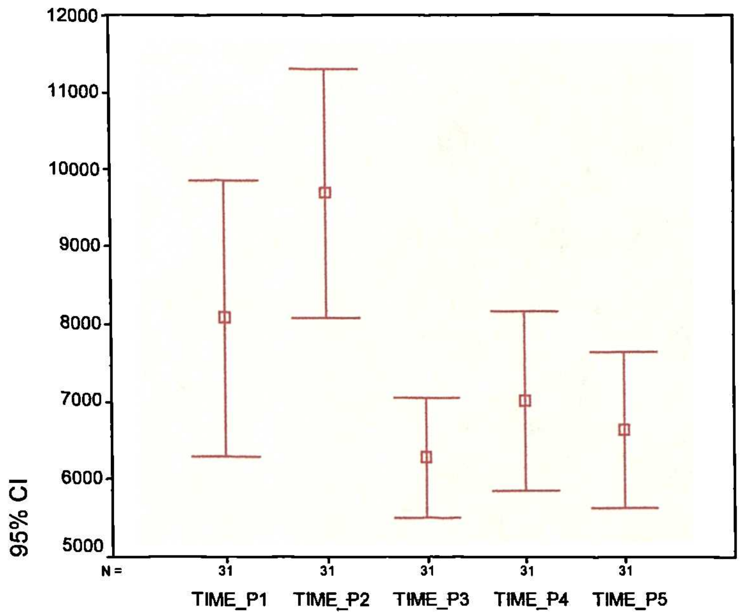


Chart 8.2: Error bar graph for the variable of 'time'.

Due to the form and size of places in this experiment, which was not likely to induce exploratory behaviour, subjects did not spend any time in each place doing much more than merely performing the task. This fact was also confirmed by observation of the subjects' behaviour in these places. Accordingly, the variable of time has been taken into account in this experiment. As a result, it can be argued that the results for 'time' support the analysis of the 'easiness' results, in that:

- Place (3) is the easiest to do the task in and it took subjects significantly less time to do the task in place (3) than in places (1) and (2); a slight difference was also detected between place (3) and place (4) but no difference was detected between place (3) and place (5).
- Place (2) is considered the most difficult to orientate and do the task in and accordingly it took subjects significantly more time to do the task in there than in the other places.
- No significant differences were detected for either easiness or time measurements among places (1), (4) and (5).

8.2.3.3 The variable of viewpoint orientation within a place

The second objective of this experiment was to investigate the impact of the way that a place is positioned in relation to a path on the way that a subject is positioning his viewpoint, while moving within this place. Since the response values for this dependent variable were provided by nominal measurements, frequency tables and bar graphs were studied for the purpose of identifying possible patterns among responses in the five places. Since there were no precedents for predicting the outcome of this part of the experiment, no specific hypothesis about the behaviour of subjects in each place was defined. The aim of analysing the results is to find out whether subjects thought that they needed to position themselves in a particular way in order to orientate and feel comfortable enough to perform the task in each place.

In the following table of frequencies:

- response (1) corresponds to a subject trying to position the y axis of his viewpoint parallel to the small dimension of the place and vertical to the surface that one could refer to as a 'floor',
- response (2) corresponds to a subject trying to position the y axis of his viewpoint parallel to this floor,
- response (3) corresponds to a subject positioning his viewpoint randomly and
- response (4) corresponds to a subject trying to maintain the y axis of his viewpoint parallel to a global vertical orientation.

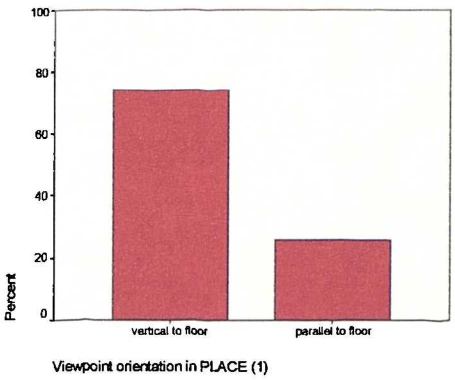
	response (1)		response (2)		response(3)		response (4)	
	Count	%	Count	%	Count	%	Count	%
PLACE (1)	23	74.2%	8	25.8%				
PLACE (2)	23	74.2%	2	6.5%	4	12.9%	2	6.5%
PLACE (3)	29	93.5%	1	3.2%	1	3.2%		
PLACE (4)	26	83.9%	3	9.7%	2	6.5%		
PLACE (5)	28	90.3%			3	9.7%		

Table 8.1: Table of frequencies for the variable of viewpoint orientation.

It may be concluded from this table that, in all five places, subjects largely preferred to position their viewpoint perpendicularly to the two planes defined by the two larger dimensions, which could be seen as the 'floor' and the 'ceiling' of the place. The responses of subjects will be studied individually for each place:

1) In place (1), 74.2% of the subjects positioned themselves vertically to the 'floor', while 25.8% of the subjects felt comfortable to move their viewpoint around parallel to the 'floor'. This behaviour may be attributed to the fact that this place was positioned in such a way in relation to the path that a subject who entered it could see the floor and ceiling as if they were walls. Consequently a quarter of the subjects adapted to the fact that the were moving around in a space with the volumetric proportions of a small gorge while the others tried to position their viewpoint so that they could move around as if this space was a normal room - where the walls are smaller than the floor and the ceiling.

2) As in place (1) so in place (2), 74.2% of the subjects clearly attempted to position their viewpoint vertically to the floor but the rest of them - 8 subjects - either moved randomly within the place or chose one of the other two situations. The behaviour of these 8 subjects can be attributed to their confusion, which occurred as they entered the place and they were immediately faced with a dark tilted floor which was too close to their viewpoint. By loosing orientation, subjects did not know how the place was positioned in relation to the path and randomly placed their viewpoint in an attempt to find their bearings, in order to do the task. Although only 8 of the subjects behaved like that, many subjects were confused by the way that this place was positioned and this is also supported by the results of the analysis for the variables of easiness of orientation and time. Those subjects who understood that the place was tilted in relation to the path positioned their viewpoint vertically to the surface that they thought was the tilted floor of the place.



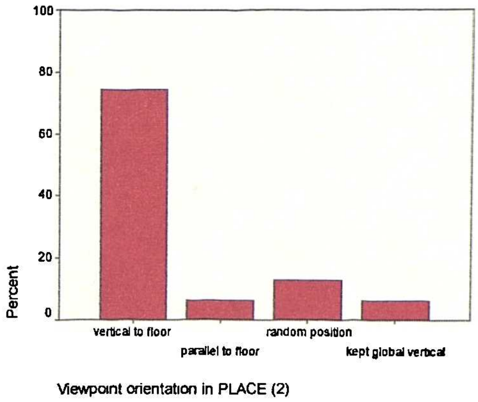


Chart 8.3: Bar graphs for the frequencies of viewpoint orientation in places (1) and (2).

3) In place (3), almost all of the subjects (93.5%) attempted to position their viewpoint vertically to the floor of the place; only 2 other subjects did otherwise and this may be attributed to bad navigation skills or a non-vertical orientation of the viewpoint while entering the place. Most subjects saw this place as a realistic room, because it was not rotated in any way; they felt like behaving as they would in a real space. Accordingly, they saw the planes defined by the two larger dimensions as a floor and a ceiling and positioned their viewpoint vertically to this plane.

4) In place (4), fewer subjects than in place (3) (83.9%) positioned their viewpoint vertically to the floor and few others (9.7%) positioned their viewpoint parallel to the floor, while only 2 subjects moved randomly around the place shifting between different orientations. Since this space was rolled at a -60^0 angle to the z axis of the path, it was possible for a subject who entered slightly rolled to perceive it as rolled at a 90^0 angle and to behave as many subjects behaved in place (1) - they positioned their viewpoint parallel to the floor. Most subjects who became aware of the way that the place was positioned in relation to the path, positioned themselves vertically to the floor.

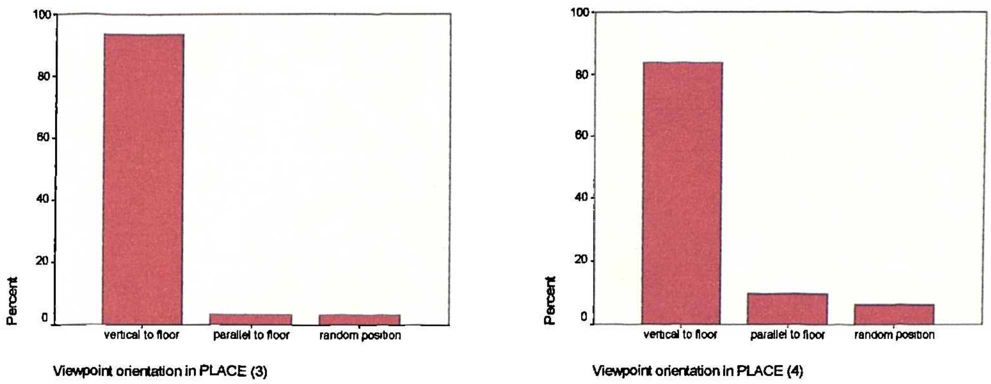


Chart 8.4: Bar graphs for the frequencies of viewpoint orientation in places (3) and (4).

5) In place (5) as in place (3), the large majority of subjects (90.3%) positioned their viewpoints vertically to the floor and only 3 subjects moved randomly around the place. Although this place was rotated along two axis - rolled at 30^0 to the z axis and tilted at -45^0 to the x axis of the path - the angles of rotations were not too big - as in the case of places (1), (2) and (4) - therefore most subjects thought that they were stepping into a room the floor of which was slightly rotated and consequently behaved as in the case of place (3).

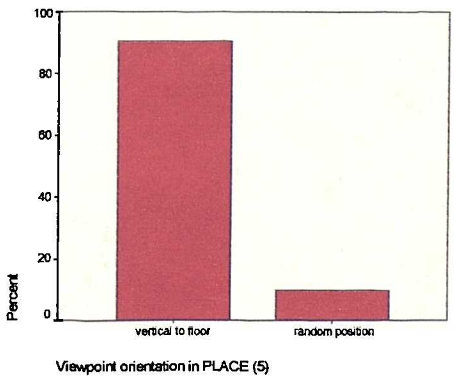


Chart 8.5: Bar graph for the frequencies of viewpoint orientation in place (5).

8.2.4 Analysis phase - Observations during the experiment

This section includes a summary of the observations made by subjects and by the author during the experiment. Further details about these observations are presented in appendix (A.5.3).

8.2.4.1 General observations

Differentiating between easiness of orientation in each place was difficult or unclear for subjects who were particularly good at navigating because it was very easy for them to manoeuvre their viewpoint within space; sometimes they even moved in unpredictable ways in an attempt to challenge themselves and achieve something more difficult.

On the other hand, subjects who had low navigational skills or were tired at the time of the experiment, did not seem to feel a need or to make an effort to be positioned in a particular direction but tried to move around randomly and do the task; to them accomplishing the task was primary and they focused on that without paying much attention to their surroundings.

During the experiment it became obvious that the task of comparing sizes of objects had been made difficult by the fact that the viewing angle of the application window (0.8) was slightly bigger than a normal angle (0.6) and as a result the perspective of the VE was slightly accentuated and distorted. When subjects panned their viewpoint around in order to view the objects, the sizes of these objects changed more abruptly than they would in a real environment and this unrealistic phenomenon seemed to make the task difficult for many of the subjects. Indeed, 7 subjects reported that this perspective made the task of comparing sizes of spheres and orientation within the place more difficult.

Finally, one of the subjects gave an interesting description for the places she *entered "like being in a gallery where you have to pan around to see all the objects/exhibits."*

8.2.4.2 Orientating the viewpoint vertically to the 'floor'

It is understood that the way that subjects had orientated their viewpoint in relation to the threshold as they entered each place may have affected the way that subjects perceived the place as being orientated in relation to the path; this variable could not be controlled. For example, if a subject entered place (4) while his viewpoint was rolled at a -60^0 angle in relation to the global vertical orientation, he would perceive place (4) as being horizontal, although it was not. The possibility of such an effect had been detected during the pilot experimental study. It was therefore decided that subjects would be asked to maintain the y axis of their viewpoint parallel to a global vertical orientation, as they entered each place, but it was stressed to them that they were free to move anyway they felt after entering the place. The word 'floor' was not used by the author during this prompt, in order to avoid influencing subjects to consider one of the path's surfaces as a floor. It is understood that the way that subjects were prompted may have affected their overall response in a manner that has not been predicted, but it was nevertheless considered the best possible way to make subjects enter all places in a similar way.

As was concluded from the analysis, the majority of subjects in all five places wanted to position their viewpoint vertically to the surface that they perceived as a 'floor'. With reference to this viewpoint and for the purpose of explaining the spatial behaviour of subjects, it is essential to consider a subjective coordinate system for a subject where

- x as the horizontal axis of the subject's viewpoint
- y as the vertical axis of the viewpoint and
- z as the axis perpendicular to the viewpoint and extending away from the subject.[14]

[14] This convention was dictated by the way that the coordinate axes of the user viewpoint are considered when authoring a simulation with WorldUp, which was used for developing this experiment and is in accordance with the convention for the (x,y,z) axes used by the Magellan input device (Figure 6.6).

Using this coordinate system as reference, it can be suggested that humans feel more comfortable to yaw their viewpoint - rotate around the y axis - rather than pitch their viewpoint - rotate around the x axis - when they are looking around in a space and exploring it. It is natural to pitch our head up or down at rather small angles, but it would seem unnatural to tilt our whole body 360^0, as would be the case for a subject moving his viewpoint parallel to the floor in place (1).

Accordingly, it can be suggested that a human in an enclosed space, tends to position his viewpoint so that the largest area of this space is parallel to the (x,z) plane of his subjective coordinate system and tends to translate and rotate this viewpoint along this (x,z) plane for the purpose of exploring the space; consequently, the smallest dimension of this space is perceived as height. In order to explain this phenomenon, it can also be suggested that humans are more used to being in places where walls are rarely much bigger than floors or ceilings. Such places are more realistic and are similar to the majority of spaces that we experience, in our everyday life. In an urban context we may experience much higher walls, but this is usually the case when we are in a space which, unlike a place, is not completely enclosing us. At least 9 subjects' observations, which are described in detail in the appendix, support these suggestions. Of course, such suggestions are valid only for a place of form and proportions such as the places used in this experiment; for places of different form and volumetric proportions with objects placed within them in a different manner, further experiments should be conducted.

8.2.4.3 Methods followed by subjects when performing the task

In this sub-section, observations have been used for studying the method that subjects have followed in order to orientate and perform the task in each place.

A crucial factor which clearly aided orientation in a place was the ability to view the structure and orientation of the place in relation to the path, from within the threshold before entering the place. This certainly seemed to be the case in all places apart from

place (2), in which subjects quite often lost their bearings, just as they entered the place. It is understood, however, that it was more difficult for subjects to make use of such cues, when experiencing one of these spaces for the first time, because they did not know what kind of space to anticipate. After the experience of entering a place for the first time though, it became easier for them to focus on cues that informed them of the orientation of forthcoming spaces, since they knew what to expect. Observations by 16 subjects - similar with the following quotes - supported this suggestion:
"It is important to be able to see how the elements you are heading towards are structured before you enter the place defined by these elements" or
"you could see enough of the place as you entered to feel easily orientated with a little manoeuvre."

It has so far been argued that subjects generally felt they could orientate easier if they could see how the place they were about to enter was orientated in relation to the path and threshold that they had just navigated. As they entered, subjects tended to position their viewpoint vertically to the biggest surface of the place which they understood to be the floor. A possible method which was followed for orientating when entering each place and which may explain these suggestions was indicated by two subjects: On entering the place, they thought they had to shift the subjective coordinate system of their viewpoint from adapting to the coordinate system of the path to that of the place, while passing through the threshold. Another subject also explained that he *"tried to line-up (his) point-of-view with the place before entering (and that).... the line of view would have to be aligned with the longest axis within the space"*.

When they were inside a place most subjects tried to move towards one of the corners of the place from where they could view simultaneously as many spheres as possible, in order to perform the task. This was not easy due to the apparent small size of the place. Three subjects also reported that they considered the size of the path too narrow.

On the way out, the fact that the threshold - as an extension of the path - was projecting itself within the place, thus manifesting its spatial relation to this place, informed subjects of which direction they had to move towards, when they attempted to exit the place and to enter the path. The orientation of the threshold within the place, therefore, aided orientation of subjects on the way out. Indeed, 3 subjects reported that exiting a place was made easier because the threshold was projecting itself out of the wall:
"it is harder to see the orientation of the room on the way in but it is easier to see the orientation of the corridor (and the threshold) on the way out".

After exiting the threshold and as subjects moved towards the central hall, the number which was positioned at the entrance of the path helped them orientate in relation to a global vertical orientation. It is also possible that, after performing the task in one or two places, some subjects learned how spheres were positioned in a place and consequently used this position to help them orientate within each place.

8.2.4.4 The need for relating to a floor and a ceiling

Some subjects (6) felt that it was significant for them to establish a relation with surfaces in the place that they saw as floor, ceiling and walls. One of them attributed this need to the fact that a floor and a ceiling made her feel safe. Four of these subjects also reported that the colours of the surfaces affected the way that they orientated within the place. It seems that the difference in colour between the floor/ceiling and the walls of the place influenced the identification of these surfaces within each place. Subjects may have learned which was the colour of walls and of floor/ceiling, after experiencing 2-3 places and on this basis they identified them as such.

However, since the colour of both bigger surfaces - which could be seen as floor and ceiling - was the same, subjects had to detect other cues in order to differentiate between the two, if they felt they needed to do so. Since the environment was shaded, some surfaces appeared darker than others according to their angle of orientation. Very few subjects reported that they preferred to see the darker of the two surfaces as a floor.

8.2.4.5 Thresholds

The way that the three-dimensional thresholds, which could be referred to as 'buffers', were implemented generally confused at least 9 subjects. These thresholds were in fact small cubic spaces, which helped subjects adjust their viewpoints appropriately for entering each place. Some of them attributed this confusion and consequent disorientation to the following reasons:

- *"On entering you pass this threshold and you think you have entered (on the basis of having experienced flat thresholds in the previous experiments) but you have not entered yet; the same happens on the way out (and at least this is consistent)".*
- Thresholds do not inform subjects of what is ahead of them in the place: "*the vale produced by the 3 consecutive transparent surfaces is slightly disorientating*".
- Thresholds do not help subjects determine a certain direction from which to enter the place. A subject felt he hesitated because he was not sure whether he had to go through them or move sideways into the place. They certainly help to determine a direction for movement on the way out though.

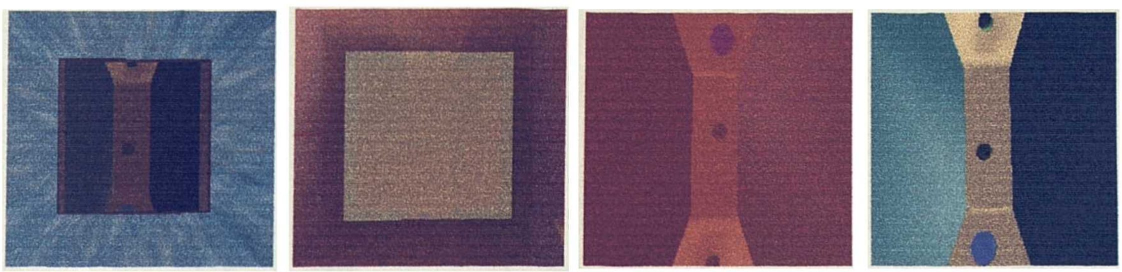


Figure 8.6: Four consecutive views describing the passage through the threshold while entering place (1).

One of the 9 subjects found the threshold confusing as he entered place (5) where there is a shift of the floor at an angle. However, the same subject found the threshold enjoyable and not confusing in the case of places (1) and (3), where place, threshold and path all meet at 90^0angles.

8.2.4.6 Observations in place (1)

Few of the subjects (5) who positioned their viewpoints vertically to the floor in this place, kept moving upside-down and did not seem to mind that. On the other hand, 2 subjects who kept moving parallel to the floor, got the impression that this place was smaller and narrower than the others: *"I felt the floor was very low"*. It was not possible, to detect any effect of the order, with which places were presented to subjects, on the way that subjects positioned their viewpoints in place (1).

At least half of the subjects tried to position their viewpoints vertically to what they saw as the 'floor' of the path, as they exited this place.

- Most of them (11) did so after exiting the threshold, possibly because they saw the number at the entrance of the path or after passing through the number and into the central hall.
- Only 3 subjects repositioned themselves while passing through the threshold.

This may have happened because subjects could not differentiate between the up and down direction when they were inside this place, since there were no cues to inform them of their relation to a global frame of reference; the way that this place was rotated did not help either because it was symmetrical. This explanation is also supported by the fact that many subjects ended up coming out of the place with their viewpoint upside-down or parallel to any surface of the path.

8.2.4.7 Observations in place (2)

The observations of most subjects were in support of the results which were presented earlier. According to these, place (2) was the most difficult to orientate in and accordingly it took subjects significantly more time to do the task in there than in the other places. Subjects were generally confused and disorientated because the floor surface was tilted and, as a result, the position of the place in relation to the path was not visible to them as they were entering the place from the path. Only one subject reported the opposite.

Most subjects had negative feelings about experiencing and orientating in place (2). Many of them got stuck on the floor surface as they entered the place and got completely lost and disorientated when this happened. Others felt confused or thought that this place made it more difficult for them to orientate and do the task.

Fewer subjects than in place (1), made an effort to reposition their viewpoint vertically to the floor of the path as they exited the place. This may have happened because subjects became very disorientated when inside this place.

8.2.4.8 Observations in place (3)

Most subjects did not report something about their experience in this place. This phenomenon could be attributed to the fact that they found it quite easy and straightforward to orientate and perform the task in there and therefore had to spent very little time in it. This suggestion is in agreement with the results of the analysis, where place (3) is clearly the easiest to orient in and the one that subjects spent less time in. All subjects who reported something about this place had positive feelings about it. They also attributed the easiness of orientation to

- the regularity of the way that boundaries were positioned
- the coordination of the entrance and the place that was entered and
- the fact that the relation of the place to the path was visible before entering the place.

8.2.4.9 Observations in place (4)

Some subjects had positive and others negative feelings about place (4):

- Some of them found it easy to orientate in this place and were not bothered by the 60^0 angle roll;
- Few others felt it was easy to enter the place but difficult to position themselves vertical to the floor path, on the way out.
- Some other subjects though, found it difficult to orientate in this place because of the way it was rotated in relation to the path.

The majority of subjects felt they had to position their viewpoint vertically to what they saw as the floor of the path, on their way out of the place; they did so either before entering or after exiting the threshold. This may be attributed to the fact that subjects were more aware of the spatial relation of this place to the path, while being inside the place. It is interesting to mention that

- In place (1), where subjects seemed confused in terms of their orientation to a global coordinate system, most subjects positioned their viewpoints vertically to the floor of the path by using the number - which was a direct sign indicating global orientation - as a cue;
- In place (4) most subjects who positioned their viewpoints vertically to the floor of the path, did so before they entered the threshold; this probably implies that they were more aware of their global orientation, while they were inside the place and this made them feel less confused.

8.2.4.10 Observations in place (5)

Some subjects reported that it was more difficult to exit this place than to enter it. One subject attributed this phenomenon to the awkward angle at which the threshold - and the path - was positioned in relation to the place. Although the angles at which the place is rotated are not as big as in the other places, the fact that it is rotated along two axis - and not one as is the case with all four other places - makes the spatial relation of the path with the place quite unnatural and therefore awkward and difficult to comprehend.

The awkward angle and the accentuated perspective may also have lead few subjects to believe that the proportions of the place were not the same as in all other places and that the regular and rectangular shape of the place they had previously experienced was slightly distorted in the case of place (5).

Most subjects (10) who felt like positioning their viewpoint vertically to the path floor, did so when they were inside the threshold on the way out of the place.

8.3 EXPERIMENT (6)

8.3.1 Planning phase

In an attempt to investigate possible solutions for the problem of structuring domains by arranging places and paths in three-dimensional space within a VE, experiment (5) has investigated the issue of positioning a place in relation to a path, for the purpose of aiding orientation while navigating into the place and performing an activity there.

During the design of pilot VEs, it became evident that if a path was orientated in some particular ways in relation to the two places that it was connecting, then subjects became disorientated when moving along this path. This phenomenon indicated the need for investigating the impact of the way that a path is positioned, in relation to the two places it connects, on the way that subjects orientate while entering, moving along and exiting this path, by experimental methods.

Therefore, the aim of experiment (6) was to investigate the ways that paths would have to be positioned between two places in three-dimensional space, in order to aid orientation whilst:

- entering from one place into the path
- navigating the path through to the other place

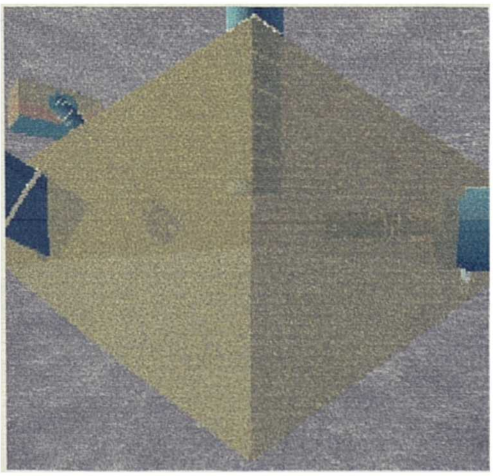
- exiting the path into another place.

A second objective is to investigate how subjects position their viewpoint in relation to the path while navigating through it towards the place at its end, dependant upon how the path is positioned in relation to the two places. As there were no precedents for the possible spatial behaviour of subjects in such a VE, no particular hypotheses were formulated for the two objectives.

8.3.2 Design phase

As in the case of experiment (5), in order to identify how should paths be positioned between two places in order to ease orientation while navigating this path, a VE was designed for testing the impact of positioning a path in different ways between two places. This VE consisted of:

- A central hall which functioned as a starting place
- 5 identical places which functioned as 'target places' for each path
- 5 paths which connected the central hall with each of the 5 target places and which were positioned in different ways in relation to each other.



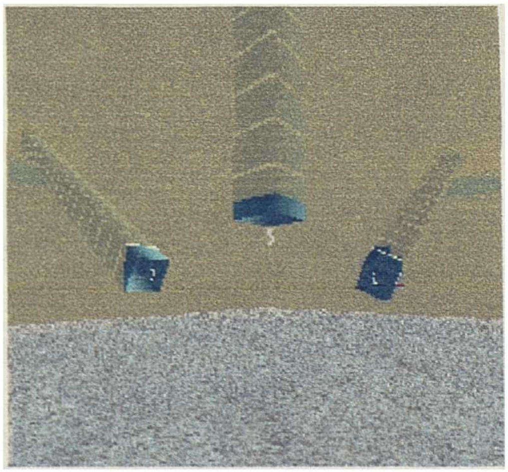


Figure 8.7: External view looking from the corner of the central hall towards its centre - on the left - and interior view looking from another corner of the central hall towards path (5) - on the right. In both images the horizon is seen in the background.

The number of paths which were used in this experiment was limited to 5, since it would be beyond the scope of this project to investigate every possible way of positioning a path between two places. The only activity that subjects were asked to perform was:

- to enter each path,
- move through the path towards the target place at the end of it,
- come out of the path into the place,
- then re-enter the path and navigate back to the central hall, from where they would enter the next path.

The first dependent variable studied in this experiment was a measurement of how easily subjects orientated whilst entering the path, navigating the path towards the target place, entering the path from the target place and finally navigating back to the central hall. The value for this variable was given as an answer to the following question, which was asked when each subject returned to the central hall:

"How easy was it for you to orientate when:

- *entering the path*
- *moving along the path towards the place, then*
- *entering the path again and*
- *moving through the path back to the central hall ?*

Answer with marks out of 100 where:

0. it was very difficult

100. it was very easy"

This dependent variable was expected to help to identify which of the ways of positioning paths between two places were preferable, because they were easier for orientation and which were problematic and should be avoided, when designing domains of paths and places in VEs. Studying the experience of exiting the path into the target place or into the central hall on the way back was not directly relevant to the objectives of this experiment, as it had more to do with orientation within a place rather than in a path.

The second dependent variable measured was the time spent while performing the task. When inside a path, subjects very rarely had a chance to wander around doing something which was not related to the task. In fact, subjects generally tried to navigate and exit the paths as soon as possible, without being prompted to do so, and therefore the variable of time has been taken into account in this experiment. Possible reasons for subjects wanting to navigate and come out of the path quickly may be that:

- A path, as shown in experiment (2), induces movement along its main axis;
- The volumetric proportions of these particular paths made them seem quite narrow and this fact made subjects want to move quickly out of there.

A third dependent variable investigated was the way that subjects positioned their viewpoints in relation to the path. The author observed the way that subjects navigated in each path, and attempted to detect how they wanted to position their viewpoints, in order to orientate while navigating in each path.

Originally it was intended to record one response for each subject which would reflect the overall way that he positioned his viewpoint while doing the task. During the pilot experiment it became evident that subjects often positioned their viewpoints in different ways on the way out and on the way back. Therefore it was decided that both responses for the way out and the way back would be recorded separately so that any possible differences between the two kinds of responses could be revealed. This dependent variable was intended to indicate how subjects prefer to position their viewpoints while moving through a path of this particular form and additionally to give insights into how subjects feel about moving through paths positioned in these ways. The results of this part of the experiment can also inform the way that paths and places are composed into domains, which accommodate navigation through their interior space.

Four different possible options for positioning a viewpoint within a path, while navigating it, were identified after the pilot experimental study, which involved three subjects. These four options corresponded to the four possible values that the second dependent variable took. In order to describe these options, we firstly have to consider two coordinate systems:

- With reference to the (x,y) plane of the viewpoint, x is the horizontal axis and y is the vertical axis; the y axis of the viewpoint can be seen as corresponding to the posture of the subject who views the display and consequently the viewpoint.
- With reference to the (x,y,z) coordinate system of each path, z is the main axis of the path's direction and its section is the plane defined by the horizontal x and vertical y axis.

Accordingly, the four possible options for positioning a viewpoint are:

1) The y axis of the viewpoint is perpendicular to one of the surfaces of the path;
2) The y axis of the viewpoint is diagonally positioned in relation to the rectangular section of the path;
3) The viewpoint is rolled around or moved randomly;
4) The y axis of the viewpoint is aligned with the z axis of the path; this way of positioning a viewpoint resembles the vertical movement in a lift.

The independent variables which may have influenced the behaviour of subjects in this VE are:

1) The way that the spatial elements comprising the experimental domain are spatially arranged in relation to each other. Firstly, the way that each path is positioned between two places is described by the axis and the angle of rotation of the path in relation to the two places. This qualitative factor was set at specific levels of interest and its impact on the dependent variables was studied. All target places were positioned in a similar way and in accordance with the way that paths had to be positioned for the needs of the experiment; the 'floor'

and 'ceiling' of each place were parallel to the 'floor' and 'ceiling' of the central hall. However:

- two of these places were positioned higher than the floor level of the central hall, because in these cases the paths which connected them were pitched upwards and
- in only one case the place was positioned perpendicularly to the floor of the central hall, because a parallel position was found to be very problematic during the pilot study.

2) The physical characteristics of places in the experimental domain. The starting place for all paths was the central hall and all five target places were identical in all their physical characteristics.

3) The physical characteristics of each path - form, volume, material of boundaries; As this factor would affect the spatial behaviour and responses of subjects, it was rigidly controlled so that all five paths in the VE were identical. The surfaces of the paths were assigned a semi-transparent material in order to afford a view of the context at all times. The shape of the path was parallelepiped with a square section. The length of these paths was bigger than the length of the paths in experiment (1). A series of frames were positioned at equal intervals outside the path, as in the case of path (3) in experiment (1). This formal element was expected to enhance the sense of movement while navigating along the path, according to the results of experiment (1). The material which was assigned on these frames was white. The contrast of this material against the transparent dark cyan material which was assigned on the path's boundaries was essential for making the frames visible, for the subject who navigated inside the path.

4) The order with which the subjects experienced one path after the other was randomised.

Along with the surfaces of the paths, most other surfaces of the experimental domain were assigned a semi-transparent material. The only opaque surfaces were the 'floors' and 'ceilings' of the target places and the textured floor of the central hall. The fact that most enclosures in this VE were transparent aimed at enhancing orientation by keeping subjects aware of their spatial relation to the surroundings of the experimental domain, at all times. Furthermore, the same textured environmental sphere and horizon, which were used in experiments (4) and (5) and have been described in (7.2.2), were designed to function as a background to the experimental domain in order to provide cues for orientation to a global reference frame and for informing subjects of their direction of movement. Subjects were constrained from entering these surroundings and moving outside the limits of this sphere. This spherical enclosure was concentric with the central hall and its diameter was big enough to afford subjects the spatial experience of comparing the local environment of the experimental domain to the global environment of the sphere. The red horizon, which was also used in experiments (4) and (5), aimed at informing subjects of their relation to a global horizontal orientation, at all times.

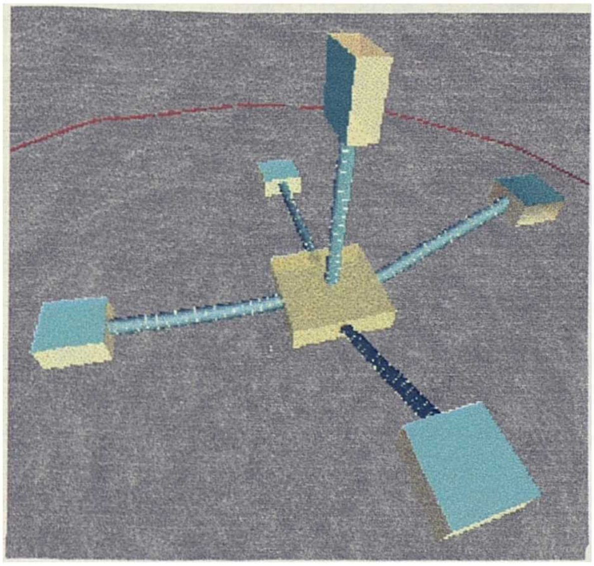


Figure 8.8: External view of the experimental domain from the top; the textured, spherical environmental enclosure of the universe with the horizon are both seen in the background.

As explained at the beginning of this subsection, the 5 ways of positioning the path in relation to the places, which have been examined in this experiment, did not exhaust all possible options for positioning a path between two places. The way that these paths have been positioned can be described with reference to one of them, which can be seen as the 'control path' and to which no rotation had been applied. If an (x,y,z) coordinate system is considered for this path, z is the axis of the path's direction, x is the horizontal and y the vertical axis of the path's section. The floor of the control path, which was defined by the x and z and axis, was parallel to the floor of the central hall. By taking this path as a reference, rotations were applied along the z or x axis of the path. Accordingly, the 5 positions of the paths were:

1) Path (1) was rotated along the x axis - or pitched upwards - at a 30^0 angle
2) Path (2) is the control path to which no rotation has been applied
3) Path (3) is rotated along the x axis - or pitched upwards - at a 30^0 angle and also rotated along the z axis - rolled - at a 60^0 angle
4) Path (4) is rotated along the z axis - rolled - at a 60^0 angle and
5) Path (5) is rotated along the x axis - or pitched upwards - at a 90^0 angle or can be seen as perpendicular to the ceiling of the central hall directly above the hall's centre.

The ascending order of paths did not correspond to any presupposed order of degree of rotation or possible difficulty of these paths. Numbers were randomly assigned to each path in order to avoid any unpredictable effects on the response of subjects.

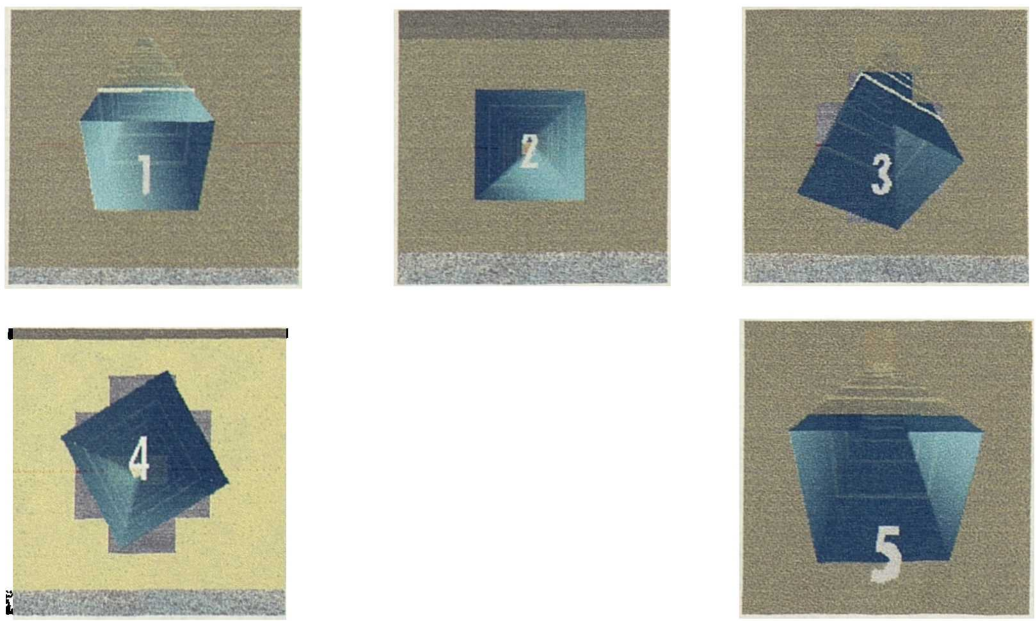


Figure 8.9: Views of the entrances to the 5 paths from within the central hall; top left is path (1), top in the middle is path (2), top right is path (3), bottom left is path (4) and bottom right is path (5).

Finally, 32 subjects - 12 female and 20 male - participated in this experiment.

8.3.3 Analysis phase - Statistical analysis of results

In order to identify how paths should be positioned between two places so that orientating whilst navigating the path becomes easier, this experiment investigated the impact of different ways of positioning a path between two places, on the criteria:

- how easily do subjects orientate while performing the task and
- the way that subjects position their viewpoints in relation to the path, whilst navigating this path.

Since all subjects experienced all paths, a repeated measures general linear model ANOVA procedure was used for the analysis of the results for the variables of 'easiness of orientation' and 'time'; both these variables relate to how easily subjects orientated while traversing the paths. The within-subjects factor was named 'path' and had 5 levels, each of them corresponding to each of the paths of the experimental domain. The measures which were recorded at each level corresponded to the two dependent variables of 'easiness of orientation' and 'time'.

For the variable of the 'way of positioning the subject's viewpoint', the tables and bar charts of frequencies for the 4 different values of the response are investigated in order to study the spatial behaviour of subjects in each path. Any patterns among spatial behaviour in different paths are established on the basis of these tables and charts.

8.3.3.1 The variable of easiness of orientation

The null hypotheses to be rejected by the analysis of results for this variable is that: "In all five cases of paths, subjects found it equally easy to orientate while entering and moving through the paths". The test of sphericity for the measure of 'easiness' of orientation showed that there was a need for adjusting the degrees of freedom for performing the within-subjects effects test; this test is presented in appendix (A.6.1). The results of the corrected tests showed that:

- The F statistic for the within-subjects effects was significant ($F=14.982$, $df=3.089$, $p<0.05$).
- The within-subjects tests showed significance for the contrasts between:
- path (1) - path (2) ($F=15.825$, $df=1$, $p<0.05$)
- path (2) - path (3) ($F=36.708$, $df=1$, $p<0.05$)
- path (3) - path (4) ($F=8.028$, $df=1$, $p<0.05$)
- path (1) - path (3) ($F=16.633$, $df=1$, $p<0.05$)
- path (2) - path (5) ($F=25.279$, $df=1$, $p<0.05$) and
- also the contrast between path (3) - path (5) was very close to being significant as well ($F=3.823$, $df=1$, $p<0.1$);
- On the basis of the following error bar graph, it can also be suggested that the contrast between path (2) - path (4) is also significant;
- The contrast between path (1) - path (5) ($F=2.697$, $df=1$, $p<0.1$) was not significant enough to be considered as evidence but was neither too small to be ignored;
- The contrasts between all other paths were not significant.

An explanation of the above mentioned procedure along with tables of the tests of sphericity, within-subjects effects and within-subjects contrasts can be found in appendix (A.6.1). The above mentioned results for the variable of 'easiness' of orientation are also supported by the following error bar graph.

The results of the analysis provide sufficient evidence for the rejection of the null hypothesis for the variable of 'easiness' of orientation. In specific, it can be concluded that:

- The control path (2), which was not rotated at all, was clearly the easiest to orientate into. This conclusion implies that all other four paths to which a rotation had been applied, were clearly more difficult to orientate into than path (2).
- Path (3), which was rotated along both x and z axes, was clearly the most difficult to orientate into. Only the path (3) - path (5) contrast was not significant enough to justify a comparison between easiness of orientation in these two paths; this fact implies that it is difficult to differentiate between easiness of orientation in these two paths.
- Path (5) was clearly more difficult than path (2) but was slightly more difficult than path (1). It was also slightly easier than path (3).
- All other contrasts among the other three paths were not significant enough to be considered.

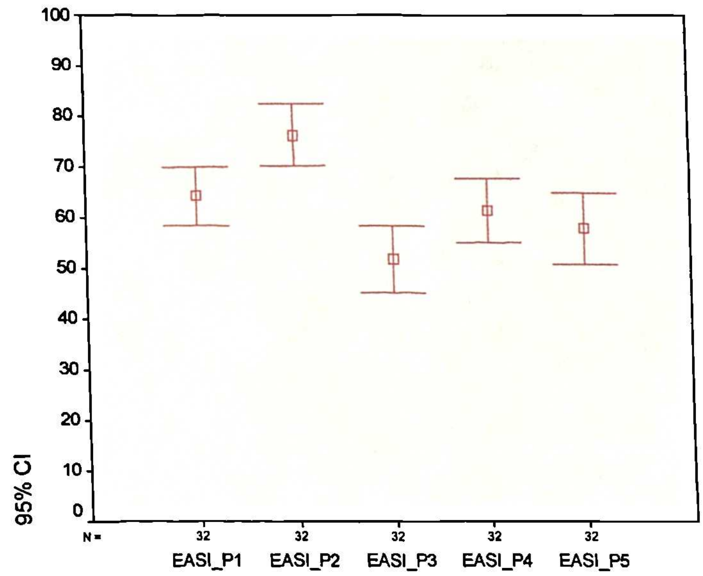


Chart 8.6: Error bar graph for the variable of 'easiness' of *orientation*.

8.3.3.2 The variable of time

For the variable of time, the analysis of the results aims at rejecting the null hypothesis that: "In all five cases of paths, subjects spent an equal amount of time while performing the task of navigating through each of these paths". The test of sphericity for the measure of 'time' showed that there was no need for adjusting the degrees of freedom for performing the within-subjects effects test; this test is presented in appendix (A.6.2). Assuming sphericity, the results of tests showed that:

- The F statistic for the within-subjects effects test was significant ($F=4.956$, $df=4$, $p<0.05$)
- The within-subjects tests showed significance for the contrasts between:
  - path (1) - path (2) ($F=5.404$, $df=1$, $p<0.05$)
  - path (2) - path (3) ($F=12.288$, $df=1$, $p<0.05$)
  - path (3) - path (4) ($F=7.659$, $df=1$, $p<0.05$)
  - path (4) - path (5) ($F=9.429$, $df=1$, $p<0.05$) and
  - path (2) - path (5) ($F=12.853$, $df=1$, $p<0.05$)
- All other contrasts were not significant enough to be considered.

An explanation of the above mentioned procedure along with tables of the tests of sphericity, within-subjects effects and within-subjects contrasts can be found in appendix (A.6.2). The above mentioned results for the variable of 'time' are also supported by the following error bar graph.

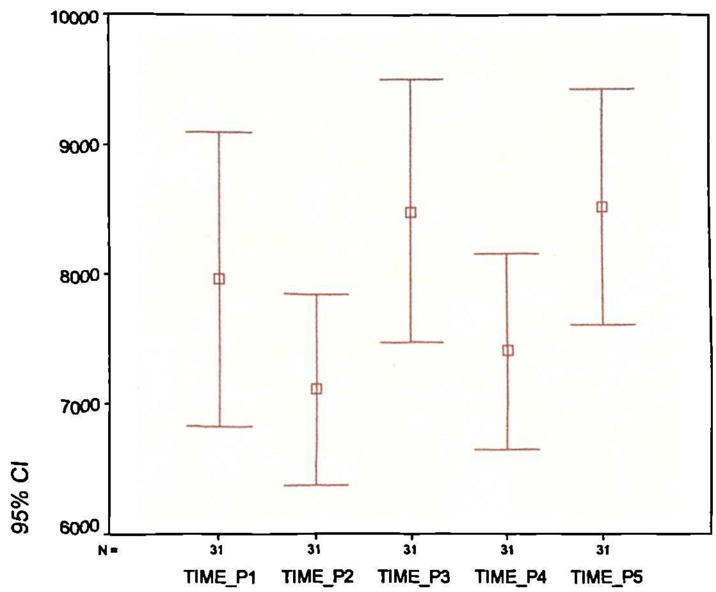


Chart 8.7: Error bar graph for the variable of 'time'.

The results of the analysis provide evidence for the rejection of the null hypothesis for the variable of 'time'. In specific, it can be concluded that:

- The time that subjects spent in path (2) was less than the time they spent in paths (1), (3) and (5).
- The time that subjects spent in path (3) was more than the time they spent in paths (2) and (4).
- The time that subjects spent in path (4) was less than the time they spent in paths (3) and (5).
- The time that subjects spent in path (5) was more than the time they spent in paths (2) and (4).
- There were no significant differences among times spent in paths (1), (3) and (5) or between times spent in paths (2) and (4).

8.3.3.3 Considering both variables for defining easiness of orientation in paths

Considering the fact that subjects generally tried to navigate through the paths in the quickest way possible, the response for the variable of easiness can be seen as somehow subjective but the response for the variable of time may be considered as more objective, in showing how quickly and easily did subjects manage to navigate each path. Accordingly, it is essential to consider both results for variables of 'easiness' and 'time' and to examine whether these results are in agreement in order to determine the easiness with which subjects orientated in each path.

By comparing the results for the 'easiness' and 'time' variables, it can be concluded that:

- The control path (2), to which no rotation was applied, was the easiest to orientate in and subjects spent the least time in it as well; the only exception, in terms of contrasts for time, was that the time spent in path (4) was equally small.
- The path (3), to which rotations along both axes had been applied, was the most difficult to orientate in. However, path (5) was almost equally difficult in terms of

time spent in it and contrast between path (3) - path (1) did not show significance; the time spent in this path was higher than in paths (2) and (4), although times spent paths (1) and (5) were equally high.

- Although subjects found path (4) more difficult for orientation than path (2), they spent an equally small time in there. Also, subjects found path (4) easier than path (3) whilst the time spent in path (4) was less than the time spent in paths (3) and (5) as well. It was not possible to differentiate between paths (1) and (4) in terms of easiness or time.

As a conclusion, we may suggest that:

- Applying both a pitch and roll rotation to a path makes it very difficult for a subject to orientate in there and should generally be avoided.
- If the paths to which no rotation along the x axis - pitch rotation - has been applied are compared, in terms of easiness of orientation, with the paths to which such rotation has been applied - (2) compared with (1) and (4) compared with (3) - then it can be concluded that the application of such a rotation results in making orientation in a path significantly more difficult; the results for both variables are in agreement with this conclusion. In other words it can be argued that pitched paths are generally more difficult to orientate into than horizontally positioned paths.
- If the paths to which no rotation along the z axis - roll rotation - has been applied are compared, in terms of easiness of orientation, with the paths to which such rotation has been applied - (2) compared with (4) and (1) compared with (3) :
    - the results for the variable of easiness, clearly indicate that the application of such a rotation results in making orientation in a path significantly more difficult, whilst
    - the results for the variable of time, do not support this suggestion.

It may then be suggested that subjects thought that such a rotation made their orientation more difficult but their performance, in terms of time, did not support such a claim.

8.3.3.4 The variable of viewpoint orientation within each path

The aim of this part of the experiment was to investigate the way that subjects position their viewpoint while moving within a path, dependant upon the way that this path is positioned between the two places that it connects. Since responses for this dependent variable were recorded in nominal measures, only frequency tables and bar graphs were studied for the purpose of establishing a certain pattern for responses in each of the five paths. As there were no precedents which would suggest a possible outcome for this part of the experiment, no specific hypothesis about the spatial behaviour of subjects in each path had been defined. The aim of analysing the results is to find out whether "subjects feel the need to position their viewpoints in a particular way, in order to orientate and feel comfortable to navigate in each path". In this analysis, the thesis refers to the route segments:

- from the central hall to the target place as 'on the way out' and
- from the target place to the central hall as 'on the way back'.

As was explained in (8.3.2), the way that subjects position their viewpoint will be studied individually for the 'on the way out' and the 'on the way back' route segments that subjects have covered. The tables of frequencies for this variable are presented in appendix (A.6.3). The responses of subjects will be studied individually for each path.

1) In path (1):

- On the way out, many subjects (75%) tried to position their viewpoint vertically to a boundary of the path while few of them moved randomly (15.6%) or diagonally to the section of the path (6.3%);
- On the way back, even more subjects moved their viewpoint vertically to a boundary (87.5%) and only 3 subjects did otherwise.

It may be argued that on the way out, subjects did not have many cues to inform them of their relation to a global horizontal/vertical orientation, so more of them may have preferred to move randomly or diagonally to the section of the path. On the way back though, several cues - view of the central hall, the other paths and places and the number of the path - informed subjects of their orientation and therefore more of them felt the need to conform with a vertical position of their viewpoint, in relation to the shape of the path they traversed.

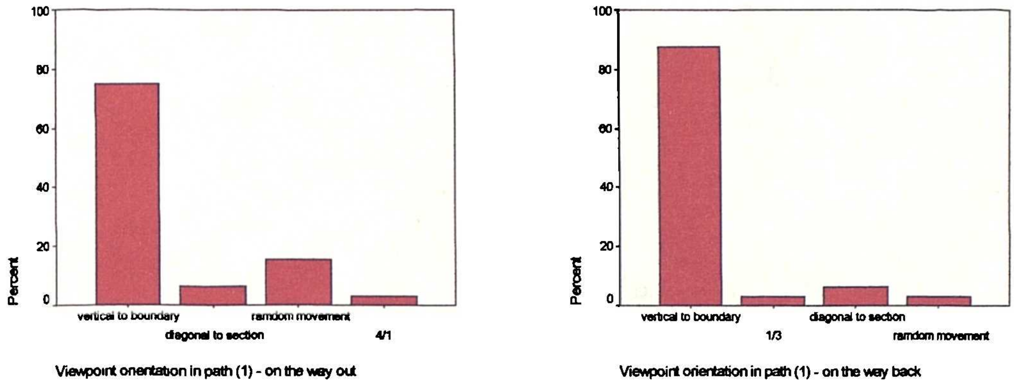


Chart 8.9: Bar graphs for the frequencies of viewpoint orientation in path (1), on the way out and on the way back to the central hall.

2) In path (2):

- On the way out, all subjects (96.9%) apart from 1 positioned their viewpoints vertically to one of the boundaries of the path;
- On the way back, again most subjects (84.4%) moved vertically to a boundary, while 4 subjects preferred to move diagonally or randomly along the path.

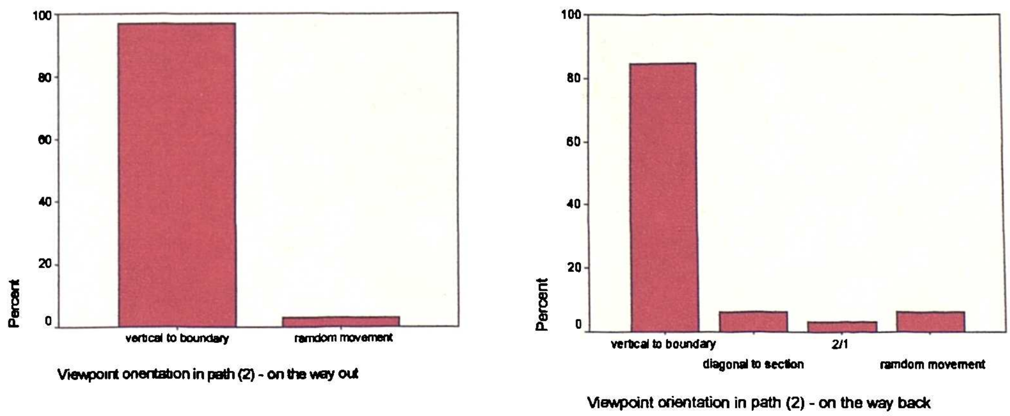


Chart 8.10: Bar graphs for the viewpoint orientation in path (2), on the way out and on the way back to the central hall.

3) In path (3)

- On the way out, over half of the subjects (53.1%) were clearly vertical to a boundary and another 15.6% shifted between a vertical and a diagonal position; several subjects (21.9%) though were clearly diagonal to the path's section and 3 others moved randomly or rolled around.
- On the way back, the same number of subjects (53.1%) moved vertically to a boundary or shifted between a vertical and a diagonal position (15.6%); this time though, more subjects (25%) moved clearly diagonally and only 2 subjects did otherwise.

Since this path is rotated along the z axis of its direction at a -60^0 angle, subjects may have felt inclined to keep their viewpoint at a perpendicular position in relation to the global horizon. However, since this path proved to be the most difficult of all to navigate and orientate into, subjects often rolled their viewpoint around or lost their bearings and moved randomly. The phenomenon of more subjects moving diagonally on the way back can be attributed to the fact that they saw cues that made them feel inclined to position their viewpoint vertically to the floor of the central hall and parallel to the number at the beginning of the path.

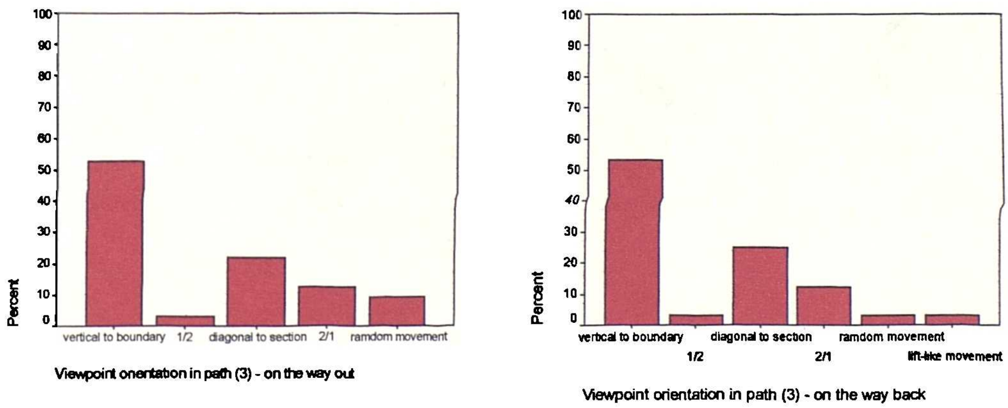
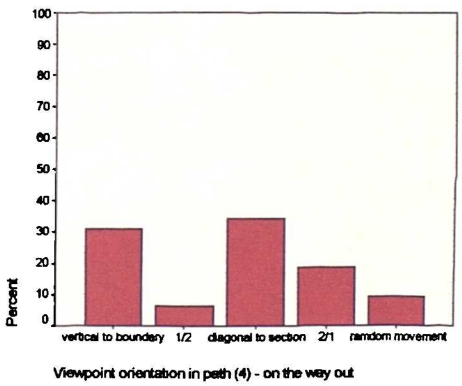


Chart 8.11: Bar graphs for the viewpoint orientation in path (3), on the way out and on the way back to the central hall.

4) In path (4):

- On the way out, subjects' responses were divided between diagonal and vertical viewpoint position: just over a third of the subjects (34.4%) positioned their viewpoint diagonally to the section of the path and almost the same number of subjects (31.3%) moved vertically to the path, while a 25.1% of subjects shifted between these two positions; only 3 subjects moved randomly.
- On the way back, most subjects (56.3%) moved diagonally to the section of the path, the same number of subjects as before moved vertically to a boundary (31.3%) and only 2 shifted between the two positions; only 2 others moved randomly as well.

It is interesting to mention that 7 of the subjects who shifted between the two positions on the way out felt like moving diagonally on the way back. This phenomenon may be attributed to the influence of the diagonally positioned number at the beginning of the path or to the prominence of horizontal elements - such as the floor of the central hall - which were only visible on the way back.



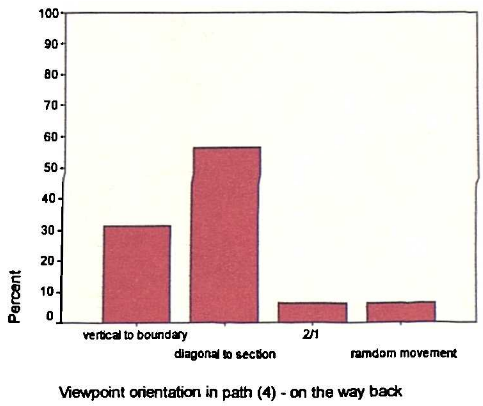
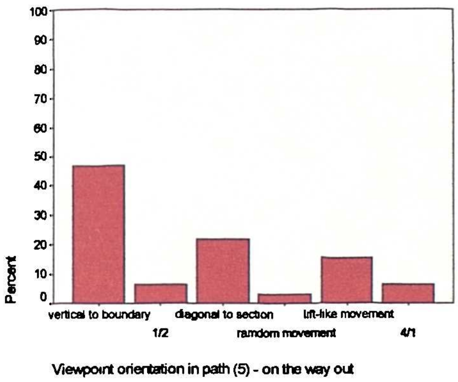


Chart 8.12: Bar graphs for the viewpoint orientation in path (4), on the way out and on the way back to the central hall.

5) In path (5):

- On the way out, almost half of the subjects (46.9%) moved vertically to a boundary of the path and significantly fewer subjects (21.9%) moved diagonally. An interesting event was that 7 subjects (21.9%) wanted to move up the path as if they were in a lift, and either did so or found that difficult to accomplish and changed the orientation of their viewpoint along the way; only 3 subjects did otherwise.
- On the way back, clearly most subjects (62.5%) moved vertically to a boundary of the path, 5 subjects (15.6%) moved diagonally to the section of the path and 3 others shifted between these two positions. Only 1 subject tried to move down this path as in a lift while 3 others moved randomly.



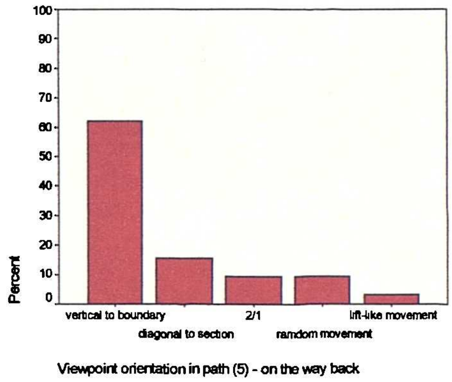


Chart 8.13: Bar graphs for the viewpoint orientation in path (5), on the way out and on the way back to the central hall.

The following possible explanations for these results could be suggested:

- On the way out subjects had very few cues to guide them for orientation and since they clearly knew that this path was going upwards, some of them felt like experimenting with a lift-like movement while most of the others implemented the strategy that they had used in the other paths, which were not rolled.
- On the way back though, there were many cues to guide for orientation - the number framed by the entrance of the path, the boundaries of the central hall and other paths and places; all of these formal elements were at 90^0 angles

with the boundaries of the path. Therefore, the majority of subjects positioned their viewpoint vertically to a boundary and only 8 of them did not do so. Only 1 subject tried to go down as in a lift, since the others had already experienced the difficulty of doing so.

Taking into account that the above mentioned results are specific for paths of a parallelepiped shape with a square section, it can be argued that

- In paths (1) and (2) which were not rotated along their z axis, most subjects preferred to position their viewpoints vertically to one of the boundaries of the path;
- In paths (3) and (4), which were rotated along their z axis, the number of subjects who positioned their viewpoint diagonally to the section of the path was equal or even bigger than those who tried to position their viewpoints vertically to one of the boundaries of the path.
- In path (5), which was vertically positioned to the central hall but was not rotated along its z axis,
  - on the way out responses were mixed but
  - on the way back most subjects clearly positioned their viewpoint vertically to a boundary of the path.

8.3.4 Observations during the experiment

This section includes a summary of the observations made by subjects and by the author during the experiment. Further details about these observations are presented in appendix (A.6.4).

8.3.4.1 General observations

Subjects with low navigational skills, occasionally rolled around and did not seem to be able to keep their viewpoint at the stable position that they desired; when this was the case, the most likely position of the viewpoint has been used as a response for the 3rd variable. Some of these subjects did not mind having their viewpoint positioned upside-down while they entered a path; they probably did so because they concentrated on performing the task and on navigating through the paths rather than positioning their viewpoint in a particular way in relation to the path. The narrow path did not help these subjects and quite often they seemed to get stuck on the boundaries of the path. Subjects with low navigation skills may have been influenced more than subjects who navigated well, in the way that they positioned their viewpoint in the path, by their orientation which they unintentionally had achieved when they entered this path. On the other hand, subjects who navigated very well found it very easy to complete the task and may therefore have found it difficult to differentiate between the paths in terms of easiness of orientation.

The numbers positioned at the entrance of each path were strongly indicating verticality and have aided orientation, according to 3 subjects. Several others also indicated that the numbers were very influential in helping them to keep the y axis of their viewpoint parallel to a global vertical orientation, while they navigated each path. These cases will be later described in detail for each path. Another subject also suggested that the number gave him a sense of where up and down was, as he entered the paths and as he moved towards the central floor on the way back. When navigating the path towards the target place though, the number is not visible so he had no sense of where up and down was.

It is also important to stress that the shape of the path's section is symmetrical and as such it does not inform subjects of their relation to a global up or down direction or any other orientation whatsoever; if the shape were rectangle with one dimension significantly larger than the other then it would have provided a cue for aiding the subjects' awareness of their global orientation.

Few subjects (4) reported that the semi-transparent materials assigned to the majority of boundaries in this VE helped them orientate a lot because *"they give you an awareness of the overall picture; the enhanced perspective effect given by the frames along the path helped also"*. On the other hand, the use of semi-transparent materials on the boundaries of paths has some negative effects according to few other subjects (5). These subjects felt confused, because the semi-transparency of surfaces was not making it clear where the limits of the enclosure and the extends of the space available for manoeuvring were, so they did not know when they were going to collide with those boundaries and get stuck while they were moving along the paths; one subject thought that the textured transparent paths in experiment (1) were more helpful in this sense. Another subject characteristically said: "*I can not tell what is the size of me*", meaning that she could not know when she would bounce off the surfaces of the paths but also revealing another reason for not being able to tell the distance from the surface of a path: the lack of an avatar of herself.

Paths were seen as narrow and tight by many subjects; indeed their volumetric proportions were such that many subjects seemed to get easily stuck on the path's boundaries and thus felt that their ability to manoeuvre and navigate was being limited by these proportions: "*Paths feel very restrictive and give you a sense of claustrophobia that makes you want to move through the path and out of it quickly*". This phenomenon was more evident in the case of subjects with low navigational skills; these subjects got stuck on boundaries and lost their orientation very often. However, it is not clear if increasing the size of both width and height would solve this problem; indeed, from the experience of designing the pilot VEs, it may be suggested that the sense of scale within an enclosed space in VEs may not depend on the absolute value of its dimensions but may be a result of the proportions of these dimensions.

The use of such paths was questioned, in general. One subject reported that she *"felt constrained to have such a corridor for movement towards a space. If flying was free it would be less constraining to position yourself and travel in space to go somewhere"*.

8.3.4.2 Strategies for navigating along paths

When subjects were faced with the problem of how to plan for the task of navigating along each path, they seemed to employ different strategies. Quite often they seemed to experiment with such strategies in the first paths that they experienced and once they found a particular strategy to be successful, they implemented it on their routes along the rest of the paths, as well. At the end of the experiment, subjects were encouraged to talk about whether they had employed any particular strategy for navigating and the most important of the strategies that they mentioned are presented here. These strategies were not mutually exclusive; in fact more than one of them may have been used by the same subject:

1) With respect to a strategy for orientation when inside a path,

- some subjects aligned their viewpoint just after entering the path, orientated themselves and then navigated along the path;
- others simply moved along the path and corrected the position of their viewpoint as they moved along, when needed without pausing for doing so.

2) With respect to the way that the viewpoint was positioned within a path:

- Several subjects reported that they preferred to position their viewpoint vertically to boundary of the path. This preference is clearly in support of the results for the third variable - presented in (8.3.3.4). A possible explanation for this preference was that by following this method, the viewpoint was aligned with the rectangular frame of the path and this visual regularity was making navigation seem easier.
- Other subjects who followed this method in the case of paths (1), (2) and (5), found it difficult to do the same with paths (3) and (4), which were rolled - or skewed as they described them - and felt they had to employ a different strategy. However, their observations on such strategies vary significantly.

3) Some subjects seemed to change their strategy, from one path to the next or even in the same path, as they went through the experiment. For instance, on the absence or definite orientation cues on the way out in paths (3) and (4), subjects try to position their viewpoints vertically but on the way back, when the number and the central hall was visible to them, they seemed to position their viewpoints diagonally to the section of the path and aligned with the direction of the number. Other subjects have reported several changes of strategy which are not consistent with each other.

4) Few subjects reported that they positioned their viewpoints while navigating along the paths, by trying to align the rectangular frame of their display screen to elements of the VE - such as the target place or the frames around the paths.

5) Finally some subjects tried to keep the y axis of their viewpoint vertical to a global horizontal orientation, most of the time in this VE. This horizontal orientation may have been indicated by

   - The floor of the central hall, which could be seen as a home or starting point and was a significant space for the whole spatial experience of subjects in this VE; accordingly the orientation of the central hall may have influenced the way that subjects orientated in other spaces of this VE.
   - The red horizon of the environmental enclosure. Some subjects seemed to be influenced by this horizon in the way they orientated in this VE. However, 3 subjects reported certain confusion by the fact that this element looks like a real horizon but does not function exactly like one. Although it is clear that the horizon at times informed subjects of their relation to a global horizontal direction, its negative impact makes its implementation questionable.

An interesting observation, made by several subjects, revealed that they generally found the route 'on the way back' easier than the route 'on the way out', irrespective of the rotation applied to the path. This phenomenon may be explained by the fact that

- On the way out, there are no cues, apart from the boundaries of the path and the target place at the end of the path, to inform subjects of their relation to a global orientation;
- On the way back, subjects can see several cues - the number at the entrance of the path, the central hall and its boundaries, the other paths and places - which inform them of their relation to a global orientation.

Subjects often became physically involved while trying to accomplish the task. In path (5) this involvement was clearly manifested by the movement of their bodies, in their effort to manoeuvre their viewpoint in order to enter the path. Many moved as if they were actually immersed in the VE and their bodily movement would help them position their viewpoint so as to enter the path.

8.3.4.3 Observations about path (1)

The majority of subjects felt they wanted to position their viewpoint vertical to one of the boundaries of this path.

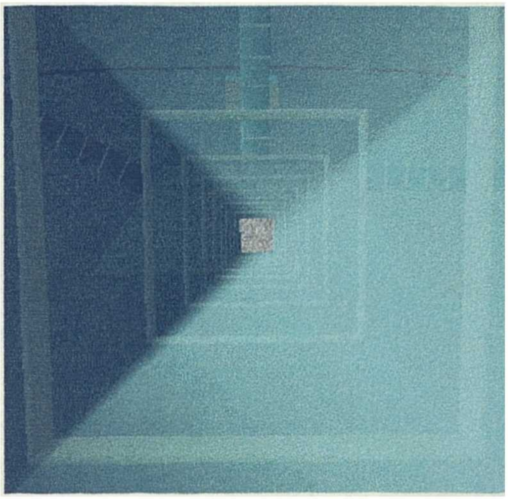
- On the way out though, some subjects moved randomly or diagonally, probably due to the lack of cues for orientation but
- on the way back, most of them seemed to move vertically to a boundary, since there were many cues to help them keep their viewpoint steady as they moved along the path.

Indeed, some subjects reported that on the way down there were many elements - the central hall and its boundaries, other places and paths, the number - that helped them orientate while on the way up only the target place aided orientation.

Several subjects also reported that they found navigating along this path difficult because it was pitched. This fact made it difficult for them:

- to enter the path from the hall;
- to orientate while inside the path;

- to enter the path from the target place;
- to exit the path into the target place on the way up was also confusing because as subjects entered the target place they were too close to its ceiling and they could see little else from the surface of this ceiling, whilst there was not enough space for them to manoeuvre their viewpoint.



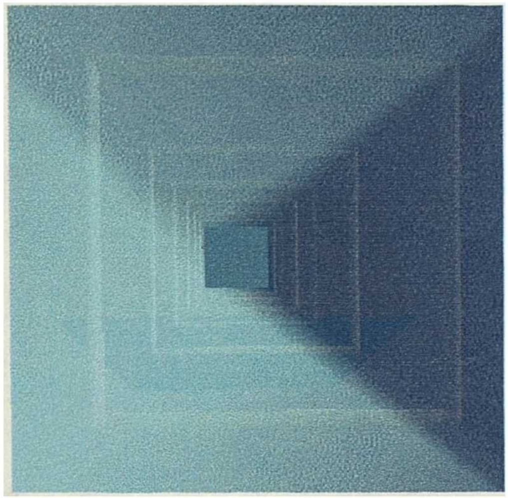


Figure 8.10: Views inside path (1); from the centre of the path looking towards the entrance from the central hall -on the left - and looking towards the exit to the target place - on the right.

8.3.4.4 Observations about path (2)

Almost all subjects in path (2) felt they wanted to move whilst their viewpoint was positioned vertically to one of the boundaries of the path. One subject attributed her will to do so to the fact that this path was aligned to the target place and the central hall. Most subjects moved through this path quite easily and since they did not have many difficulties few of them reported something. Those who did were very positive about their experience in this path; they found navigating along the path easy and pleasant. One subject described this path as an ordinary space and thought that the alignment of the path with the horizon eased navigation. These observations were in agreement with the analysis of the results presented in (8.3.3) for all three variables.

It is interesting to mention, however, that at least 3 subjects reported that they saw path (2) as being pitched upwards although this was not the case. This may be attributed to the fact that they had seen the other pitched paths before and they expected this one to be pitched as well. This phenomenon shows how relative the sense of up and down is in a VE, due to the lack of complexity and of cues for orientation.

8.3.4.5 Observations about path (3)

Subjects tried to position their viewpoints in varied ways, when they navigated in this path. Many of them tried to position their viewpoint vertically to a boundary of the path; however, the number of subjects who did so was considerably smaller than in other paths.

Almost one third (10) of the subjects moved towards the target place on the way out, with their viewpoint either diagonal to the section or randomly positioned; on the way down though they positioned their viewpoint vertically to a boundary. On the other hand though, some subjects (5) navigated the path on the way out with their viewpoint vertical to a boundary of the path but returned to the central hall diagonally positioned to the section of the path.

Few subjects (2) positioned their viewpoint diagonally to the section of the path, both while on the way up and on the way down. Some subjects may have wanted to move diagonally but they found it was difficult to do so:

- due to the awkward angle at which the path was rotated or
- due to their low navigational skills.

They either moved their viewpoint randomly or moved vertically to a boundary, since both these responses seemed easier to do, at least on the way out.

Since the path was difficult to orientate in, as an enclosure, many subjects relied on other cues for orientation. One of the most prominent cues was the number at the entrance of the path, which can be seen as indicating a global vertical orientation. Some subjects entered the path, on the way out, with their viewpoint diagonal to the section, because this number was also positioned this way; they probably did so because they wanted to keep the y axis of their viewpoint parallel to the axis of the number. Similarly on the way back, several subjects wanted to position their viewpoint diagonally to the section probably for the same reason; in this case however, other cues - the central hall and other paths and places - may have also been responsible for this behaviour.

According to the cues that were available, some subjects (4) confirmed that it was more difficult to orientate when navigating this path on the way out than on the way back. According to their explanations, this phenomenon may be attributed to the fact that

- On the way out there were no cues for orientation, apart from the exit of the path, which framed the ceiling of the target place.
- On the way down however, subjects focused on the entrance of the path, which appropriately framed the number and the texture of the central hall and possibly saw the other paths and places. Due to these cues, subjects shifted to a diagonal position to align themselves with the orientation indicated by these elements.

However, not all subjects conformed to this kind of spatial behaviour.

Finally, many subjects reported that they found this path most difficult to orientate into, in agreement with the analysis of the experimental results. They reported that the reason for considering this path problematic was the fact that it is rotated along two axes - pitched and rolled. This awkward angle of rotation made it difficult for subjects to manoeuvre their viewpoint in order to:

- enter the path from the central hall
- enter the path from the target place
- enter from the path into target place
- and to orientate while navigating inside the path.

8.3.4.6 Observations about path (4)

Responses about this path:

- on the way out were clearly divided between subjects positioning their viewpoint diagonally to the section or vertically to a boundary,
- but on the way back, most subjects had their viewpoint diagonal to the path's section.

Some subjects (8) reported that they preferred keeping their viewpoint at a diagonal position - which corresponded to maintaining a global vertical posture - while navigating the path because:

- it was easier and gave them more space to move or because
- they were aware of other elements of the VE which induced a need to keep parallel to a global vertical orientation - the horizon, the number in the entrance of the path, the central hall.

Some others tried to enter the path and navigate diagonally to the section, both on the way out and back, but did not report why they did so.

However, there were many subjects who seemed to be influenced by cues which induced a global vertical posture, but still felt like positioning their viewpoint vertical to a boundary, on the absence of such strong cues. Again, the number in the entrance of the path and the horizon were reported as strong cues which influenced the orientation of the subjects' viewpoint: *"when I saw the number this dictated diagonal positioning"*. Fewer subjects were not influenced by such cues at all and mainly positioned their viewpoint vertically to a boundary of the path.

Subjects had mixed feelings about the easiness of orientating in this path. Some of them thought that it was easy and pleasant to navigate this path whereas others thought that this experience was more difficult, unpleasant, disorientating, distracting and confusing.

In some occasions, the same subject reported both positive and negative feelings about the experience of navigating and orientating in this path.

It can however be argued that the roll rotation that was applied to this path seemed to bother subjects less than the pitch rotation that was applied to paths (1) and (3). It seems that the activities of entering the path from both places and exiting the path into these places become significantly more problematic when a path is pitched than when a path is rolled.

8.3.4.7 Observations about path (5)

An interesting phenomenon which occurred in this path was that 7 subjects - 2 male and 5 female - wanted to navigate towards the target place as if they were in a lift; in other words the y axis of their viewpoint was aligned with the z axis of the path. Subjects may have done so because they thought they had to keep the y axis of their viewpoint parallel to a global vertical orientation or because they simply wanted to challenge themselves with attempting a different way of navigating.

These subjects generally found this method of navigating through a path to be very problematic. It can be suggested that this was due to the fact that:

- They could not see where they were heading towards, as they were moving;
- They could not see the extends of the enclosure that was surrounding them; since they were directly facing the boundaries of the path and were not able to view any of the path's ends, subjects could not know what was their distance from the end of the route.

It was, however, suggested by a subject that if the path was much wider it might have been easier to navigate through it by using this method. Most of the subjects were confused by this method of navigating; only the ones who were very skilful at navigating managed to enjoy such an experience.

The way that the path was positioned in relation to the central hall showed that a subject can indeed be physically involved while navigating in a desktop VE. Almost all of the subjects were aware of the fact that they were moving vertically, which is an unnatural thing to do. Several subjects reported that they clearly felt physically or kinaesthetically influenced by the fact that they were moving along a vertically orientated path. Indeed, 5 subjects reported that they felt like *"going up"* or *"falling"*, when they navigated up or down this path. Some of them found this difficult and disorientating because the spatial relation of their viewpoint with the VE was significantly changed in this case. Only two of the subjects found this experience exciting or enjoyable.

It can also be argued that although there were very few cues to inform subjects of their unnatural vertical movement along the path, the fact that they had to manoeuvre their viewpoint in order to enter the path was quite effective in making them feel that they were really moving upwards. Indeed, most subjects seemed to be making a physical effort which was manifested in their bodily movements, when they tried to pitch their viewpoint at a 90^0 angle in order to position it in the entrance of this path. In agreement with this observation, almost half of the subjects (14) reported that they found it difficult or disorientating to adjust their position in order to enter the path from the central hall. Once they entered the path though, it seemed that it was much easier for them to orientate and move along.

Finally, some subjects (8) felt that the fact that the target place was vertically positioned in relation to the central hall - and all other target places - made the task of entering and orientating in this place quite difficult. This was due to the fact that they had to adjust to the peculiar orientation of the place when they entered in there. One of the subjects saw the *"walls as floors"*. Indeed, in the other target places all vertical boundaries - which are seen as walls - were transparent but in the case of this target place the two bigger vertical boundaries were opaque; this phenomenon caused confusion.

CHAPTER (9)

9. CONCLUSIONS AND FUTURE WORK

9.1 Conclusions

This thesis aimed to develop an architectural way of thinking about designing space in VEs. Literature from the fields of philosophy, architectural and cultural theory, urban planning, perceptual psychology, architectural psychology, environmental cognition, geography, artificial intelligence, VR technology and human factors aspects of VEs was reviewed. The result of this literature review was the development of an architectural framework and guidelines, which proposed a way for imposing form and structure onto space in a VE, for the purpose of making our interaction and navigation within such a VE a structured and meaningful experience. This framework described the possible spatial and space-establishing elements that the three-dimensional content of a VE may consist of. It also hypothesised on the significance of these elements for a navigating participant and suggested guidelines for possible ways of designing and structuring these elements.

A complete evaluation of this framework was not considered possible within the limits of this project and as a result this thesis cannot propose a complete theory for the spatial design of VEs, on the basis of such an evaluation. However, the framework which was presented in chapter (5) is seen as one of the main results of this thesis, since it still provides a possible context and suggests a series of useful guidelines for designing space in VEs. This context and guidelines may be an essential aid for researchers, designers and developers of VEs, who do not have a relevant background in designing three-dimensional content. Users would ultimately benefit from using more efficient and legible VEs, which could be produced by following this context and guidelines.

Following this framework, the researcher designed several pilot VEs, according to requirements presented in (6.2), for the purpose of testing its usefulness through the course of the VE design process. The experience of designing these pilot VEs resulted in identifying several key design issues which formulated the objectives for three of the experiments - (1), (5) and (6) - that took place in the following phase of the research. The other three experiments - (2), (3) and (4) - aimed at evaluating certain significant suggestions made within the design framework. These suggestions were also seen as giving answers to significant design issues which were identified, as such, during the design of pilot VEs.

The conclusions arrived at as a result of these six experiments are presented in this section. Consequently, several aspects of the framework, proposed in chapter (5), will be discussed, on the basis of having experienced the implementation of this framework and of having observed the experimental process. It is however understood that there is no conclusive evidence in support of the suggestions made in this discussion. Finally, directions for the continuation of this research in the future will be proposed.

9.1.1 Experiment (1)

The aim of this experiment was to investigate what impact certain formal elements - texture maps or repetitive frame-objects - applied on the surfaces of path boundaries have on the impression of movement experienced by subjects, who navigate along these paths. From the analysis of the results, the impression of movement that subjects felt:

- Was significantly enhanced when they navigated in a path on the boundaries of which a dynamic texture had been applied;
- Was clearly more enhanced in another path on the boundaries of which both the same texture and a series of rhythmically repeated formal elements - frames - had been applied, along the length of the path.

It may then be suggested that it is effective and pleasant to navigate in paths which have elements, such as certain textures or rhythmically repeated objects, integrated in their form. The addition of repetitive elements like frames, in the case of this experiment, on the boundaries of a path may also amplify the perspective effect and consequently enhance the perception of depth within the path. It is understood that these conclusions apply to a linear path of a rectangular section and to the application of the particular type of texture map that was used and the particular frame objects which were applied on the boundaries of the path. Further experiments could be conducted in order to investigate:

- The impact of applying several different types of texture maps, which may vary in terms of pattern, density, colour and other parameters. The work of Julesz (1975) on the visual perception of textures, could inform such experimental research.
- The impact of applying different types of repetitive objects along the length of a linear path, which may intersect with the form of the path in varying ways: they could be wholly external, or internal or be partly outside and partly inside the interior of the path.

Other experiments may also test the validity of this experiment's conclusions on paths of several non-linear forms.

9.1.2 Experiment (2)

This experiment aimed at investigating the way that subjects navigated in spaces of different volumetric proportions. It particularly aimed at evaluating the hypothesis that: "the volumetric proportions of a space may affect the behaviour of a subject within the boundaries of this space, by inducing a certain kind of movement:

- Being inside a path would induce movement along the path's main axis.
- Being inside a place was speculated to induce movement which focuses on the centre or the boundaries of the space."

The analysis of the results for the way that subjects navigated in each place, provided evidence in support of the hypothesis and led to the following conclusions:

- Both the horizontal and vertical longitudinal spaces which were used in the experiment, induced movement along the main axis of the space towards its extents;
- Both centralised spaces induced movement along the boundaries of the space from where subjects observed the space;

Additionally the significance of the centre of a space, as a strategic point from where a considerable number of subjects preferred to observe the interior of all four spaces, has also been identified. The analysis of the results for the variable 'time' did not contradict this hypothesis but neither did it provide evidence in its support.

When inside each of the spaces, subjects were not able to see any cues which would inform them of their orientation in relation to a global reference system, due to the opacity of these spaces' boundaries. In the absence of such cues and due to the overall symmetrical spatial arrangement, most subjects did not understand that space (1) was vertical and space (3) was horizontal and also were not bothered or confused when rolling around during navigation. In fact, since the environment was undifferentiated, orientation did not seem important to them and they seemed more occupied with:

- finding out the shape of the space, by reaching its extents and relating their position to the other extents of the space;
- knowing where the exit from the space was in relation to their position at each time.

Subjects seemed to explore an unknown space by moving to a corner of the space and then trying to observe the space from there. This could be attributed to the facts that

- The corner may provide the best possible view in an enclosed space.
- In the context of a space, a subject may feel more secure in there because the corner could be considered as a subset of the space or because the subject may feel that his back is protected.

9.1.3 Experiment (3)

This experiment aimed at investigating the impact of the degree of 'centralisation/ directionality' which characterises the shape of a place on aspects of spatial behaviour in this place. The analysis of the results showed no evidence to suggest that the degree of centralisation which is implicit in the shape of a place significantly affected:

- the ease with which a task was performed in this place or
- the apparent size of the place.

This result may be seen as an indication that this implicit attribute of a place has no impact on the specific aspects of spatial behaviour which were investigated. However, there is a possibility that the design of the experiment failed to control all possible parameters that may have affected the subjects' response. The result could also be due to the particular shapes of the places which were tested, the viewpoint perspective or the quality of rendering, which may have negatively influenced the accurate perception of space. Therefore, there is a need to repeat this experiment with differently shaped places and on a high-end system.

The need to perform a task may also have had an impact on responses; subjects may have concentrated on performing the task and viewing the objects much more than paying attention to the enclosure surrounding them, while being in these places. Future experiments should avoid involving a task, in the hope that subjects will concentrate more on the properties of the place.

Despite the lack of evidence for suggesting any impact of the spatial attribute being investigated, the observed behaviour of subjects lead to the following suggestions:

- Subjects felt generally constrained about moving within the obliquely shaped place (1), possibly due to the acute angles of its boundaries; more subjects expressed negative than positive feelings about being in this place.

- Subjects felt generally more positive about moving in place (3) than in any of the three places, despite the fact that they felt more constrained in doing the task because they could not move back into the corners of this place. They probably enjoyed the slightly more interesting form and colour scheme of the enclosure and the lack of acute angles in the place.

9.1.4 Experiment (4)

This experiment attempted to investigate the validity of the hypothesis that:
"when the 'inside' and 'outside' of a place in a VE are clearly defined and consequently this place is explicitly established by its boundaries as a spatial element out of the void, then

- a subject may feel secure and comfortable enough to engage in an activity in this place and
- accordingly, performance of a particular activity in there is also positively affected."

Additionally, the impact of the degree of explicitness in establishing a place was studied on the distraction that subjects felt, while performing a task in this place.

Most subjects who took part in this experiment seemed to enjoy moving freely in space and preferred being in open spaces like place (1), while less subjects were more influenced by gravity and preferred more enclosed spaces with a floor, like place (3) and place (4). Although the analysis of the results was generally not in support of the hypothesis, several interesting and useful conclusions were reached and are presented below.

1) Attempting to define place (1) by four small cubes, which indicated the corners of its rectangular volume, proved an unsuccessful way of defining a place. Despite the lack of a sense of enclosure, most subjects adapted to the openness of this space and felt positive about navigating and performing the task there,

without being constrained by any boundaries. On the other hand, they felt certain insecurity and distraction due to the openness of the space, the lack of boundaries and most importantly the lack of a floor.

2) Attempting to define place (2) by solid beam-like objects which indicated its edges proved a more successful way of defining the limits of a place. Despite the more clearly felt sense of enclosure, many subjects felt negative about navigating and performing the task in this place, mainly due to the lack of a floor and the obstruction on movement caused by the space-defining objects.

3) Place (3) was clearly more defined as an enclosure than place (2) by the same beam-like objects and the addition of a floor and a wall as boundaries. The majority of subjects considered this as an optimum place, because it made them feel quite comfortable and made the task execution relatively easy, while at the same time it did not cause significant insecurity or distraction. This may be due to the fact that this place combined a clearly defined enclosure and at the same time the freedom to view or move towards the surroundings, which aided orientation.

4) Finally, place (4) was completely enclosed by opaque boundaries and as such was the most explicitly defined place of the four. Despite the clear sense of enclosure, the majority of subjects felt negative about navigating and performing the task, while a minority felt the opposite. This was mainly attributed to the fact that movement and task execution were constrained and viewing the surroundings for orientation was not possible due to the complete enclosure; moreover this enclosure caused sense of confinement and distraction.

9.1.4.1 Conclusions about the sense of comfort and easiness of task execution

With reference to the comfort that subjects experienced in each place and contrary to the hypothesis, the most explicitly established place (4) seemed to be one of the less comfortable places to be in. Subjects found being in either the completely open and least explicitly established place (1) or the more realistic but still partly open to the surroundings place (3) more comfortable. In fact, some subjects considered place (3) as an optimum place in terms of comfort because it was enclosed enough to make them feel they were inside a place and at the same time open enough to afford views to the outside and to make subjects feel unconstrained from a complete enclosure. It is also interesting to mention that most subjects felt less comfortable in the slightly defined place (2) than in the completely open place (1). Although the analysis did not provide evidence, the recorded observations are clearly in support of these suggestions.

A possible interpretation of these preferences, based on observations made during the experiment is that:

- When subjects enter a completely open place like (1), they do not experience it as a place and accordingly are not bothered by the lack of a floor, but enjoy the freedom of movement afforded by the openness of the place.
- When they enter a slightly more explicitly defined place like (2), they interpret it as a place and feel negatively about the lack of a floor, while at the same time the frames defining the place hinder their movement and disturb them.
- When they enter a place like (3), they are comfortable enough because the place is clearly defined and has a floor, but on the other hand they are happy to be free to view and move outside the limits of the place.

With reference to the easiness of task execution in each place, the hypothesis was similarly proven wrong. Indeed, subjects found it more difficult to execute the task in the most explicitly established place (4) than in the other less explicitly established places. Although the easiness of task execution did not significantly differ between all three open places (1), (2) and (3), it is interesting to mention that place (2) - which had no surfaces as boundaries - was slightly more difficult than place (3) - which had a floor and a wall as boundaries - and than place (1) as well.

In an attempt to interpret these results, on the basis of observations made during the experiment, it may be suggested that subjects found executing the task to be relatively easy in place (1) due to the openness of the space and the consequent lack of movement constraints. According to this explanation, it seems awkward that subjects found it equally easy to execute the task in place (3). It is possible that responses for easiness of task execution may have been influenced by responses for the sense of comfort; this suggestion is also supported by the similarity of the error bar graphs for these two variables - presented in (7.2.3.1) and (7.2.3.2). This explanation could also account for the fact that place (2) was considered a bit more problematic than places (1) and (3).

9.1.4.2 Conclusions about the sense of security and experienced distraction

With reference to the sense of security that subjects felt in each place, the analysis has provided evidence in support of the hypothesis. Accordingly, places (1) and (2) which were very open, less explicitly established by their boundaries and most importantly had no floor were seen as significantly less secure than places (3) and (4) which were more explicitly defined by boundaries and had a floor. Additionally, as the degree of explicitness with which these places were established increased, from place (2) to place (3) and from place (3) to place (4), so did the sense of security that subjects felt when being in these places.

Similarly, in agreement with the hypothesis, the sense of distraction that subjects experienced in all three open places (1), (2) and (3) was significantly bigger than the distraction they felt in the completely enclosed place (4). On the basis of the analysis, it can finally be suggested that the more secure a place is the less distracted a subject may feel inside this place. This suggestion is also supported by the error bar graphs presented in (7.2.3.3) and (7.2.3.4).

Although the analysis did not show evidence to support a difference between security or distraction experienced in places (1) and (2), on the basis of observations it may be suggested that subjects felt slightly less secure and more distracted in place (2) than in place (1). This phenomenon could be attributed to the fact that subjects did not see place

(1) as a defined place, while place (2) was more defined by the frame objects but equally open to the surroundings; as a result subjects felt slightly more exposed and unsafe among the surroundings, when in place (2).

It may generally be argued that when a space that we enter seems more *'like a real space'* then our expectations about spatial behaviour in this space are also more realistic and we may feel affected by gravity. On the other hand, when entering a space where it is clear that real world constraints are not applicable - like place (1) - we may adapt our spatial behaviour to the lack of constraints and feel freer to navigate without gravity.

9.1.5 Experiment (5)

Experiments (5) and (6) have attempted to give answers to the issue of arranging places and paths in three-dimensional space, in order to structure domains which accommodate navigation through their interior space. Experiment (5), in specific, aimed at investigating how places have to be positioned in relation to a horizontal path, in order to ease the task of navigating into the place and performing an activity inside this place. Additionally, the experiment investigated the way that subjects position their viewpoint in relation to a place, when they try to orientate and perform a task in this place, dependent upon how this place is positioned in relation to the path.

The analysis of the results, with respect to how easy it was for the subjects to orientate in each place, showed that:

- The place to which no rotation at all had been applied, was clearly the easiest of the five to orientate in. It may therefore be argued that any rotation applied to a place, which is alligned to the path, will result in making orientation within this place more difficult.
- The place the floor of which had been pitched, was the most difficult to orientate in. It may therefore be suggested that positioning a place in relation to a horizontal path in this manner should generally be avoided, as it causes confusion and disorientation.

- It was not possible to differentiate between the other three places in terms of easiness of orientation.

The analysis of the results for the time variable also provided support for these conclusions:

- The place to which no rotation had been applied was the easiest to do the task in and it took subjects less time to do the task in this place than in three of the other places.
- The place the floor of which had been pitched was considered the most difficult to orientate in and accordingly it took subjects significantly more time to do the task in there than in the other places.
- No significant differences were detected for either easiness or time measurements among places (1), (4) and (5).

With reference to the way that subjects orientated their viewpoint in each place, the analysis showed that in all five places, subjects largely preferred to position their viewpoint vertically to the two biggest boundaries, which could be seen as the 'floor' and the 'ceiling' of the place. Additionally:

- Since place (1) was rolled 90^0 along the z axis, subjects who entered it may have seen the floor and ceiling as if they were walls. As a result, 25% of them adapted to the awkward volumetric proportions of the space and felt comfortable to keep their viewpoint positioned parallel to the 'floor'.
- Place (2) was pitched 45^0 along the x axis. The way that this place was rotated in relation to the path caused confusion to a large number of subjects, who entered the place and were immediately faced with a dark pitched floor which was too close to their viewpoint. As a result, 25% of the subjects moved their viewpoint randomly within this place.
- Place (3), which was not rotated at all, was seen by most subjects as a realistic room. As a result, they felt like behaving as they would in a real space and accordingly saw the two biggest boundaries as a floor and a ceiling and attempted to position their viewpoint vertically to this plane.

- Place (5), may have been rotated along both axes but the angles of rotation were not too significant. As a result, most subjects saw this place as a normal room, the floor of which was slightly rotated and consequently behaved as in the case of place (3).

On the basis of observing the behaviour of subjects, several significant suggestions can be made:

- Most of the subjects felt more comfortable to yaw - rotate around the y axis - than to pitch - rotate around the x axis - their viewpoint within a place, in order to look around and perform the task. It seems natural to pitch one's head up or down at a small angle, in order to look around when inside an enclosure, but it would seem very awkward to pitch one's whole body 360^0; on the other hand, it seems natural to yaw one's viewpoint at any angle.
- Many subjects felt that a crucial factor which aided orientation in a place was the ability to view and understand the structure and orientation of the place in relation to the path, before entering this place from within the threshold. The orientation of a part of the threshold within the place, which indicated the orientation of the path connected to this threshold, clearly directed the orientation of subjects on their way out of the place.
- The task of comparing the size of objects within a place was made difficult by the fact that the perspective of the VE was slightly accentuated and distorted; this was due to the viewing angle of the application window (0.8) which was slightly bigger than a normal angle (0.6).

9.1.6 Experiment (6)

Experiment (6) has attempted to investigate how paths have to be positioned for connecting two places in three-dimensional space, in order to ease the task of entering from one place into the path and navigating through this path towards the other place.

Additionally the experiment investigated the way that subjects position their viewpoint in relation to the path while navigating through this path towards the place at its end, dependant upon how the path is positioned in relation to the two places it connects.

The analysis of the results with respect to how easy it was for subjects to orientate while navigating the path, lead to the following conclusions:

- The path to which no rotation at all had been applied was clearly the easiest to orientate into; on the other hand, all paths to which a rotation had been applied were clearly more difficult to orientate into. It may therefore be argued that when a pitch or a roll rotation is applied to a path which connects two places in relation to the orientation of these places, orientation while navigating this path becomes more difficult.
- The path which had been rotated along both axes, was clearly the most difficult to orientate into. Accordingly, it may be suggested that the application of such a rotation on a path which connects two places should generally be avoided, as it causes disorientation and makes navigating the path very difficult.
- The application of a rotation along the x axis - pitch rotation - results in making orientation in a path significantly more difficult. In other words, pitched paths are generally more difficult to orientate into than horizontally positioned paths. According to subjects' observations, this difficulty was not only experienced during navigation in the path but also when subjects attempted to enter or come out of the path; this phenomenon was due to the spatial relation of the place with the end of the path.
- Subjects also thought that a rotation along the z axis - roll rotation - made their orientation more difficult but their performance, in terms of time, did not support such a claim. On the basis of observations however, it can be suggested that the activities of entering a path from either of the two places and exiting the path into these places became significantly more problematic when a path was pitched than when a path was rolled.

- The path which was vertically positioned in relation to the central hall was clearly more difficult than the path which was not rotated at all but slightly more difficult than the path which was only pitched. This path, though, was slightly easier than the path to which both rotations had been applied. From observations, it became evident that the main problem that subjects had with orientating in relation to this path was when they tried to enter it and when they came out of it and into the place at its end. It may therefore be suggested that positioning a path vertically to a place is a possible solution but certain caution should be given to the way that the entrance to this path is accommodated by the appropriate design solution.

These results were partly supported by the analysis for the variable of time, as well.

With reference to the way that subjects positioned their viewpoints in each path, the results showed that:

- In the paths which were not rotated along the z axis - rolled - most subjects preferred to position their viewpoints vertically to one of the boundaries of the path.
- In the paths which were rolled, the number of subjects who positioned their viewpoint diagonally to the section of the path was equal or even bigger than those who tried to position their viewpoints vertically to one of the boundaries of the path.
- In the path which was vertical to the central hall and was not rolled, subjects behaved like in the case of the other paths which were not rolled; however on the way out, due to the lack of cues for orientation, their responses were mixed and unexpected.

From observations of the behaviour of subjects this experiment lead to some other significant suggestions:

- When an enclosure - in this case a path - is positioned so that orientation in it is confusing, subjects rely on other cues for orientation - for example the number in the entrance of the paths, the boundaries of the central hall and the horizon. The lack of such cues makes orientation during navigation even more difficult.

- The symmetrical shape of the section of a path does not provide a cue for aiding the subjects' awareness of their global orientation. A certain asymmetry or implicit direction on the shape of the section of the path would possibly provide such a cue. On the other hand, the numbers which signified the entrance to each path strongly indicated a global vertical direction and thus helped subjects in this respect.
- The use of semi-transparent materials on the surfaces of most boundaries in this VE helped users orientate in relation to the context. However, the use of such material on the surfaces of paths was not as successful, because it confused subjects who navigated these paths as to where the limits of their enclosure were and thus made the task of navigation more difficult.
- Many subjects thought that these paths were narrow, due to their volumetric proportions. As was also suggested in experiment (2), such a phenomenon could be considered as an indication that the sense of scale in an enclosed space is more related to the place's volumetric proportions than to its actual size. Accordingly the sense of narrowness that subjects have experienced may be attributed to the large length of these paths. This suggestion however should be evaluated by empirical methods in future experiments.

9.2 Discussing aspects of the proposed framework

In addition to the guidelines suggested by the proposed framework, several other suggestions which have important implications for the design of space in VEs are presented below. These suggestions came about as a result of the experience of implementing the framework, proposed in chapter (5), and of observing subjects' responses to the experiments. They are not based on any evidence and may be seen as speculative, subjective and somehow arbitrary but nevertheless they are considered to be significant for advancing this research in the future.

9.2.1 The question of accessibility of the exterior of a domain

During experiment (6), the use of paths for channelling movement between two places was questioned. If a subject was allowed to fly freely from the central hall to another place he would not feel constrained and navigational performance would probably be eased. It could, however, be argued that this path is also helpful in that it clearly defines the target for movement and constrains the available space to a straight linear tube, the length of which is shorter than any other distance which could be travelled. One should therefore balance these advantages against the disadvantage of feeling constrained and having to avoid the boundaries of the path, in order to design the most appropriate solution for ergonomically effective channels of movement within a VE.

In the same vein, it is also valid to question the assumption that navigation within a VE should generally be constrained within the interior of such structures of spatial elements like domains comprising of places, paths and intersections. It is understood, of course, that this is not the only possible way of dealing with the design of space in VEs.

The framework proposed in chapter (5) was based on the implicit assumption of the human need for existing, navigating and acting in environments which have form and structure and are seen as systems of meaningful places - as presented in (1.3) and argued by Relph (1976, p.1). Later in (4.12) it has also been suggested that humans show preference for experiencing structured and legible environments. Accordingly, this thesis has assumed the need for imposing form and structure onto the three-dimensional content of a VE by designing compositions of certain spatial elements but has not necessarily suggested that a subject should only move in the interior of such compositions.

In five of the previously presented experiments, navigation was constrained within the interior of the experimental domains for the purpose of limiting the activity of subjects to the aspects of the VE which were investigated. In experiment (4) however, subjects were free to move inside or outside the experimental domain. Their navigational behaviour showed that most of them could cope with such a transition without significant problems. However, there were several subjects who felt happy about flying without constraints around the experimental domain while there were others who were reluctant to abandon the security of navigating in the interior of a domain. It is speculated that their preference, in this respect, could be related to each subject's personality. It is therefore suggested that a subject should have the choice of navigating both inside and outside such compositions of spatial elements, designed on the basis of the proposed framework, which are used for structuring a certain experience in three-dimensional space. This suggestion is considered of central importance for designing space in a VE, because it implies that the form of all spatial elements will be visible and thus potentially meaningful both from inside and from outside.

9.2.2 Collision detection

The implementation of collision detection on the boundaries of all spatial elements, with the exception of thresholds, functioned as expected - as explained in (6.5) - during the experiments. Subjects generally thought that the 'solidity' of boundaries gave a necessary consistency to the representation and were guided by these boundaries as they navigated within the experimental domains. It can then be suggested that this solidity is one of the aspects of reality that humans expect to experience in a VE.

On the other hand, in the VE that subjects experienced for training in navigation by using the "Magellan" input device, collision detection was not implemented. In this case, subjects may have been happy to fly around without constraints and to observe the experimental domain, but once they were inside the interior of this domain they were confused by the inconsistency of being able to go through boundaries. It may therefore be suggested that if such compositions of spatial elements are to be designed in a VE, they should constrain the movement of subjects with the implementation of collision detection on all boundaries, apart from specifically designed and signified thresholds, which would afford passage to and from the interior of these compositions. If collision detection is not implemented, such compositions would confuse rather than aid navigation in a VE.

9.2.3 The structure of spatial elements in a VE

A very significant issue which has only been briefly dealt with in (5.7), is the way that the spatial elements can be structured within a VE. Several suggestions had been made with respect to each individual element. It was however, difficult to hypothesise about this issue before attempting to implement these sparse suggestions by designing the pilot VEs. Following this design process and on the basis of the experimental process as well, several other useful suggestions can be made, with respect to the structure of spatial elements within a VE:

- A domain may be a composition of spatial elements comprising paths, intersections, and places, which are defined by boundaries; it may also include several landmarks, signs or other objects integrated in its structure. Spatial elements can be organised according to several types of configurations - as presented in (5.7): centralised, linear, radial, clustered or grid configurations.
- A VE may comprise several domains which
  - could be located in the same universe - as defined in (5.6.5). In this case subjects should be able to navigate freely from one domain to the other, preferably without the need of a path which connects these domains. This suggestion is based on the model presented in (5.6.4), according to which a VE may be seen as comprising known regions within which distances are better known, but between which distance knowledge is less precise. Accordingly, in each region, one particular element - a landmark or a place - functions as a reference point which cognitively anchors the entire region. Having observed subjects' experiences with navigating paths in experiment (6), it is expected that a path linking two

domains would probably be too long and would consequently frustrate subjects who would try to navigate it.

- Different domains, however, could be located in different universes. In this case, these domains could be linked by portals, the function of which has been explained in (5.6.5).

- Finally, each universe could be enclosed in a sphere, or other symmetrical volume, which determines its final extents, outside which a subject cannot navigate (Figure 9.1). This constraint was seen as necessary, since navigating into the monochromatic chaos of the void which lies beyond these extents is disorientating, brings uneasiness, frustration and generally proved undesirable during the design of the pilot VEs or during the pilot experimental study. This sphere was successfully implemented in experiments (4), (5) and (6) with a horizon - as described in (7.2.2) - which informed subjects of their orientation in relation to a global reference frame. The implementation of the horizon concept, however, should be improved, since it was considered problematic by a number of subjects in experiment (6).

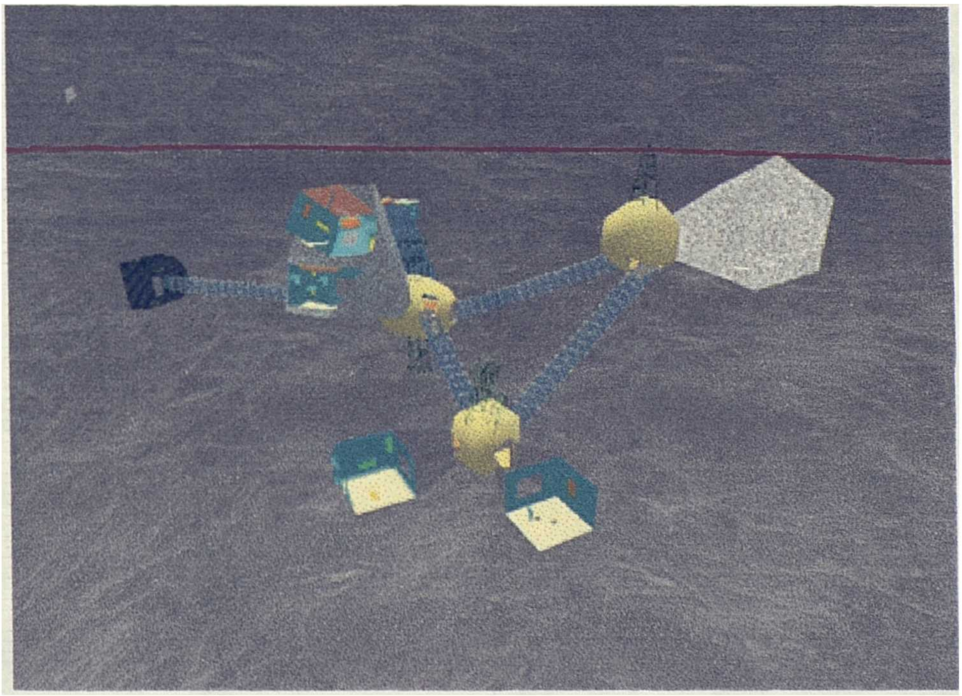


Figure 9.1: A domain, comprising places, paths, intersections and landmarks, is enclosed within an environmental enclosure, which determines the limits of the universe that this domain is a part of.

9.2.4 Thresholds - buffers - intersections

Subjects adapted easily to the idea of a threshold and the way that these were implemented in the experimental VEs, after having experienced these spatial elements once or twice. It became obvious however, that an important requirement for this adaptation was that all thresholds were consistent, in terms of their form. Indeed, in all experiments, thresholds were flat surfaces of a symmetrical shape to which a dark red semi-transparent material had been assigned.

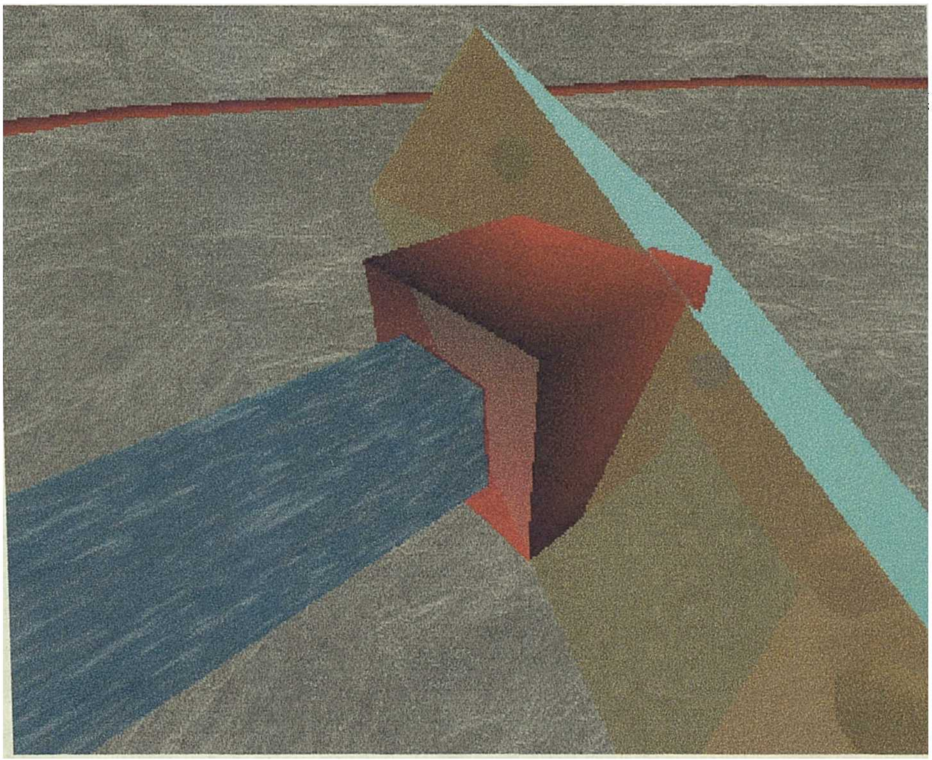


Figure 9.2: A 'buffer' which links a path with the rotated place (5) in experiment (5).

In experiment (5) however, the use of a three-dimensional threshold, which functioned as a buffer between the path and the place and as an entrance to the place, was found during the design process to be absolutely necessary for linking the two spatial elements in three-dimensions and for accommodating the various rotations of the place in relation to the path. This threshold, however was not a space-establishing element but a small cubic space, which accommodated the necessary adjustment of the subject's viewpoint in three-dimensions for entering the rotated place. The need for such a space revealed the possibility for another type of spatial element which could appropriately be called a 'buffer'. This element could be defined as an intermediate space which spatially expresses the need for adjustment of the subject's viewpoint when moving from one space into another (Figure 9.2). In this sense, a buffer is relative to an intersection as it is a space which accommodates the interaction between a path and a place. In order to differentiate between the two elements, it is suggested that:

- An intersection may be considered as a bigger scale space of interaction between two spatial elements; an intersection could be large enough, in relation to the elements that it links, to function as a space on its own and to house certain activities apart from its central function of diverting navigation.
- A buffer may be seen as a smaller scale space which merely accommodates the viewpoint adjustments, which are necessary for entering or exiting a space; in this sense the buffer can be seen as a three-dimensional threshold.

The specific implementation of the buffer in experiment (5) however, proved confusing and problematic for a number of subjects. These problems, which have been presented in (8.2.4.5), should be investigated in future experimental work, for the purpose of improving the design of such a spatial element.

9.2.5 Other general suggestions

Several other sparse suggestions can be made for evaluating the framework proposed in chapter (5), on the basis of the design and experimental processes:

- Following the argument of this thesis, a spatial element is considered as an object or another component of the three-dimensional content of the VE, which is described by certain properties and characteristics, rather than a part of an infinite space as the arena where 'solid' objects are arranged and activities take place, according to Ellis (1993) and Kalawsky's (1993) approaches.

- It has been suggested in (5.5.1) that the way in which a subject functionally relates to a VE may become a very important parameter according to which this subject will associate with an object as a landmark. From the observations of subjects and their experience in the experimental VEs, it can be suggested that the way they functionally related to places has certainly influenced the way they associated with these places. Indeed, in the experiments where there was a task to perform in certain places, many subjects seemed to pay less attention to the setting and to concentrate on the objects relevant to the task; as a result they often found it difficult to respond on certain aspects of this place. On the other hand, when subjects were not asked to perform a task involving objects in a place, they seemed to concentrate more on the setting.

- The need for creating relatively differentiated settings for aiding orientation and wayfinding was stressed in (5.6.2). It was actually suggested that in a relatively undifferentiated setting, which lacks environmental features, as may often be the case in VEs, subjects tend to rely on geographical orientation for wayfinding. This may not be always possible though, because many VEs may not include any cues for orientation to a global reference system. In the case of experiment (2), where due to the opacity of the space's boundaries there were no such cues available, subjects felt the need to always be aware of where the exit was, as a means for being orientated to the local reference system of each place.

- Subjects often became physically involved while trying to accomplish the task. In the path of experiment (6), which was vertical to the central hall, this involvement was clearly manifested by the movement of their bodies, in their effort to manoeuvre their viewpoint in order to enter the path. Many moved as if they were actually immersed in the VE and their bodily movement would help them position their viewpoint so as to enter the path.

9.3 Future work

This project has proposed an architectural framework for the design of space in VEs and has also attempted to investigate aspects of this framework by empirical methods of research. In this last section, aspects of the issue of designing space in VEs which have not been dealt with by this thesis will be presented, as possible directions for future research.

- This thesis has investigated the design of space in VEs with respect to a participant who navigates in this VE. Aspects of interaction with elements of this VE have not been discussed and could well be the subject of future research.

- A systematic analysis of the relations between environmental cognition, assessment, decision-making and action, for a subject who navigates within a VE, has not been attempted as these issues are far too complex to be investigated in one thesis. These may well be the subjects of future research in environmental cognition within VEs.

- This thesis has focused on desktop VE systems, mainly because of practical limitations determined by the resources available for the experimental stage of this project. These resources afforded the use of a desktop system for evaluation of the framework, proposed by the thesis as a result of the literature review. It is however suggested that many of the conclusions that this thesis has arrived at may be valid for immersive VE systems as well. Furthermore, it was suggested in (5.6.2) that users of immersive VEs may have an advantage in storing route knowledge in relation to users of desktop VEs, because they are involved in active interaction for the purpose of navigation. It would therefore be useful to evaluate this suggestion as well as the validity of suggestions made in the proposed framework for navigation in immersive VEs, by means of further experimental research.

- The literature review which was presented in chapter (4) has investigated the way that humans create representations of real-world spaces - called cognitive maps - in their memory. It would be useful to conduct experiments, involving the analysis of the spatial representations produced by subjects who have navigated in VEs, in order to investigate the way that humans remember space in VEs. The production of a cognitive map requires a certain experience built by navigating an environment at least once.
    - It is reasonable then to suggest that by measuring and analysing the manner with which the knowledge of the structure and the detail of a VE evolves over time, as a result of navigating this VE, we could identify whether a cognitive mapping process does indeed take place in VEs, as it does in the real world. However, it is understood that there are certain problems involved in asking people to draw cognitive maps from memory, in order to analyse them (Smyth et al., 1994, p.312) and these should be taken into account in the design of such experimental studies.
    - Another possible objective for related experiments would be to find out whether the production of cognitive maps is facilitated by navigating in VEs which are designed according to this framework. This could be achieved by comparing the cognitive maps produced by subjects who navigated in such VEs with maps produced by the same subjects after navigating within VEs, designed as realistic representations of environments. If this was found to be true, the use of such a framework, at least in specific applications, would be justified.
    - Finally, a possible objective would be to study the cognitive maps, produced as a result of navigating within different types of VEs, in order to identify the elements that these maps consist of. This would indicate whether the elements which are proposed within the framework are really to be found in the cognitive representations of space in VEs. Of particular interest would be to investigate the form of cognitive maps produced as a result of navigating within a VE, in which portals have been implemented and where, as a result, space is non-contiguous - as explained in (5.3.3).

- This thesis has focussed on investigating space in VEs, which have been designed as static visualisations of a pre-determined databases, affording limited addition or subtraction of data. It is understood though, that the three-dimensional visualisation of an updateable database by a dynamically evolving VE is seen as the ultimate goal of this research in the future. If the efficiency and validity of the proposed framework is evaluated in the case of static VEs, then this framework may provide requirements for a dynamically evolving system. Such a system would generate spatial structures comprising appropriately arranged spatial elements in three-dimensional space, which would function as the setting where the objects which represent the visualised data could reside. The use of such a setting, as a context for visualised information, would aim at aiding navigation and wayfinding within complex information structures. It is, however, acknowledged that the ever-changing character of such a visualisation would possibly hinder the production of cognitive maps and consequently the remembering of spatial structures, thus confusing wayfinding. A real-time system which supported data visualisation in the form of three-dimensional, navigable spatial structures has been presented by Wenz (1997).

- In experiment (2), some subjects saw the cubic space (4) which was twice the size of space (2), as smaller than space (2). A similar effect has been identified in experiment (6), where the relatively large length of paths made them seem too narrow. This phenomenon could be seen as an indication that the sense of scale in an enclosed space in a VE is more dependent on the volumetric proportions of this space than on its actual size. This suggestion could be the subject of future experimental work.

- It has been suggested in (5.7) that there should be cues which may inform a participant in a VE of the relation of their viewpoint to certain global cues, such as the centre of the VE, a global vertical - above and below - and a horizontal direction.

A sense of orientation to such cues, at all times, was assumed to be necessary for navigation and wayfinding. The use of a horizon in experiments (4), (5) and (6) showed that subjects were indeed aided by such an element as a global reference for orientation. However, some problems in the implementation of this element were also detected. Since VEs are highly unnatural environments and differ fundamentally from REs, as it has been explained in section (5.3), the need for global cues for orientation in a VE has to be systematically evaluated by experimental methods of research.

- The six experiments, conducted as a part of this project, investigated the spatial behaviour of subjects in an individual spatial element or within a limited composition of such elements. These experimental VEs did not include any networks of paths so spatial elements like intersections were not integrated in them. The scale of these VEs was limited, so they all consisted of only one domain, comprising several places and paths. Additionally, all designed VEs consisted of one universe. Signs were not implemented in either the pilot VEs or the experiments, as the complexity of the design issues which the author had already identified was too great to allow for implementing signs within the time limits of this project. Landmarks, however, were implemented in the pilot VEs but have not been integrated in any of the experiments.

Future experimental research could investigate issues relating to the use of signs, landmarks, intersections, multi-domain or multi-universe VEs and portals which support the teleportation of subjects between remote positions

- within the same universe or
- among different universes.

A possible experiment could evaluate a significant suggestion made in (5.6.3), according to which an intersection of paths or a place located at such a position, may influence the way that subjects remember a route which is anchored to this place or intersection.

- As suggested in (5.6.1), a place elicits the behaviour and particularly the cognitive and affective responses of a subject to a specific place. Additionally, planning for different goals may alter how the place is cognitively and affectively represented and consequently how a subject behaves in this place. These suggestions have important implications for the way that space in designed in any environment and their validity in VEs should be tested by means of experimental research.

- Finally, a VE can be thought of as a behaviour-modification tool. With respect to education, training or psychotherapy applications, Nat Durlach (1995, p.277) argues that *"even if behaviour-modification is not the goal, experiences encountered in VR can lead to such modification"*. This result of experiencing a VE has not been considered in this project. It would however be interesting to study the short-term and long term effects of experiencing a VE, designed according the proposed framework, on the spatial behaviour of subjects in the real world.

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APPENDIX

A.1 Experiment (1)

A.1.1 Statistical Analysis

The test of sphericity for the measure of 'sense of movement' showed that there was a need for the adjustment of degrees of freedom, with the use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: EASINESS

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PLACE	.406	25.592	9	.002	.671	.743	.250

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: PLACE

Accordingly, the tests of within-subjects effects for the Greenhouse-Geiser adjustment showed:

Tests of Within-Subjects Effects for within-subject factor: PATH

Measure: SENSE OF MOVEMENT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Sphericity assumed	9602.882	2	4801.441	38.313	.000	76.627	1.000
Greenhouse -Geiser	9602.882	2	5645.398	38.31	.00		

a. Computed using alpha = .05

A repeated type of test was performed in order to investigate the contrasts between place (1) - place (2) and place (2) - place (3).

Tests of Within-Subjects Contrasts for within-subject factor: PATH - Repeated type of contrast

Measure: SENSE OF MOVEMENT

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PATH	PATH_1	7770.471	1	7770.471	25.628	.000	25.628	.998
	PATH_2	2355.559	1	2355.559	16.183	.000	16.183	.974
Error(PATH)	PATH_1	10005.529	33	303.198				
	PATH_2	4803.441	33	145.559				

a. Computed using alpha = .05

A simple (last) type of test was performed in order to investigate the contrast between path (1) - path (3).

Tests of Within-Subjects Contrasts for within-subject factor: PATH - Simple (last) type of contrast

Measure: Sense of movement

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PATH	PATH_1	18682.618	1	18682.618	61.626	.000	61.626	1.000
	PATH_2	2355.559	1	2355.559	16.183	.000	16.183	.974
Error(PATH)	PATH_1	10004.382	33	303.163				
	PATH_2	4803.441	33	145.559				

a. Computed using alpha = .05

A.1.2 Observations

Two subjects reported that the enclosure in path (2) felt more open, bigger and freer to move in, possibly because of the lack of cues for defining the definite limits (edges) of the path, which are significantly more visible in the cases of path1 and path 3 (because they are defined by the succession of frames). Also, the nature of the texture that has been used may have contributed to the impression of flow and the lack of limits. 4 subjects have reported a sense of floating and a sense of a less defined space. However others (1) reported that this path felt more enclosed "like a glass tube in a swimming pool", it did not seem realistic as a path as well.

One reported that there is a clear problem of scale in path 2; because of the lack of clear limits the distance of the subject from these limits is not also clear and so subjects may easily bounce on surfaces.

Generally, the ones who reported that impression of movement was lower in (2), (3) than in (1) felt that the texture made the environment unrealistic and they did not like that; on the other hand they thought that the message of movement was clearer in the simplest path (1) where due to the lack of texture the shading effect was stronger resulting in a stronger sense of depth and perspective.

The fact that a clearly visible goal approaching or receding gave a strong impression of movement was confirmed in all three paths. When in paths 2 and 3 the goal was somehow concealed on the way out towards the end_place because of the way the texture covering it decreased the effect of shading, few (3) subjects reported that they felt less impression of movement on the way out and more on the way back to the central hall where the goal was much more clearly visible.

Many subjects generally did not seem to mind rolling around when moving along the paths. This was more evident with the ones whose *navigation* skills were low. The fact that they were not bothered with moving upside/down or at 90^0 angle to the global vertical orientation may be attributed to the lack of environmental cues for orientation. This was felt more on their way out, where there was almost no other objects apart from the end_place to orientate to, rather than on the way back to the central hall, where they could see the overall domain through the transparent surfaces of paths and thus orientate better.

A.2 EXPERIMENT (2)

A.2.1 Statistical analysis

For the variable of the way of movement, the tables of frequencies are as follows:

	Response in space 1	
	No. of subjects	%
1	2	6.3
1/2	14	43.8
1/3	1	3.1
2	15	46.9
Total	32	100.0

	Response in space 3	
	No. of subjects	%
1	1	3.1
1/2	12	37.5
2	16	50.0
2/1	1	3.1
2/3	1	3.1
3	1	3.1
Total	32	100.0

	Response in space 2	
	No. of subjects	%
1	2	6.3
1/3	8	25.0
3	20	62.5
3/1	2	6.3
Total	32	100.0

	Response in space 4	
	No. of subjects	%
1/3	9	28.1
2/3	1	3.1
3	21	65.6
3/1	1	3.1
Total	32	100.0

With respect to the measure of 'time', the test of sphericity showed that there was a need for the adjustment of degrees of freedom, with the use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: TIME

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
SPACE	.546	17.980	5	.003	.714	.769	.333

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: SPACE

Accordingly, the tests of within-subjects effects for the Greenhouse-Geiser adjustment showed:

Tests of Within-Subjects Effects for within-subject factor: SPACE

Measure: TIME

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power[a]
Sphericity assumed	1.0E+08	3	3.4E+07	7.280	.000	.190	21.840	.980
Grrenhouse - Geisser	1.0E+08	2	4.7E+07	7.28	.00			

a. Computed using alpha = .05

A repeated type of test was performed in order to investigate the contrasts between space (1) - space (2), space (2) - space (3) and space (3) - space (4).

Tests of Within-Subjects Contrasts for within-subject factor: SPACE - Repeated type of contrast

Measure: TIME

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power[a]
SPACE	SPACE_1	1.0E+08	1	1.0E+08	11.064	.002	.263	11.064	.896
	SPACE_2	6.2E+07	1	6.2E+07	12.894	.001	.294	12.894	.935
	SPACE_3	9.3E+07	1	9.3E+07	14.634	.001	.321	14.634	.959
Error(SPACE)	SPACE_1	2.8E+08	31	9138368					
	SPACE_2	1.5E+08	31	4777955					
	SPACE_3	2.0E+08	31	6338265					

a. Computed using alpha = .05

A simple (first) type of test was performed in order to study the contrasts between: space (1) - space (3) and space (1) - space (4).

Tests of Within-Subjects Contrasts for within-subject factor: SPACE - Simple (first) type of contrast

Measure: TIME

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
SPACE	SPACE_1	1.0E+08	1	1.0E+08	11.064	.002	11.064	.896
	SPACE_2	4867200	1	4867200	.328	.571	.328	.086
	SPACE_3	1.4E+08	1	1.4E+08	9.839	.004	9.839	.860
Error(SPACE)	SPACE_1	2.8E+08	31	9138368				
	SPACE_2	4.6E+08	31	1.5E+07				
	SPACE_3	4.4E+08	31	1.4E+07				

a. Computed using alpha = .05

A simple (last) type of test was performed in order to investigate the contrast between space (2) - space (4).

Tests of Within-Subjects Contrasts for within-subject factor: SPACE - Simple (last) type of contrast

Measure: TIME

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power[a]
SPACE	SPACE_1	1.4E+08	1	1.4E+08	9.839	.004	.241	9.839	.860
	SPACE_2	3175200	1	3175200	.521	.476	.017	.521	.108
	SPACE_3	9.3E+07	1	9.3E+07	14.634	.001	.321	14.634	.959
Error(SPACE)	SPACE_1	4.4E+08	31	1.4E+07					
	SPACE_2	1.9E+08	31	6089110					
	SPACE_3	2.0E+08	31	6338265					

a. Computed using alpha = .05

A.2.2 Observations

With respect to place (1), eight of the subjects who saw the place as being vertical, felt quite strong positive or negative feelings about being in this place:

- Three female subjects reported that they enjoyed the non-realistic character of this space and were excited or thrilled by moving within it or that they felt like swimming
- Two male and one female subjects reported that they found place1 disorientating because it was placed vertically while we are used to corridors being horizontal; one of them reported a feeling of vertigo.

- One female found this space quite claustrophobic and felt relief on exit.

Subjects who saw this place as being horizontal felt more neutral.

Although most subjects moved towards both extends in places (1) and (3), in some cases:

- they started to move towards their extends but stopped halfway and returned to the other end or
- they moved only towards one of the extends.

In all these cases:

- subjects had already experienced a longitudinal place before so they already knew what to expect and they did not want to spend much time in this second longitudinal place or
- they had low navigation skills.

Generally, subjects did not seem to bother about their orientation, so quite often they ended up moving upside/down or at weird angles.

- This can be attributed to the lack of cues for orientation within the places; as subjects could not tell if they were upright or not they did not feel uncomfortable about maintaining awkward orientations while moving in these places.
- It could also be attributed to low navigation skills with the input device, which often resulted in uncontrolled rolling and difficulty to keep a steady posture; this happened in all places and in such a case the subject seemed to care more about getting on with moving through the place rather than maintaining a certain orientation.

Especially in places (1) and (3) verticality and horizontallity seemed to less important and subjects seemed to shift between the two notions quite easily.

Subjects who understood place (1) as being vertical and place (3) as horizontal thought that 3 was bigger than 1 but more enclosed, because the *dark green floor* and *ceiling* feel as more constraining boundaries, whereas the dark green surfaces in 1 seem more like thresholds to other spaces.(top one seemed like a skylight). Also 1 subject who saw

place 1 as vertical felt that the length was more on the way up then on the way down from the threshold, so he had to compare them by looking around from the centre.
1 subject reported that she saw the dark green colour as representing floor and ceiling ("like you want to step on something darker" as is usually the case in real rooms) However, 1 subject attributed her willingness to move to the end in place 1 but halfway in place 3 in that the extends of place 1 are dark green and of a similar shape to a threshold so she thought they were thresholds too.

In place (2), many subjects (13) preferred to observe the place from corners of its boundaries as they could get a better view of the overall place from there. Four subjects reported that they thought this place was more like a room and this made them feel more comfortable to move in there. However, ten subjects still rolled around a lot in there.

In place (4) also, many subjects (12) preferred to observe the place from corners of its boundaries. More subjects (15) rolled around quite a lot in here; this could be attributed to low navigation skills and to the small apparent size of the space.

Additionally, the time spend in this space was significantly less than the time spent in any other place. This is described above by statistical figures. This phenomenon could be explained by the facts that:

- although place 4 was actually twice the size of place 2, the apparent size of this place was smaller because it was cubic, so subjects (4) felt more claustrophobic and less comfortable to be in and wanted to come out quicker
- because of its shape, this space was visually scanned in less time than the other spaces and so subjects quickly found very little to explore and thought that the place was less interesting, so they wanted to move out
- most subjects found place4 less likeable than place2.

Also in place 4, (2) subjects used the number as a reference when inside the place in order to orientate within the place.

A.3 EXPERIMENT (3)

A.3.1 Statistical analysis

The test of sphericity for the measure of 'easiness' showed that there was no need for the adjustment of degrees of freedom in order to calculate the F statistic in the within-subjects tests of effects and contrasts.

Mauchly's Test of Sphericity[b]

Measure: EASINESS

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PLACE	.975	.917	2	.632	.975	1.000	.500

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: PLACE

Assuming sphericity of data for the measure of 'easiness', the within-subjects test for effects showed:

Tests of Within-Subjects Effects for the Within-Subjects factor: PLACE

Measure: EASINESS
Sphericity Assumed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	276.860	2	138.430	.827	.441	1.654	.187

a. Computed using alpha = .05

The test of sphericity for the measure of 'size' showed that there was no need for the adjustment of degrees of freedom in order to calculate the F statistic in the within-subjects tests of effects and contrasts.

Mauchly's Test of Sphericity[b]

Measure: SIZE

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PLACE	.996	.131	2	.937	.996	1.000	.500

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: PLACE

Assuming sphericity of data for measure of 'size', the within-subjects test of effects showed:

Tests of Within-Subjects Effects for the Within-Subjects factor: PLACE

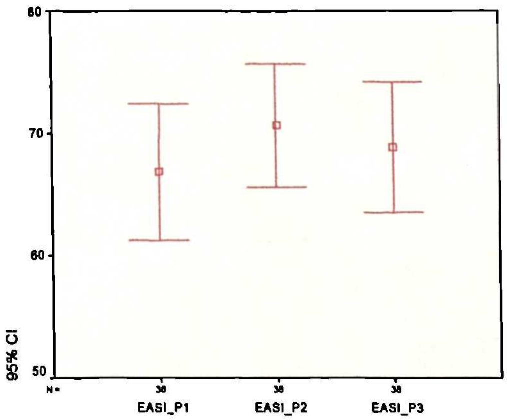
Measure: SIZE
Sphericity Assumed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	277.737	2	138.868	1.143	.324	2.287	.244

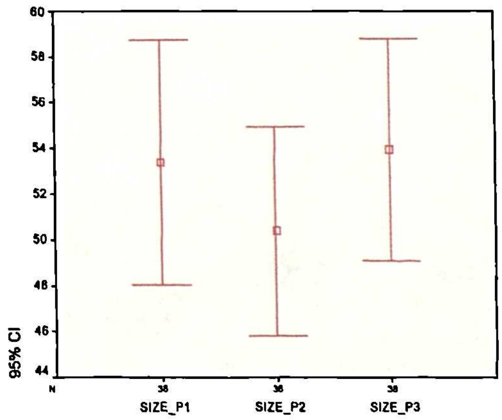
a. Computed using alpha = .05

The general linear model repeated measures ANOVA of the data indicated that the null hypothesis could not be rejected for both measures of the easiness of task execution and of the apparent size of place, as well. This thesis therefore, did not attempt to investigate the within-subjects contrasts or the descriptive statistics for these data. This result is also supported by the following error bar graphs of means for the two variables.

Error bar graph for the easiness variable



Error bar graph for the size variable



A.3.2 Observations

It became evident that some subjects (especially the ones with difficulty in navigation who rolled a lot) concentrated mainly on the task itself and ignored the enclosure. Three subjects found it difficult to answer the questions because of this. Similarly 3 others reported that they found little or no difference between the three places in terms of easiness or in terms of size, but reported no reason for this.

It is interesting to stress that in place3:

- According to the subjects' responses, the mean for the easiness of task execution in this place was the lower of the three places but
- The majority of subjects (17) felt positive about doing the task and moving around in this place.

It is also interesting to stress the contradiction in place1 between:

- The fact that the mean for the easiness of task execution in this place is the highest of the three while
- the majority of subjects (16) who expressed an opinion were negative about this place, due to its limiting shape.

In general the space of the places seemed to be a bit smaller than needed and this was displayed by the fact that many subjects felt the need to get an overall view from behind the threshold - which was transparent - before they entered the place. The shape and limited size of all places made at least half of the subjects to roll around a lot when moving within them.

1) With respect to place (1), subjects' reports on its size were rather contradictory. Only one subject thought that the larger size of the place made it easier for her to do the

task, although she was still bothered because she had to move through the numbers and she found this uncomfortable because the numbers felt like obstacles that you might crash into. This contradictory result is in agreement with the small significance of the F statistic for the apparent size of place, where place (1) has a slightly higher mean than the other two places.

Other 3 subjects also felt negative about moving in place (1) :

- Two of them felt confused and distracted because the shape of the place and the number of corners in this shape, were not clear
- one felt that it was harder to orientate in this place because the shape was not regular.

On the other hand, 5 subjects felt positive about this place:

- Two of them thought that the shape helped them in the task because it stood out more since the walls were angled
- Two others thought that it was easier to tell where the corners were, because of their oblique angles and this made the space easier to understand
- One of them felt that the stretched corners helped her to have a view from further and this was preferable; she also felt the implicit linear direction.

2) With respect to place (2), subjects seemed more neutral about this place; very few expressed an opinion but merely responded to what they were asked. The few who observed something gave contradictory observations:

- Three subjects thought that the shape of place 2 felt more constraining that the shape of the other two places; two of them attributed this to the lack of space in the circular path around the podium "a podium of this size needed a larger room to move in".
- Three other subjects felt positive about this space:
- one felt that the podium made the task easier,
- another felt that this was the most comfortable place, not too small, not too big

- another felt that his was the biggest place of the three.

3) With respect to place (3), although the sizes of the three places were the same, in this place it was objectively more difficult than in the other two places to move back into its corners in order to be able to observe all numbers at the same time. This is certainly displayed by the images of the places' interior views which are taken from corners of these places.

   It is therefore very interesting that

   - four subjects felt that they could not go back into the corners to view the numbers so this made the task more difficult and the space felt smaller but
   - five of them felt that it was a bit bigger.

   One also reported that it felt a higher space as well; this may be ought to the fact that the majority of forms in it are vertical.

   However, even if this place made it more difficult to view all numbers at the same time, 17 subjects felt positive about being in it:

   - Four subjects reported that the arrangement of the interior induced circular movement around the podium and for two of them this made the task feel easier.
   - Three subjects said that chamfered corners were guiding you around the space and help you out again; one explained this: "I want to move towards corners so the space makes me want to visit all corners and so it makes me want to move around; this is not difficult however". This could also be due to the fact that both the perimeter and the podium are round and so induce a stronger circular movement.
   - Six subjects felt that this place was certainly more comfortable because of the chamfered corners and the colour scheme; as a result they found it aesthetically preferable to the other two places: "it had a nicer ambience";
   - These chamfered corners were also favoured by other four subjects either because:

- The angle of the corners (because of the octagonal/rectangular shape) were more open than the corners of the other two spaces so one could not get lost in them and this made the task easier
- The bigger number of corners and surfaces and the richer colour scheme aided orientation

"This room felt smoother", probably because the bigger angle and more numerous corners make the transition between surfaces feel smoother. This concept of eliminating small angles in the corners of a place may be related to Tai Chi architectural principles.

- Another subject also found this place more interesting than the other two for exploration (as it is the most complex).

On the other hand, 9 subjects reported negative feelings about this place:

- Three of them reported that the shape of the space and the second colour on the walls made them feel distracted from the task and thus made the task a bit more difficult
- Two of them felt that the chamfered corners made the space feel awkward and disorientating
- Three - female - subjects reported that the colours and the walls confused them a bit
- One also reported that it felt trickier in this place and that more attention was needed when moving around.

These negative quotes, however, may have coincided with a sense of comfort or with liking the place as well.

Only one subject had a problem with the shape of the threshold; she thought that entering and exiting through a surface which is angled seems unnatural and makes you feel as though you are entering diagonally.

A.4 EXPERIMENT (4)

A.4.1 Statistical analysis - The variable of 'comfort'

The test of sphericity for the measure of 'comfort' showed that there was a need for the adjustment of degrees of freedom, with the use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: COMFORT

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PLACE	.571	20.043	5	.001	.718	.764	.333

a. Is used to adjust the degrees of freedom for the averaged tests of significance.

b. Design: Intercept
Within Subjects Design: PLACE

Accordingly, the tests of within-subjects effects for the Greenhouse-Geiser adjustment showed:

Tests of Within-Subjects Effects for the within-subjects factor: PLACE

Measure: COMFORT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Sphericity assumed	2709.763	3	903.254	2.211	.091	6.634	.548
Greenhouse - Geiser	2709.763	2	1257.996	2.21	.11		

a. Computed using alpha = .05

A repeated type test was performed in order to investigate the contrasts between place (1) - place (2), place (2) - place (3), place (3) - place (4).

Tests of Within-Subjects Contrasts

Measure: COMFORT

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	1592.526	1	1592.526	3.696	.062	3.696	.465
	PLACE_2	3335.158	1	3335.158	4.093	.050	4.093	.504
	PLACE_3	3720.421	1	3720.421	5.301	.027	5.301	.611
Error(PLACE)	PLACE_1	15941.474	37	430.851				
	PLACE_2	30150.842	37	814.888				
	PLACE_3	25967.579	37	701.826				

a. Computed using alpha = .05

A simple (first) type test was performed to investigate the contrast between place (1) - place (3) and place (1) - place (4).

Tests of Within-Subjects Contrastsfor within-subjects factor: PLACE - Simple (first) type of contrast

Measure: COMFORT

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	1592.526	1	1592.526	3.696	.062	3.696	.465
	PLACE_2	318.421	1	318.421	.558	.460	.558	.113
	PLACE_3	1862.000	1	1862.000	1.893	.177	1.893	.268
Error(PLACE)	PLACE_1	15941.474	37	430.851				
	PLACE_2	21119.579	37	570.799				
	PLACE_3	36386.000	37	983.405				

a. Computed using alpha = .05

A simple (last) type test was performed for investigating the contrast between: place (2) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Simple (last) type of contrast

Measure: COMFORT

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	1862.000	1	1862.000	1.893	.177	1.893	.268
	PLACE_2	10.526	1	10.526	.008	.931	.008	.051
	PLACE_3	3720.421	1	3720.421	5.301	.027	5.301	.611
Error(PLACE)	PLACE_1	36386.000	37	983.405				
	PLACE_2	51797.474	37	1399.932				
	PLACE_3	25967.579	37	701.826				

a. Computed using alpha = .05

A.4.2 Statistical analysis - The variable of 'easiness' of task execution

The test of sphericity for the measure of 'easiness' of task execution showed that there was no need for adjusting the degrees of freedom, by making use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: EASINESS

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PLACE	.743	10.312	5	.067	.825	.891	.333

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers (by default) of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: PLACE

Accordingly, the tests of within-subjects effects with the assumption of sphericity showed:

Tests of Within-Subjects Effects for the within-subjects factor: PLACE

Measure: EASINESS
Sphericity Assumed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	21.649	3	7.216	4.771	.004	14.313	.891

a. Computed using alpha = .05

A repeated type of test was performed in order to investigate the contrast between: place (1) - place (2), place (2) - place (3) and place (3) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Repeated type of contrast

Measure: EASINESS

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	3.892	1	3.892	1.590	.215	1.590	.233
	PLACE_2	6.081	1	6.081	2.519	.121	2.519	.339
	PLACE_3	35.027	1	35.027	15.573	.000	15.573	.970
Error(PLACE)	PLACE_1	88.108	36	2.447				
	PLACE_2	86.919	36	2.414				
	PLACE_3	80.973	36	2.249				

a. Computed using alpha = .05

A simple (first) type of test was performed in order to investigate the contrast between: place (1) - place (3) and place (1) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Simple (first) type of contrast

Measure: EASINESS

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	3.892	1	3.892	1.590	.215	1.590	.233
	PLACE_2	.243	1	.243	.087	.770	.087	.059
	PLACE_3	29.432	1	29.432	6.323	.017	6.323	.687
Error(PLACE)	PLACE_1	88.108	36	2.447				
	PLACE_2	100.757	36	2.799				
	PLACE_3	167.568	36	4.655				

a. Computed using alpha = .05

A simple (last) type of test was performed in order to investigate the contrast between: place (2) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Simple (last) type of contrast

Measure: EASINESS

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	29.432	1	29.432	6.323	.017	6.323	.687
	PLACE_2	11.919	1	11.919	3.324	.077	3.324	.427
	PLACE_3	35.027	1	35.027	15.573	.000	15.573	.970
Error(PLACE)	PLACE_1	167.568	36	4.655				
	PLACE_2	129.081	36	3.586				
	PLACE_3	80.973	36	2.249				

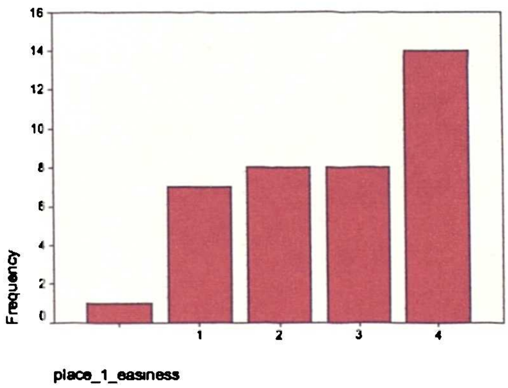
a. Computed using alpha = .05

It is interesting to study the tables of frequencies and the relevant bar charts for the variable of easiness of task execution, in terms of how many times did subjects consider each place easiest or most difficult.

place_1_easiness

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	2.6	2.6	2.6
	1	7	18.4	18.4	21.1
	2	8	21.1	21.1	42.1
	3	8	21.1	21.1	63.2
	4	14	36.8	36.8	100.0
	Total	38	100.0	100.0	
Total		38	100.0		

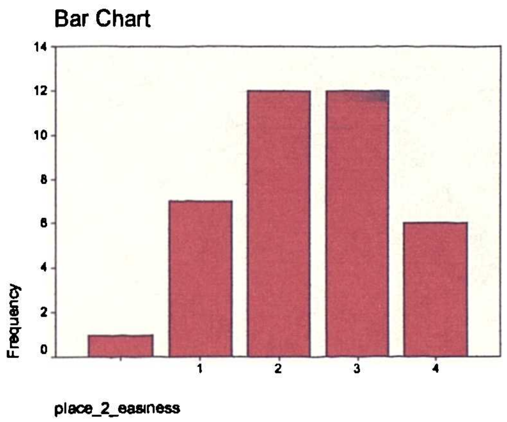
Bar Chart



In the less explicitly established place (1) a similar number of subjects positioned this place as 2nd, 3rd or 4th in the scale of 'easiness' of task execution but considerably more subjects thought that it was the 1st in the scale.

place_2_easiness

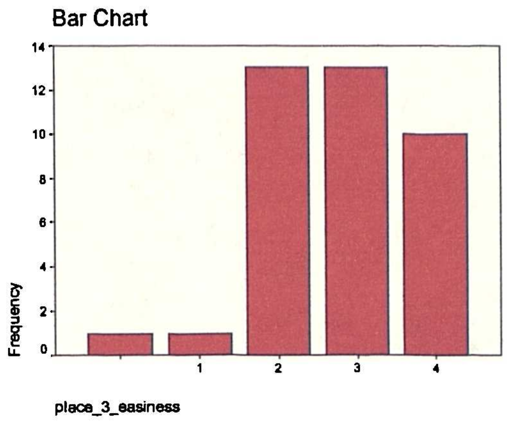
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	2.6	2.6	2.6
	1	7	18.4	18.4	21.1
	2	12	31.6	31.6	52.6
	3	12	31.6	31.6	84.2
	4	6	15.8	15.8	100.0
	Total	38	100.0	100.0	
Total		38	100.0		



In the slightly more explicitly established place (2), the same number of subjects postitioned this place in a intermediary 2nd or 3rd place in terms of easiness but considerably less thought that it was in an extreme 1st or 4th position; however a similar number of subjects thought that it was best or worst, which is a contradictory response.

place_3_easiness

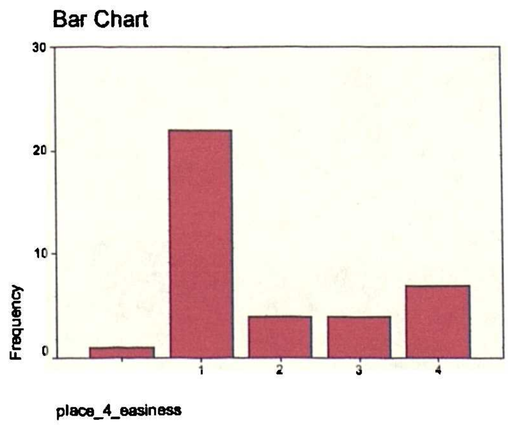
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	2.6	2.6	2.6
	1	1	2.6	2.6	5.3
	2	13	34.2	34.2	39.5
	3	13	34.2	34.2	73.7
	4	10	26.3	26.3	100.0
	Total	38	100.0	100.0	
Total		38	100.0		



In the case of the explicit but not completely enclosed place (3), most subjects positioned this at an intermediary 2nd or 3rd position, a few less at the 1st position and only one subject thought that was the worst one. This means that for the majority of subjects this was certainly not the most difficult place for executing the task.

place_4_easiness

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	2.6	2.6	2.6
	1	22	57.9	57.9	60.5
	2	4	10.5	10.5	71.1
	3	4	10.5	10.5	81.6
	4	7	18.4	18.4	100.0
	Total	38	100.0	100.0	
Total		38	100.0		



In place (4), most subjects (22) considered this to be the most difficult of all places and considerably less subjects thought that it was in the contrasting best position, while a similarly small number of subjects positioned it at an intermediary position (2nd or 3rd).

A.4.3 The variable of security

The test of sphericity for the measure of 'security' showed that there was a need for adjusting the degrees of freedom, by making use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: SECURITY

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PLACE	.528	22.788	5	.000	.693	.735	.333

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: PLACE

Accordingly, the tests of within-subjects effects for the Greenhouse-Geiser adjustment showed:

Tests of Within-Subjects Effects for the within-subjects factor: PLACE

Measure: SECURITY

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Sphericity assumed	16695.230	3	5565.077	16.633	.000	49.900	1.000
Greenhouse - Geiser	16695.230	2	8034.023	16.66	.00		

a. Computed using alpha = .05

A repeated type of test was performed in order to investigate the contrast between: place (1) - place (2), place (2) - place (3) and place (3) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Repeated type of contrast

Measure: SECURITY

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	404.632	1	404.632	.949	.336	.949	.158
	PLACE_2	9347.789	1	9347.789	15.786	.000	15.786	.972
	PLACE_3	4359.184	1	4359.184	10.950	.002	10.950	.897
Error(PLACE)	PLACE_1	15775.368	37	426.361				
	PLACE_2	21910.211	37	592.168				
	PLACE_3	14729.816	37	398.103				

a. Computed using alpha = .05

A simple (first) type of test was performed to investigate the contrasts between: place (1) - place (3) and place (1) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Simple (first) type of contrast

Measure: SECURITY

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	404.632	1	404.632	.949	.336	.949	.158
	PLACE_2	5862.737	1	5862.737	10.509	.003	10.509	.884
	PLACE_3	20332.658	1	20332.658	20.317	.000	20.317	.992
Error(PLACE)	PLACE_1	15775.368	37	426.361				
	PLACE_2	20641.263	37	557.872				
	PLACE_3	37028.342	37	1000.766				

a. Computed using alpha = .05

A simple (last) type test was performed in order to investigate the contrasts between: place (2) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Simple (last) type of contrast

Measure: SECURITY

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	20332.658	1	20332.658	20.317	.000	20.317	.992
	PLACE_2	26473.921	1	26473.921	25.466	.000	25.466	.998
	PLACE_3	4359.184	1	4359.184	10.950	.002	10.950	.897
Error(PLACE)	PLACE_1	37028.342	37	1000.766				
	PLACE_2	38465.079	37	1039.597				
	PLACE_3	14729.816	37	398.103				

a. Computed using alpha = .05

The test of sphericity for the measure of 'distraction' showed that there was a need for adjusting the degrees of freedom, by making use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: DISTRACT

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PLACE	.707	12 393	5	.030	.808	.868	.333

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers (by default) of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: PLACE

Accordingly, the tests of within-subjects effects for the Greenhouse-Geiser adjustment showed:

Tests of Within-Subjects Effects for the within-subjects factor: PLACE

Measure: DISTRACT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Sphericity assumed	33631.711	3	11210.570	18.681	.000	56.044	1.000
Greenhouse - Geiser	33631.711	2	13879.628	18.68	.00		

a. Computed using alpha = .05

A repeated type of test was performed to investigate the contrasts between: place (1) - place (2), place (2) - place (3) and place (3) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Repeated type of contrast

Measure: DISTRACT

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	132.658	1	132.658	.155	.696	.155	.067
	PLACE_2	2197.921	1	2197.921	2.170	.149	2.170	.300
	PLACE_3	32599.184	1	32599.184	31.146	.000	31.146	1.000
Error(PLACE)	PLACE_1	31682.342	37	856.280				
	PLACE_2	37471.079	37	1012.732				
	PLACE_3	38725.816	37	1046.644				

a. Computed using alpha = .05

A simple (first) type of test was performed to investigate the contrasts between: place (1) - place (3) and place (1) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Simple (first) type of contrast

Measure: DISTRACT

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	132.658	1	132.658	.155	.696	.155	.067
	PLACE_2	1250.632	1	1250.632	1.259	.269	1.259	.194
	PLACE_3	46620.026	1	46620.026	24.319	.000	24.319	.998
Error(PLACE)	PLACE_1	31682.342	37	856.280				
	PLACE_2	36743.368	37	993.064				
	PLACE_3	70930.974	37	1917.053				

a. Computed using alpha = .05

A simple (last) type of test was performed to investigate the contrasts between: place (2) - place (4).

Tests of Within-Subjects Contrasts for within-subjects factor: PLACE - Simple (last) type of contrast

Measure: DISTRACT

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	46620.026	1	46620.026	24.319	.000	24.319	.998
	PLACE_2	51726.421	1	51726.421	37.610	.000	37.610	1.000
	PLACE_3	32599.184	1	32599.184	31.146	.000	31.146	1.000
Error(PLACE)	PLACE_1	70930.974	37	1917.053				
	PLACE_2	50887.579	37	1375.340				
	PLACE_3	38725.816	37	1046.644				

a. Computed using alpha = .05

A.4.5 Observations during the experiment

A.4.5.1 Place (1)

Almost all of the 35 subjects moved out of the vary vaguely defined boundaries of this place. The three ones who did not move out had either not realised that they could or they were not confident enough to move around an open space, due to their low navigational skills. Four of the subjects who moved out got lost and disorientated, due to bad navigation skills again. Only 7 people went out so far away from the experimental domain and reached the grids area or the very limits of the VE.

One could then conclude that the cubes which were positioned so as to define the place by indicating its corners, were not successful at that. Indeed, less than a third of the subjects saw the cubes as clearly defining a place; the others either were not sure what the cubes defined or thought that they did not define a space at all; few subjects also did not see the cubes at all.) More precisely:

- 12 of the subjects saw the cubes as corners defining a place *"like the remnants of the previously seen rooms",* one of them did not directly perceive them but understood that something implicitly defined the corners of a place;
- 6 others saw them as defining a certain structure but were not sure what this structure stood for;
- 14 subjects saw the cubes but thought that they do not define any place but they are more like another object hanging in space: *"no definition of an inner space at all, the cubes were more objects than boundaries"*; only one of them simply related the cubes to the exit of the place.
- 6 subjects did not notice the cubes at all

Indeed 17 subjects reported that they felt positive about being free to move around space without the constraint of boundaries:

- For 10 of them this freedom made them feel comfortable: *"very comfortable because there was a lot of space to move around, it was interesting and it felt good being in the dome-like space; even though the space was expansive it felt secure because you were not confined"* or "total flexibility"
- Other 7 subjects reported positive feelings associated with this sense of freedom like: excitement, interest, willingness to explore the surroundings (adventure) or enjoyment: "good fun that there's nothing around you and yet you do not fall"; "felt good, like being in space". Three of them described the open space like an atrium (social space) a dome or a cathedral-like space rather than a room.

They also described the experience of navigating in this open space as "much *like being in a swimming pool, because of the sense of being suspended and because of the apparent slowness of movement*", or *"this is not like a room, more like coming into a mesh of floating objects, like swimming through a salmon fish farm"*

5 other subjects felt positive about the grids in the background because they provided a sense of orientation and direction in relation to the objects and the context; they were also helpful because they were penetrable.

On the other hand, on the basis of the statistical analysis, it can be argued that the majority of subjects felt very insecure and distracted by their surroundings, when being in place (1). In support of this suggestions, many (18) of the subjects reported negative feelings associated with insecurity or distraction, as a result of the existence of the cubes, the openness of space or the lack of boundaries.) More precisely:

- 6 subjects were aware of the cubes but were distracted by them, because they were trying to identify how they stood in the context;
- 3 subjects were very distracted by "too much happening in the background".
- 5 strongly influenced by gravity subjects were affected by the openness of the space and the lack of "floor" and felt vertigo or *"the fear of the open space"* or fear of height: *"when I came in place1 I could fall down"*; *"I would prefer the spheres to be*

closer to the bottom of the space"; one of them reported the lack of limits as lack of privacy as well.

- 4 subjects reported a feeling of lostness, which they attributed to the lack of clear limits: "*when facing away from the balls and the places you were lost*". This was not pleasant for them, but they still found place1 preferable to place2 on this aspect.

Only 1 subject reported that he was not distracted, because "there were no walls to be careful not to bash into" and another subject knew where the exit was and so felt secure enough to explore a bit.

A.4.5.2 Place (2)

Some (11) subjects reported positive feelings about the screen-like structure which defined this place:

- 9 subjects reported that the frame was giving a sense of place and a definition of *inside* and *outside* which improved the sense of comfort, it "*seemed like a smaller more manageable space*". They felt it was good that there was a place defined but at the same time you were free to move out of it. "*knowing that you can go beyond the frame was good; you feel that boundaries are not needed*" or "*most interesting like if you were floating but still in a defined place*".
- 2 felt that the frame was giving a sense of orientation.

However, 5 other subjects felt the need to orientate with the help of the place's surroundings, like the grids. Another subject felt that the grids gave a sense of place as a part of the whole and enhanced the sense of comfort "*they didn't distract me, they gave depth to what I was doing*". Only 1 subject reported that this place was the easiest to do the task in, because of the freedom of movement and the little distraction.

On the other hand, from the analysis of the results it can be argued that the majority of subjects felt mostly insecure and distracted by their surroundings in place (2). It has to be made clear though that more than one of the observations quoted here may have been made by the same subject. These observations were associated with the following aspect of place (2):

- 11 subjects felt negative about the lack of floor and boundaries in this place:
  - 5 of them found that the lack of floor or boundaries was difficult to get used to, distracting or insecure;
  - 3 of them reported a new and frightening experience because of the lack of boundaries and floor: *"felt like on a space platform, free, very open, a lot of depth"*.
  - 3 of them reported a shock or a disconcerting feel at the beginning but then they gradually felt more comfortable with it.

  They attributed these feelings to the fact that one enters from a simple space that has floors (central hall and paths) into this dynamic and complex place: *"from an austere corridor into a pretty busy and vibrant environment"* and one said *"you feel like falling"*. (Interestingly enough, most of these subjects did not report the same negative feelings for place1, or when they did they thought that place1 was preferable to place2.) 4 subjects who felt unpleasant because they could get lost in place1, still thought that place1 was preferable to place2 in this respect.
  - Only 2 subjects reported that they were not affected by the lack of floor and boundaries

- 17 subjects felt negative about the enclosing screen-like structure which defined the limits of this place:
  - 9 subjects felt that the frame generally distracted and disturbed them; *"the frame was coarsely standing out from every other object, it is very distinct whether seen from inside-out or from outside-in"* or *"place2 is less comfortable than place1 because the frame feels aggressive while the cubes felt softer"* or *"the space becomes more important than the task, more than in place1, because the space is more defined and the notional limits distract you; you make an effort to see them"*.

- 2 subjects felt that the frame was interfering with the objects and the task: "*it is a visual and functional obstruction*";
- 2 subjects thought that it was constraining them from orientating and moving about, another 1 that "*it felt like a cage*";
- 4 subjects either did not see the frame as defining a space or did not notice the frame at all and thought that the place's limits were the grids; one of them felt that the frame was not a defined space but something more like a sculpture. For all these subjects place2 was the first open space they experienced.

- 11 subjects felt negatively about the openness of the place and the complexity of the surroundings:
  - 3 felt too distracted by the grids and the adjacent place: "*I felt threatened by the ominous grids*"
  - 4 subjects felt they could get easily lost in this space; they were unsure where the limits of where they could go were (the grid or beyond) and they felt confused.
  - 1 felt vertigo.
  - 1 reported that they felt he "could have come out, forget about the task and go up and down".
  - 1 that the surroundings felt a bit confusing at the start

Finally, for 11 subjects this place was more distracting or uncomfortable than place (1), but not necessarily negative:

- 7 of them felt unreal in there: "*I entered an open box which was a defined space but I could come out of it as well and I had to understand that; it felt unreal, fascinating therefore distracting*"
- 2 of them this place was more distracting than place1 but in a pleasant way; "*you felt like wanting to go out and explore*"

- 2 of them felt distracted but this decreased as they got used to this environment. At the same time it felt an interesting place and in that it felt preferable to place4 which was secretive and enclosed.

A.4.5.3 Place (3)

More than half of the subjects (20) reported that they thought place (3) was comfortable and optimum:

- 12 of them thought that this was so because it combined:
    - the clearly defined enclosure by the frame and some boundaries that made you want to move within this place's limits and at the same time
    - the freedom to view and move outside the boundaries towards the further surroundings, which provided a greater sense of orientation.
- 6 subjects felt it was comfortable and helpful because of the boundaries acting as a reference (background) for the objects at all times. "*the wall helped one to concentrate more on the task*". One of them thought that the existence of boundaries makes the further surroundings seem more apparent and more three-dimensional - she compared local to global space and understood the global space better.
- 2 other subjects felt more comfortable because of the lack of overall enclosure; these had experienced place4 before and knew they would be constrained in a wholly enclosed place.

The existence of a floor was significant for 10 subjects:

- for 6 of them the floor made them feel definitely more secure and comfortable and they had realised that when they came out of the place and felt the lack of the floor. "*this place seemed more like a real space or like being on a high-rise building*" or "*the floor helped orientation of upright and horizontal and also gave a limit so you were aware of what was outside*".

- For 4 of them, however, the floor was making them feel less secure because they were more aware of the drop and this made them feel as if they could step off the edge, whereas in places 1,2 they knew they could fly as soon as they entered. One of them stressed the significance of gravity "*I felt I was going to fall off the edge if I went out of the floor*" and moved out of the boundaries only from the top of the place so that she still had the floor under her. Only one of them found the "fear of heights" induced when she approached the end of a floor as pleasantly exciting.

13 subjects reported a sense of distraction from their surroundings:

- 2 of them felt positively distracted, secure but interested and curious to go out and explore more of their surroundings. This could be attributed to a stronger sense of place here in which one feels secure and from which one feels ready to move out and "take possession of the environment" - in the words of Norberg-Schulz.
- 4 of them felt little distraction because of the further surroundings, but they reported that this was less than the distraction experienced in places 1 and 2, because in place3 the boundaries obstructed the view to the surroundings.
- 4 of them were distracted and bothered because of the boundaries:
    - 2 of them because they were conscious of their movement while trying to avoid the boundaries around her,
    - 2 others because of the contrast between the movement of the frame against the background grids when moving around the place, (felt the difference between local and global space all the time and this distracted them)
- 3 felt very distracted because of the many different kinds of elements around them.

Only one subject with very low navigation skills felt trapped in this space.

A.4.5.4 Place (4)

6 subjects described this place as being "*more like a private space-room*", or "*an everyday space*" and 3 subjects liked the structure of the place - frame and walls.

Most subjects, reported negative observations about this place. It is understood that some subjects have reported more than one of the following observations:

- 11 subjects felt restricted or confined by the boundaries of the place.
- 8 subjects felt uncomfortable and could not move where they wanted to because they felt there was not enough space between the objects and the boundaries to view the objects properly: "*the worst space, the hardest to navigate, tighter and could not go back to see the overall view; this sense of enclosure gave me a sense of uncomfortness* ". One of them wanted the space to have bigger height because she thought that the distance between objects and ceiling or floor was very small.
- 4 subjects thought that the space seemed smaller and the objects *bigger "because you view objects relative to the context you have to make much bigger effort to avoid them in this place than in other places*".
- 5 subjects felt a bit claustrophobic, and thought the place was secretive and enclosed; one of them said "*I would feel like caged in here*" or "*I felt I wanted to move out quickly*"
- 3 subjects felt bothered that they were not able to view the surroundings of the place.
- 3 subjects found difficulty with navigating and 2 subjects with performing the task in this place.
- 3 subjects felt that it was not an interesting place.
- 5 subjects felt distracted by the colours, walls, frame or by being aware of the walls and moving to avoid them; "*I was aware of the walls as physical barriers at all times*".

A.4.5.5 General observations

It is interesting to mention the behaviour of one of the subjects who was particularly confident when flying around and wanted to explore all of the VE. This subject seemed to enjoy experimenting with all possible ways of navigating in the open space and also to fly in ways that were defeating gravity and could definitely not be performed in the real world. When she 'stepped' on the ceiling of the central hall, she felt that it would be dangerous to fall down; this shows the prominence of gravity even if one is very much aware of the lack of danger and very confident with the navigational constraints of the VE. This may be attributed to the introduction of a real world-like situation - the ceiling of the hall is like the top of a building - within a context where no real world constraints are valid. This phenomenon may make even a very confident subject return to the mental state of having to act and protect herself, while taking into account gravity or other real-world characteristics - like g acceleration.

A.5 EXPERIMENT (5)

A.5.1 The variable of easiness of orientation

The test of sphericity for the measure of 'easiness' showed that there was a need for the adjustment of degrees of freedom, with the use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: EASINESS

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PLACE	.406	25.592	9	.002	.671	.743	.250

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: PLACE

Accordingly, the tests of within-subjects effects for the Greenhouse-Geiser adjustment showed:

Tests of Within-Subjects Effects for Within-Subjects factor: PLACE

Measure: EASINESS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
sphericity assumed	11732.155	4	2933.039	14.923	.000	59.694	1.000
Greenhouse -Geiser	11732.155	3	4370.172	14.92	.00		

a. Computed using alpha = .05

A repeated type of test was performed in order to investigate the contrasts between place (1) - place (2), place (2) - place (3), place (3) - place (4) and place (4) - place (5).

Tests of Within-Subjects Contrasts for factor:PLACE - Repeated type of contrast

Measure: EASINESS

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	3100.000	1	3100.000	4.654	.039	4.654	.551
	PLACE_2	21216.806	1	21216.806	48.322	.000	48.322	1.000
	PLACE_3	7401.323	1	7401.323	29.279	.000	29.279	.999
	PLACE_4	765.032	1	765.032	1.695	.203	1.695	.243
Error(PLACE)	PLACE_1	19984.000	30	666.133				
	PLACE_2	13172.194	30	439.073				
	PLACE_3	7583.677	30	252.789				
	PLACE_4	13538.968	30	451.299				

a. Computed using alpha = .05

A simple (first) type of test was performed to investigate the contrasts between place (1) - place (3), place (1) - place (4) and place (1) - place (5).

Tests of Within-Subjects Contrasts for factor:PLACE - Simple (first) type of contrast

Measure: EASINESS

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	3100.000	1	3100.000	4.654	.039	4.654	.551
	PLACE_2	8096.806	1	8096.806	28.944	.000	28.944	.999
	PLACE_3	15.613	1	15.613	.085	.772	.085	.059
	PLACE_4	562.065	1	562.065	1.193	.283	1.193	.185
Error(PLACE)	PLACE_1	19984.000	30	666.133				
	PLACE_2	8392.194	30	279.740				
	PLACE_3	5488.387	30	182.946				
	PLACE_4	14137.935	30	471.265				

a. Computed using alpha = .05

A simple (last) type of test was performed in order to investigate the contrasts between place (2) - place (5) and place (3) - place (5).

Tests of Within-Subjects Contrasts for factor:PLACE - Simple (last) type of contrast

Measure: EASINESS

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	562.065	1	562.065	1.193	.283	1.193	.185
	PLACE_2	1022.065	1	1022.065	2.774	.106	2.774	.364
	PLACE_3	12925.452	1	12925.452	56.844	.000	56.844	1.000
	PLACE_4	765.032	1	765.032	1.695	.203	1.695	.243
Error(PLACE)	PLACE_1	14137.935	30	471.265				
	PLACE_2	11051.935	30	368.398				
	PLACE_3	6821.548	30	227.385				
	PLACE_4	13538.968	30	451.299				

a. Computed using alpha = .05

A.5.2 The variable of time

The test of sphericity for the measure of 'time' showed that there was a need for the adjustment of degrees of freedom, with the use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: TIME

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PLACE	.478	20.965	9	.013	.789	.893	.250

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: PLACE

Accordingly, the within-subjects effects test for the Greenhouse-Geiser adjustment showed:

Tests of Within-Subjects Effects for the Within-Subjects factor: PLACE

Measure: TIME

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Sphericity assumed	2.4E+08	4	5.9E+07	6.668	.000	26.670	.991
Greehouse-Geiser	2.4E+08	3	7.5E+07	6.67	.00		

a. Computed using alpha = .05

A repeated type of test was performed in order to investigate the contrasts between place (1) - place (2), place (2) - place (3), place (3) - place (4) and place (4) - place (5).

Tests of Within-Subjects Contrasts for factor:PLACE - Repeated type of contrast

Measure: TIME

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	8.1E+07	1	8.1E+07	3.312	.079	3.312	.421
	PLACE_2	3.6E+08	1	3.6E+08	31.125	.000	31.125	1.000
	PLACE_3	1.7E+07	1	1.7E+07	2.063	.161	2.063	.285
	PLACE_4	4461213	1	4461213	.269	.608	.269	.079
Error(PLACE)	PLACE_1	7.3E+08	30	2.4E+07				
	PLACE_2	3.5E+08	30	1.2E+07				
	PLACE_3	2.4E+08	30	8044901				
	PLACE_4	5.0E+08	30	1.7E+07				

a. Computed using alpha = .05

A simple (first) type of test was performed in order to investigate the contrasts between place (1) - place (3), place (1) - place (4), place (1) - place (5).

Tests of Within-Subjects Contrasts for factor:PLACE - Simple (first) type of contrast

Measure: TIME

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	8.1E+07	1	8.1E+07	3.312	.079	3.312	.421
	PLACE_2	1.0E+08	1	1.0E+08	4.525	.042	4.525	.539
	PLACE_3	3.5E+07	1	3.5E+07	1.381	.249	1.381	.206
	PLACE_4	6.5E+07	1	6.5E+07	3.248	.082	3.248	.415
Error(PLACE)	PLACE_1	7.3E+08	30	2.4E+07				
	PLACE_2	6.6E+08	30	2.2E+07				
	PLACE_3	7.7E+08	30	2.6E+07				
	PLACE_4	6.0E+08	30	2.0E+07				

a. Computed using alpha = .05

A simple (last) type of test was performed in order to investigate the contrasts between place (2) - place (5) and place (3) - place (5).

Tests of Within-Subjects Contrasts for factor:PLACE - Simple (last) type of contrast

Measure: TIME

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PLACE	PLACE_1	6.5E+07	1	6.5E+07	3.248	.082	3.248	.415
	PLACE_2	2.9E+08	1	2.9E+08	13.568	.001	13.568	.946
	PLACE_3	3846658	1	3846658	.392	.536	.392	.093
	PLACE_4	4461213	1	4461213	.269	.608	.269	.079
Error(PLACE)	PLACE_1	6.0E+08	30	2.0E+07				
	PLACE_2	6.4E+08	30	2.1E+07				
	PLACE_3	2.9E+08	30	9821218				
	PLACE_4	5.0E+08	30	1.7E+07				

a. Computed using alpha = .05

A.5.3 Observations during the experiment

A.5.3.1 General observations

At least 9 subjects' observations are in support of the suggestion that subjects tended to position their viewpoints vertically to the larger surface of the place and to move around while maintaining this orientation:

- 2 subjects reported that it was essential for them to manage to position themselves on a vertical relation to an apparently horizontal plane on which they had to remain and pan around in order to compare the spheres, in all places.
- Another 5 subjects - in places (1), (4) and (5) - reported that *"it felt easier to comprehend and comfortable to look around a tilted or rolled space when being positioned vertical to its floor"*
- One reported that he felt like positioning himself vertical to the floor as we are more used to spaces like that in the real world.

- One reported that he felt like positioning himself vertical to the floor as we are more used to spaces like that in the real world. However:
- In places (2) and (5) which were not very tilted or rolled, he did not feel he needed to do so whereas
- In places (1) and (4) he which were rolled at a larger angle - degree of offness - he felt that being vertical was more convenient.
- On the other hand, one subject who kept the upright posture in place1 reported that when he turned around on a horizontal plane he faced the large floor and because this was very close to him he saw a totally blue display so there were no cues to orientate with and he felt lost. This is an explanation why subjects hesitated to pan, while considering the small surface as horizontal. Those who stood upright in this place tilted their viewpoint around the place.

A crucial factor which aided orientation in a place was the ability to view the structure and orientation of the place in relation to the path, from within the threshold before entering the place. Observations by 16 subjects supported this suggestion:

- 4 subjects reported that *"when you are able to understand how the place is positioned as you enter the threshold and before entering the place, then it becomes easier as in the places (1), (3), (4), (5) but in the case of place (2) the position of the place was not obvious so it was more difficult."*, or *"It is important to be able to see how the elements you are heading towards are structured before you enter the place defined by these elements"*.
- In place (1), one subject paused before the threshold, looked in and tried to orientate before entering;
- 3 other subjects felt that it was easier to see that place (1) was rolled 90^0 in relation to the path, before entering the place, and thought that this helped them position themselves in order to orientate in it;
- 5 subjects acknowledged that the fact that one could clearly see the positioning of place (4) and the boundaries that defined the place before entering, made things

easier for orientation in this place; one of them stopped before the threshold and tried to observe and orientate.

- 2 subjects found orientating in place (5) easy because *"you could see enough of the room as you entered to feel easily orientated with a little manoeuvre"*.
- 1 subject also reported that "*the easier that I understood the orientation of the place in relation to the path/threshold, before entering, the more I felt like positioning myself vertically to the floor; in place (1) that this was unclear I did not feel this need at all*"

Many subjects reported that it felt easier to come into a place from the path, as there were cues to orientate and 3 of these subjects suggested that it felt more difficult to enter the path from the place because there were not many clues to orientate with; only 3 subjects reported that it was easier to exit from the place into the path.
Some subjects (6) felt that it was significant for them to establish a relation with surfaces in the place that they saw as floor, ceiling and walls. Four of these subjects also reported that the colours of the surfaces affected the way that they orientated within the place:

- One subject reported a strong sense for establishing a relationship with a floor and walls in a room: *"I definitely thought of floors and walls; you can tell what is the floor and wall after experiencing these spaces 2-3 times by the colours of the surfaces being a wall or a floor"*
- Another one also reported that he recalled the colour of the floor from 2 places he had visited and he orientated in place1 by considering blue as the colour of the floor;
- Similarly another 1 also reported that he found it important that the colours of walls and floors are different for helping orientation.

Two subjects preferred to have a darker surface as a floor, but one of them contradicted himself and therefore there can be no valid suggestion for such a tendency:

- 1 subject rolled 180^0 to be vertical to the ceiling because he thought that *"the darker surface should be the floor and the lighter the ceiling"*; But then he reported the opposite for place (2): he felt more comfortable to have the light blue surface as floor and the dark surface as ceiling.

- One subject moved to vertical but upside-down, in place (4) because he clearly preferred to have the darker surface as floor and the lighter as ceiling - ground/sky analogy.

Finally, 3 subjects referred to the 'degree of offness' of a place in relation to a path that may have to do with the angle at which the place is rotated; so when a place is 'too off' it is difficult to orientate in it:

- One of them felt that place (4) was easier than place (1) because you needed less rotation to position yourself to vertical.
- One subject justified that he found orientating in place (4) difficult because it is -60^0 rolled and this angle was bigger than in places (2) or (5).
- Another subject reported that he felt like positioning himself vertical to the but:
- In places (2) and (5) which were not very tilted or rolled, he did not feel he needed to do so whereas
- In places (1) and (4) he which were rolled at a larger angle (degree of offness) he felt that being vertical was more convenient.

On the other hand one subject felt that when there is a slight shift orientating is problematic, whereas with a 90^0 or a 180^0 shift, it seems to be there for a reason.

A.5.3.2 Place (1)

It could be suggested that subjects who had experienced any of the other four places before place (1), were likely to have followed the above mentioned method of positioning their viewpoint vertical to the floor of the place in order to orientate and consequently proceeding to do the task. Having found this method successful towards accomplishing the task, they were likely to do the same in place (1) as well. Most of the subjects who did not experience place (1) first did so but at least 6 others did not follow this method in place (1) but kept parallel to the floor. With respect to the subjects who experienced place (1) first:

- 3 of them tried to be parallel to the floor and
- 5 others tried to be vertical.

It is not possible, therefore, to detect any effect of the order of presentation on the way that subjects positioned their viewpoints in place (1).

In general, subjects had few negative or positive feelings about this place. Only one reported that she enjoyed moving in and out of this place. Three others however felt negative about it:

- 1 of them felt that if he was to be vertical to the larger surface he would have to shift his viewpoint's coordinate system at a 90^0 angle and this felt too unnatural.
- 1 subject did not like the verticality of the place. He could not orientate the way this space was positioned because it felt too unnatural so he had to orientate vertically to the floor and then do the task.
- Another felt that this place was *"a bit more difficult because on trying to position her viewpoint to vertical she was not sure which way was up".*

A.5.3.3 Place (2)

Most subjects had negative feelings about experiencing and orientating in place (2):

- 11 subjects got completely lost or disorientated on entering this place. The way that the floor of the place was tilted at a 45^0 angle in relation to the path axis resulted in:
  - a lack of space for movement for the subject who entered through the threshold;
  - a shadow was cast upon the floor surface.

  Consequently, subjects entered this place and were immediately faced with a dark floor which was so close to their viewpoint that many of them got stuck on this surface immediately after they passed the threshold. This event was very confusing because the whole display seemed to be filled with the darkness of the floor material and there were no visible cues for where one could move next: *"very disorientating,* *I didn't understand at the beginning or after where the path was positioned in relation to the place".*

- Another 8 subjects felt negative about trying to orientate in this place for various reasons:
  - 2 subjects felt it was difficult and disorientating on the way in and on the way out of this place
  - one subject felt it was difficult on the way out but not on the way into this place
  - Another subject felt strange in it because the floor was tilted
  - Another subject felt upside/down most of the time; this could be due to the darker shaded colour of the floor which is the opposite of what happens with the floors in the other places.
  - 1 felt like sliding down when she saw the threshold and could compare the way it was positioned to the floor of the place.
  - 1 reported that she felt the walls were shorter in this place
  - 1 thought that the place was smaller and more difficult to manoeuvre around
- 2 subjects also reported that they thought that this was a new kind of environment - very different from others - that one could not anticipate from having experienced places (3) or (4) and felt much worst when trying to orientate in it.

A.5.3.4 Place (3)

All subjects who reported something about this place had positive feelings about it. In specific, 7 subjects found it the easiest of all for orientation:

- 2 of them attributed this fact to the straightforwardly positioned walls
- one of them due to the coordination of the entrance and the space to be entered
- another to the fact that *"it was very much clearer to determine where the limits of each element (path, threshold, place) were when I was entering the place but most importantly this structure was confirmed when inside the place and looking out at these elements".*

- another because he could see the whole space from the threshold of the entrance
- another *"because it was easier for the brain to define this as a space he felt that there was more space in place (3)".*

Finally one of them found it easy but thought that it was also the less interesting place.

A.5.3.5 Place (4)

4 subjects found it difficult to orientate, as they entered and the place was skewed;

- one of them felt better when he positioned his viewpoint vertical to the floor
- another felt totally disorientated on the way in and only realised her bearings when she viewed the threshold from one of the boundaries of the place: *"I did not know which was the floor and which was the ceiling and found it hard to orientate myself and to get out of the space".*

The majority of subjects felt they had to position their viewpoints vertically to the floor of the path on the way out:

- most of them (11) repositioned themselves at a vertical position to the floor of the path before they entered the threshold
- fewer (6) repositioned themselves to a global vertical position as they exited the threshold, after seeing the number or after passing through the number into the central hall.

A.5.3.6 Place (5)

Six subjects reported that it was more difficult to exit this place than to enter it. One subject explained the reason for this difficulty: *"It felt difficult and I was hesitant to adjust myself to the awkward angle that the threshold was tilted and rolled"*. Two other subjects thought that both entering and coming out were difficult.

The awkward angle and the accentuated perspective may also have lead 5 subjects to feel that the proportions of the place were different from the other places:

- To one subject it felt like a higher space and she reported that she felt more comfortable at the bottom of the plane (floor).
- To another the shape seemed different *"it felt lower and wider, I felt that there was more space to turn around, but the fact that it felt lower made it slightly more difficult"*;
- Another subject also thought that tilting made this place a bit harder to scan around to see where the spheres were;
- Another subject felt it was difficult to understand the perspective of the space from inside; he felt the space was smaller and limited when entering in the threshold but felt that the space was bigger when inside the place;
- To another subject the walls did not look flat neither did the exit.

A.6 EXPERIMENT (6)

A.6.1 The variable of easiness of orientation

The test of sphericity for the measure of 'easiness' showed that there was a need for the adjustment of degrees of freedom, with the use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: EASINESS

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PATH	.497	20.589	9	.015	.772	.867	.250

a. Is used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the layers of the Tests of Within Subjects Effects table.

b. Design: Intercept
Within Subjects Design: PATH

Accordingly, the tests of within-subjects effects for the Greenhouse-Geiser adjustment showed:

Tests of Within-Subjects Effects for Within-Subjects factor: PATH

Measure: EASINESS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Sphericity assumed	10523.162	4	2630.791	14.982	.000	59.928	1.000
Greenhouse - Geiser	10523.162	3	3406.658	14.98	.00		

a. Computed using alpha = .05

A repeated type of test was performed in order to investigate the contrasts between path (1) - path (2), path (2) - path (3), path (3) - path (4) and path (4) - path (5).

Tests of Within-Subjects Contrasts for factor: PATH: Repeated type of contrast test

Measure: EASINESS

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PATH	PATH_1	4704.500	1	4704.500	15.825	.000	15.825	.971
	PATH_2	19159.031	1	19159.031	36.708	.000	36.708	1.000
	PATH_3	3003.125	1	3003.125	8.028	.008	8.028	.784
	PATH_4	413.281	1	413.281	1.488	.232	1.488	.219
Error(PATH)	PATH_1	9215.500	31	297.274				
	PATH_2	16179.969	31	521.934				
	PATH_3	11596.875	31	374.093				
	PATH_4	8611.719	31	277.797				

a. Computed using alpha = .05

A simple (first) type of test was performed in order to investigate the contrasts between path (1) - path (3), path (1) - path (4) and path (1) - path (5).

Tests of Within-Subjects Contrasts for factor: PATH: Simple (first) type of contrast test

Measure: EASINESS

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PATH	PATH_1	4704.500	1	4704.500	15.825	.000	15.825	.971
	PATH_2	4875.781	1	4875.781	16.633	.000	16.633	.977
	PATH_3	225.781	1	225.781	.651	.426	.651	.122
	PATH_4	1250.000	1	1250.000	2.697	.111	2.697	.356
Error(PATH)	PATH_1	9215.500	31	297.274				
	PATH_2	9087.219	31	293.136				
	PATH_3	10757.219	31	347.007				
	PATH_4	14368.000	31	463.484				

a. Computed using alpha = .05

A simple (last) type of test was performed in order to investigate the contrasts between path (2) - path (5) and path (3) - path (5).

Tests of Within-Subjects Contrasts for factor: PATH: Simple (last) type of contrast test

Measure: EASINESS

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PATH	PATH_1	1250.000	1	1250.000	2.697	.111	2.697	.356
	PATH_2	10804.500	1	10804.500	25.279	.000	25.279	.998
	PATH_3	1188.281	1	1188.281	3.823	.060	3.823	.474
	PATH_4	413.281	1	413.281	1.488	.232	1.488	.219
Error(PATH)	PATH_1	14368.000	31	463.484				
	PATH_2	13249.500	31	427.403				
	PATH_3	9636.719	31	310.862				
	PATH_4	8611.719	31	277.797				

a. Computed using alpha = .05

A.6.2 The variable of time

The test of sphericity for the measure of 'time' showed that there was no need for the adjustment of degrees of freedom, with the use of the Greenhouse-Geiser epsilon value, in order to calculate the F statistic in the within-subjects tests of effects.

Mauchly's Test of Sphericity[b]

Measure: TIME

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
PATH	.632	13.028	9	.162	.836	.953	.250

a. Is used to adjust the degrees of freedom for the averaged tests of significance.

b. Design: Intercept
Within Subjects Design: PATH

Therefore, the tests of within-subjects effects, on the assumption of sphericity, showed that:

Tests of Within-Subjects Effects for Within-Subjects factor: PATH

Measure: TIME

Sphericity Assumed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PATH	5.0E+07	4	1.3E+07	4.956	.001	19.822	.955

a. Computed using alpha = .05

A repeated type of test was performed in order to investigate the contrasts between path (1) - path (2), path (2) - path (3), path (3) - path (4) and path (4) - path (5).

Tests of Within-Subjects Contrasts for factor: PATH: Repeated type of contrast test

Measure: TIME

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PATH	PATH_1	2.2E+07	1	2.2E+07	5.404	.027	5.404	.614
	PATH_2	5.9E+07	1	5.9E+07	12.288	.001	12.288	.924
	PATH_3	3.7E+07	1	3.7E+07	7.659	.010	7.659	.764
	PATH_4	3.9E+07	1	3.9E+07	9.429	.005	9.429	.844
Error(PATH)	PATH_1	1.2E+08	30	4122898				
	PATH_2	1.4E+08	30	4817876				
	PATH_3	1.4E+08	30	4772005				
	PATH_4	1.2E+08	30	4129053				

a. Computed using alpha = .05

A simple (first) type of test was performed in order to investigate the contrasts between: path (1) - path (3), path (1) - path (4) and path (1) - path (5).

Tests of Within-Subjects Contrasts for factor: PATH: Simple (first) type of contrast test

Measure: TIME

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PATH	PATH_1	2.2E+07	1	2.2E+07	5.404	.027	5.404	.614
	PATH_2	8846245	1	8846245	1.598	.216	1.598	.232
	PATH_3	9432581	1	9432581	1.314	.261	1.314	.199
	PATH_4	1.0E+07	1	1.0E+07	1.386	.248	1.386	.207
Error(PATH)	PATH_1	1.2E+08	30	4122898				
	PATH_2	1.7E+08	30	5536645				
	PATH_3	2.2E+08	30	7177781				
	PATH_4	2.2E+08	30	7242449				

a. Computed using alpha = .05

A simple (last) type of test was performed in order to investigate the contrasts between: path (2) - path (5) and path (3) - path (5).

Tests of Within-Subjects Contrasts for factor: PATH: Simple (last) type of contrast test

Measure: TIME

Source	Transformed Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PATH	PATH_1	1.0E+07	1	1.0E+07	1.386	.248	1.386	.207
	PATH_2	6.2E+07	1	6.2E+07	12.853	.001	12.853	.934
	PATH_3	37625.806	1	37625.806	.008	.931	.008	.051
	PATH_4	3.9E+07	1	3.9E+07	9.429	.005	9.429	.844
Error(PATH)	PATH_1	2.2E+08	30	7242449				
	PATH_2	1.5E+08	30	4841203				
	PATH_3	1.5E+08	30	4904346				
	PATH_4	1.2E+08	30	4129053				

a. Computed using alpha = .05

A.6.3 The variable of viewpoint orientation within each path

In the following tables:

- response (1) corresponds to the vertical axis y of the subject's viewpoint being perpendicular to one of the boundaries of the path

- response (2) corresponds to the vertical axis y of the viewpoint being diagonally positioned in relation to the rectangular section of the path
- response (3) corresponds to the viewpoint being randomly moved or rolled around
- response (4) corresponds to the vertical axis y of the viewpoint being aligned with the z axis of the path, like moving vertically in a lift.

	orientation in path 1 - out		orientation in path 1 - back	
	Count	%	Count	%
1	24	75.0%	28	87.5%
1/3			1	3.1%
2	2	6.3%	2	6.3%
3	5	15.6%	1	3.1%
4/1	1	3.1%		

	orientation in path 2 - out		orientation in path 2 - back	
	Count	%	Count	%
1	31	96.9%	27	84.4%
2			2	6.3%
2/1			1	3.1%
3	1	3.1%	2	6.3%

	orientation in path 3 - out		orientation in path 3 - back	
	Count	%	Count	%
1	17	53.1%	17	53.1%
1/2	1	3.1%	1	3.1%
2	7	21.9%	8	25.0%
2/1	4	12.5%	4	12.5%
3	3	9.4%	1	3.1%
4			1	3.1%

	orientation in path 4 - out		orientation in path 4 - back	
	Count	%	Count	%
1	10	31.3%	10	31.3%
1/2	2	6.3%		
2	11	34.4%	18	56.3%
2/1	6	18.8%	2	6.3%
3	3	9.4%	2	6.3%

	orientation in path 5 - out		orientation in path 5 - back	
	Count	%	Count	%
1	15	46.9%	20	62.5%
1/2	2	6.3%		
2	7	21.9%	5	15.6%
2/1			3	9.4%
3	1	3.1%	3	9.4%
4	5	15.6%	1	3.1%
4/1	2	6.3%		

A.6.4 Observations during the experiment

A.6.4.1 Strategies for navigating along paths

Subjects were encouraged to talk about whether they had employed a particular strategy for navigating and the most important of the strategies that they mentioned will be presented here. These strategies were not mutually exclusive but could have been combined by the same subject:

1) Considering a general strategy for orientation inside a path:

- 2 subjects reported that they found it *"much easier to align yourself at the beginning just after entering the path, orientate yourself and then move along the path."*

- Another subject reported however that *"when moving along you don't want to stop; you correct yourself as you move. It seems easier to steer as you are moving and not by stopping and correcting; it gives you a sense of momentum."* This behaviour may also be attributed to the fact that the path is long and narrow and subjects tend to want to move as quickly as possible within it to come out of it; they may feel a bit claustrophobic and certainly no subjects seemed to want to stay in the path longer than needed, in order to explore the space.

2) With respect to the way that the viewpoint was positioned within a path:

- Several subjects - at least 7 - preferred to position their viewpoints vertically to a boundary of a path. One subject described this: *"I felt a strong need to position myself vertically to one of the floors while moving along the paths; when I did not do it, it was because I did not manage to."* Another subject explained that he did not mind the way he entered but when inside the path it seemed easier to navigate, while his viewpoint was perpendicular to the frame of the path.
- Some of these subjects had to employ a different strategy for paths (3) and (4) which were rolled. Indeed two subjects reported that they tried to position themselves perpendicularly to the surface of paths but when the paths were skewed - rolled - it was more difficult to do that;
  - One of them responded by entering these paths diagonally and then repositioning himself vertically to what he saw as the floor of the path.
  - Another subject two subjects wanted to enter and move into path (3) vertically to a boundary but they felt they did not need to do so in path (4) so they moved diagonally to the section.
  - Another subject felt he wanted to be vertical to the floor of all paths positioned at right angles - (1), (2), (5) - but in the rolled paths he felt freer to twist around and not any inclination to be vertical to a floor.
  - Another subject felt that if the path was positioned upright - it was not rolled - she was expected to behave in a realistic way and to keep

perpendicular to the surfaces of the paths, whereas in the rolled paths where these conventions were broken she felt much freer about how she moved within space and she preferred that.

3) Some subjects seemed to change their strategy as they went through the experiment:

- On the absence or definite orientation cues on the way out in paths (3) and (4), subjects try to position their viewpoints vertically but on the way back, when the number and the central hall was visible to them, they seemed to position their viewpoints diagonally to the section of the path and aligned with the direction of the number.
- One of the subjects felt he had to be perpendicular to the floor of a path to orientate, as he entered a path. As he experienced more paths though, he understood that this was not important anymore, when you are inside the path so you may feel free to do otherwise. He reported that *"as I experienced the paths I developed strategies by understanding how I could utilise the information (cues) available in the environment (i.e. horizon) so the approach of orientating may have changed from path to path."*
- Another subject felt she wanted to be vertical to a floor when she first entered a path but when she went into paths (3) or (4) she realised that it did not matter and she felt more comfortable to move diagonally. When in a rolled path she did not feel the need to be vertical to a floor; all she wanted was to find a stable position - one that she maintained a certain orientation - and move along the path.
- Another subject felt she wanted to position her viewpoint vertically to a boundary of a path most of the time but when she saw a number, its verticality would prevail.
- Finally a subject said about his strategy: *"first I felt I wanted to position myself perpendicular but in path (2) I found that it was easier to spin around while moving through and to orientate myself at the end".*

4) Several subjects used the frame of their display screen and tried to align it with elements of the VE such as the target place or the frames of the path, in order to position their viewpoints when they navigated along the path.:

- One of them explained: *"To enter a path, I try to position myself (the viewpoint) at the centre of the entrance and to position the target at the centre of the screen as well. I do not mind moving through paths diagonally."*
- Another subject also did not mind whether she was diagonal or perpendicular inside the paths; she only tried to position the target of the path in the centre of the screen so that the frames of the path have equal distances from each other and then move along the path.
- On a similar vein, another subject reported that, as he entered each path, he tried to position his viewpoint so that the four sides of the path's square section were parallel to the rectangular frame of the display; he used the bottom right edge of the path as a guide and tried to position its beginning at the bottom right corner of the display and then to start moving along the path.
- Another subject employed the following strategy: *"the space at the end and the boundaries of the path defined the position of my viewpoint. I didn't feel any desire to be vertical to any surface, as if I was walking at all."*
- Finally a subject explained that she felt more comfortable when being vertical to the path's boundaries because she was seeing a square - section of the path - within a rectangular display screen; she therefore positioned herself like that whenever she could but did not bother much when it was easy to move diagonally.

5) Finally some subjects tried to keep their viewpoints vertical to a global horizontal orientation, most of the time in this VE.

- One of them reported that when entering a path he felt that it was important to keep a global vertical posture in relation to the central hall. One way of explaining this feeling is that: the central hall is the 'home'-starting point for this experiment and therefore its orientation may be influencing the way that a subject orientates in the other less central spaces of the VE. In path (4) however, the particular subject found it functionally better or less confusing to be vertical to the floor of the path. Another subject also thought that the clearly defined central hall implies a verticality which may induce a need to be vertical all the time.

- Another subject felt that when she entered a path she had to be vertical to the horizon but once inside the path she could adapt to the verticality of the path. Other subjects seemed to be influenced by the horizon when orientating as well. However, three subjects reported that they were confused by the horizon; this was because this element did not actually function as a horizon, because it was located quite far away but not far enough to be realistic: *"it looks like a horizon but it did not actually act like one".*

A very interesting observation, made by several subjects, revealed that they generally found the route 'on the way back' easier than the route 'on the way out', irrespective of the rotation applied to the path. One of them explained that: *"On the way out I can see only the path I'm in and so I just concentrate on that and move; on the way back it is much better for orientation in relation to your surroundings because of transparencies and the view to other paths and places."* Another subject found it more difficult to keep orientating on the way out due to the lack of cues to compare to while navigating; on the way back she kept vertical to a boundary of the path, because it was easier due to the available cues - i.e. number at the entrance of the path, central hall, other paths and places.

One subject described his sense of presence in this VE: *"you still feel you have your body with you".* Another subject felt that the way that his body was positioned as he was doing the experiment influenced the way he perceived the direction of the paths. More specifically, he was sitting on a chair and the display screen was positioned slightly to his left; he thought that path (3) was directed towards the left and he reported he subjectively would have preferred to enter it if it was directed towards his right and not his left.

Finally one subject reported that *"in the rolled paths you are more aware of the walls of the path whereas in path (2) - which is at 90^0 angles with the hall and the target place - you focus more on the target than the actual path and its boundaries".* On this basis, it could be suggested that in order to focus the subjects' attention on the target, this position is preferable, while if one wants to make subjects focus on the boundaries of the path then a rolled path may be preferable.

A.6.4.2 Path (1)

Three subjects entered diagonally and moved this way to the top but came down vertically to what they saw as the floor of this path. Another 2 subjects moved randomly to the top but found it easier to position their viewpoint vertically, on the way down. Finally one of the subjects tried to go up this path as in a lift and found this problematic, so before completing the route she repositioned her viewpoint to a vertical position to a boundary and did the same on the way down as well.

Some subjects reported that on the way down there were may elements that helped you orientate but on the way up there were very few cues for orientation. As a result:

- 2 subjects found it difficult to orientate on the way up, but easier on the way down one of them thought that going up felt like it needed more effort but going down felt much easier as if you were gliding down a slope.
- One subject felt that on the way down it seemed steeper and more difficult to orientate than on the way up and explained this by saying *"on the way up you cannot relate to many things whereas on the way down I can relate to several elements for orientation."*
- Another subject found that the number was an important cue.

Several subjects also reported that they found navigating along this path difficult because of the way that it was rotated.

- 3 subjects mentioned that they found it difficult and disorientating to enter this path from the hall and much easier once they got inside it, probably because the path was tilted
- 3 subjects reported that they found it very difficult to control and orientate themselves because the path was tilted.
- 3 other subjects reported that as they exited the path into the target place on the way up, they entered very close to the ceiling of the place and found the experience confusing.
- Another 2 subjects found it difficult to enter the path both from the hall and from the target/place.

Finally, only two subjects reported that they found orientating in this path very easy.

A.6.4.3 Path (2)

Subjects who reported something were generally positive about this path:

- 5 subjects reported that this path was easier than the others; one of them explained that he found this path *"a lot easier because it was as it would be in ordinary space and it was also aligned with the horizon all the way through".* Another found it a lot easier to hold his vertical posture when an enclosure is horizontally placed like this path.
- Another subject reported that he liked being in this path.
- One subject reported that she was relieved to move in this path after having experienced the other 4 paths; she also felt safe.
- Finally one subject *"corkscrewed"* his way through the path and out to the target place and enjoyed it a lot.

Only one subject reported that she felt stressed because this path was aligned to the target place and hall so she had to keep upright at all times, whereas in the other paths she felt less of a need to do so.

A.6.4.4 Path (3)

Seven subjects felt it was easier to position their viewpoint vertically to a boundary and move this way up and down the path; some of them tried to do so but could not manage. 3 of them repositioned themselves vertically to the floor of the central hall on approaching the number at the entrance of the path.

Almost one third of the subjects (10) were diagonal to section or moved randomly, on the way out but re-positioned their viewpoint vertically to a boundary on the way back:

- 3 subjects went up rolling randomly but came down vertical to a boundary.
- 2 subjects went up diagonally to the section and came down vertical to a boundary .
- 3 subjects positioned their viewpoint diagonally as they entered the path both from the hall and from the target place, but repositioned the viewpoint vertically to a boundary, after entering the path in both situations.
- 2 subjects entered diagonally - probably due to the number - and then repositioned their viewpoint to a vertical position both on the way out and on the way back; when they entered the hall they positioned their viewpoints vertically to the floor of the hall.

In support of the analysis of the results, this path was found to be most difficult to orientate into. Several subjects reported specific reasons for this:

- 11 subjects found this path much harder than the others because it is tilted and rolled; this makes entering the path from the hall or from the target place very difficult, because of the awkward angle you have to position your viewpoint at, in order to approach the path. 4 of these subjects found path (3) more difficult than path (4) for orientating or concentrating during navigation, because of the awkward angle of rotation: "*Starting a horizontal path is much easier*"

- 6 subjects thought that the awkward angle of rotation made the spatial relation of the path with the two places it joined problematic. As a result, it became difficult to enter from the path into the target place and to orientate, while inside this place as well. 3 of these subjects reported that they *"hit the ceiling"* as they entered the target place - because the path was tilted. 2 other subjects found it difficult to enter the path from within the target place and one found it difficult coming out to the hall as well.
- Another subject reported that the peculiar angle of rotation of the path made her feel she had to continuously adjust the axis of her viewpoint in relation to the path while moving and this was making the task more difficult.
- Finally two other subjects found moving around in the target place problematic and disorientating.

A.6.4.5 Path (4)

There were many subjects who shifted between a global vertical posture, and positioning their viewpoint vertical to a boundary:

- 3 subjects entered the path diagonally both from the hall and the target place and then while moving inside the path they re-orientated to a vertical position; one of them felt that doing this made it more difficult on the way back because he could see more elements being rolled while moving whereas on the way out he could only see the target place being rolled.
- 9 subjects moved vertically to a boundary, on the way out and diagonally on the way back. One of them reported that he did not feel he had to be vertical to a boundary on the way back but kept horizon as a reference and moved diagonally; others possibly felt like changing the coordinate system of their viewpoint to that of the number when they saw it. 3 of those subjects had entered the path diagonally from

the central hall, probably influenced by the number before they positioned their viewpoint vertically to a boundary.

- 3 subjects entered the path diagonally at the beginning - due to the number - and then re-orientated to a vertical position for the rest of the way out and on the way back; when they exited the path they positioned their viewpoint vertical to the floor of the hall.

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The subjects who were not influenced by such cues at all and mainly positioned their viewpoint vertically to a boundary of the path were few:

- 3 subjects shifted between a diagonal and vertical position on the way out - probably due to the lack of cues - and re-orientated to a vertical position on the way back.
- 2 others moved vertically to a boundary on the way out and on the way back; one of them turned his viewpoint to a diagonal position, as he approached the number and the other on exiting the path.

Finally one subject reported that it did not matter to him whether his viewpoint was vertical or diagonal while he was navigating the path; when exiting to the target place and the hall he oriented vertically to the floor.

Subjects had mixed feelings about the easiness of orientating in this path.

- One subject found entering the path from both places and moving through the path was quite easy because the frame was oblique and she was not concerned with the orientation of her viewpoint within the path; she thought she could spin.
- 2 subjects found it pleasant to roll around as they traversed the path but also found it harder, more distracting and disorientating.
- One subject felt that path (4) was easier to enter and exit than path (3), because it was not tilted; however, it was also a bit difficult because it was rolled.
- Another subject was not bothered by the rolling of the path.

- On the other hand, 3 subjects found it difficult to orientate in the path; one of them because it was rolled.
- Another subject found it confusing because she wanted to be vertical to the horizon as she entered and as this path was rolled she could not enter perpendicularly and still be vertical to the horizon.
- Another subject found this path most unpleasant and as difficult as path (3).
- Another 2 subjects found path (4) more difficult or disorientating than path (3) but this may be because they experienced path (4) first and then path (3).

A.6.4.6 Path (5)

A number of subjects (7) navigated towards the target place as if they were in a lift - the y axis of their viewpoint was aligned with the z axis of the path:

- A female subject went up like in lift and *"felt that going up was more enjoyable like being sucked in by a hoover"*; she felt like *"jumping from the target place"* so she moved down *"with the head down"* following the same posture. She enjoyed the whole experience.
- A male subject reported that he wanted to move upwards this way because he knew this path was vertical. He realised however that it would be more difficult to do the same on the way down and so he came down vertically to one of the boundaries.
- A female subject tried to come down the same way but half way down she realised that it was too difficult so she positioned her viewpoint to a vertical position and moved down the path, while rolling a bit. She felt it was difficult to move up as in a lift because she could not see the extends of the path's boundaries - since they are semi-transparent and she could not see one of the ends of the path- and so she did not know when she was approaching those boundaries and could not avoid getting stuck on them at times. She reported *"I felt I had to move up like that instinctively as a normal relation of my body to this space (she felt she had to keep a global vertical posture). I did not feel so much uncomfortable as I felt frustrated because I could not move the way I wanted."*

- A female subject entered like in a lift and then tilted her viewpoint to the diagonal position; on the way back she moved vertically to a boundary, possibly because of cues like the shape of the central hall or the entrance of the path.
- A female subject said that she found it difficult because she chose to go up as in a lift and on the way back, the number at the entrance of the path did not indicate any direction - as was the case in the other paths - and so she felt freer to roll. The number however helped her to focus on a target for movement.
- A female subject found it difficult to go up like in a lift and thought that if the path was much wider it might have been easier; she then tilted 90^0 and continued to navigate vertically to a boundary, since she found this much easier.
- A male subject mentioned that he intended to go up as in a lift but he thought he should not because he was afraid he would get stuck on the frames. After going up and down with his viewpoint vertical to a boundary, he tried to enter the path for a second time in order to go up as in a lift and thought that it did not seem so difficult.

Several subjects were physically or kinaesthetically influenced by the fact that they navigated along a path which was vertically positioned.

- 4 subjects found it physically difficult or disorientating to move along the path because it was positioned vertically. One of them reported that his *"body alignment to the world had changed in this path and this made it more difficult"*; another reported that she *"felt it was hard to move through this path because she felt strongly she was moving upwards and this probably affected her performance"*.
- 5 others reported that they clearly felt like *"going up"* or *"falling"* while moving through the path.
  - One of them enjoyed *"going up"* and
  - another thought that the feeling of *"going up"* was confusing because she knew she was going upwards but she was moving like in the other paths and there were not enough cues to suggest upwards movement. Going down is easier though because there are more cues: *"I think more in terms of "going along" than "going down""*

- another subject thought that *"on the way back it felt more exciting and very different as you knew you were falling and you could see the top of the number approaching"*.

Some others (8) also found it difficult to orientate when they exited the path and entered the target place.

- Two of them were confused and disorientated when coming in the target place, because it was orientated vertically to the hall and therefore differently positioned than the other places.
- Three others felt disorientated or confused when they were inside the target place because:
  - it was difficult and disorientating to rotate their viewpoint in there or since
  - the place is vertically positioned the opaque floor and ceiling become walls and since all walls in the other places are transparent one of the subjects became confused and reported that "*some walls are transparent and some are not*".
- Three other subjects felt they had to understand how the target place was positioned and to orientate vertically to the floor of this place, when they entered it, in order to be able to re-enter the path.

With respect to whether it was easier for subjects to move up or down this path:

- Two subjects found it easier to move up towards the target place and more difficult towards the hall;
- Two others thought that it was easier to move down the path and difficult to move upwards to the target place because *"on the way up you were loosing sight of other clues that might have helped for orientation"*.