UNIVERSITY OF LONDON

THE EFFECT OF THE THREE-DIMENSIONAL SCALE ON THE INTELLIGIBILITY OF THE CITY

A DISSERTATION SUBMITTED TO
THE FACULTY OF THE BUILT ENVIRONMENT
UNIVERSITY COLLEGE LONDON
IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
DEPARTMENT OF ARCHITECTURE

BY

MAGDALINI MAVRIDOU

LONDON

DECEMBER 2011

To my daughter

Abstract

This thesis attempts to investigate the issue of three-dimensional scale of the urban environment through an urban, spatial and cognitive approach. The research question of the thesis is whether the three-dimensional scale can affect the intelligibility of the city. Three-dimensional scale in this thesis is differentiated from the classical concepts of scale used in architecture, urban design and geography and a new definition of scale, called cityscape scale, is introduced. Cityscape scale is defined as the relation of space and form as this is perceived by the moving human mind in an urban environment.

The intelligibility of the built environment is defined as a combination of the spatial intelligibility developed by space syntax and of Lynch's legibility. This means that the three-dimensional scale as a relation of space and form is considered as an important visual element of the city but at the same time, since space is included in this relation, spatial intelligibility is equally important. Consequently, the type of intelligibility which is in the interest of this thesis is not simply an attribute of the built environment but it also involves how the built environment is perceived by people moving in it and how it is comprehended by them.

In order to investigate the research question two virtual experiments have been set up testing, the first, how differences of the three-dimensional scale affect the perception of urban environmental properties and, the second, how it affects navigation and wayfinding. The findings point towards important effects of the three-dimensional scale on the visual legibility of the built environment, and not only the legibility of scale, but it seems that these do not affect navigation as the main factor that affects navigation remains the spatial layout.

Contents

Acknowledgments

I would like first and most of all to express my gratitude to my supervisor Professor Ruth Conroy Dalton for her continuous and restless support, for her valuable guidance and her talented competency of problem solving. My gratitude goes also to my second supervisor Professor Bill Hillier for the instructive conversations and feedback at crucial steps of the research.

Dr Christoph Hoelscher is also thankfully acknowledged who has been as a third supervisor to me especially regarding cognitive issues and during my visit in The Centre for Cognitive Science in Freiburg, Germany when my second experiment took place. His feedback, guidance and support have been important elements for the completion of the thesis.

I would also like to thank my sponsors, the Greek Scholarships Foundation (IKY) for offering a three years scholarship and the German Research Foundation, specifically the Transregional Collaborative Research Center SFB/TR 8 "Spatial Cognition", which has funded my four months stay at the Centre for Cognitive Science in Freiburg as Guest Researcher and the conduct of the second experiment.

There are people at the Bartlett School of Graduate Studies in UCL who have helped throughout all these years and are specially acknowledged. Chiron Mottram is gratefully acknowledged for his unconditional assistance and patience with the conduct of the first virtual experiment and with the provision of Candle software in both experiments. Shinichi Iida is thanked for his support with many technical issues regarding UCL software. Finally, the late Alasdair Turner for his help with Depthmap software issues, for his valuable feedback during my seminars and conferences presentations and most of all for his support and faith in me.

For the second virtual experiment that was conducted in Freiburg, Germany, I am much indebted, besides Dr Christoph Hoelscher, to Dr Simon Buechner and Martin Broesamle for their willingness to offer advice and assistance, for sharing their knowledge, for giving valuable feedback and for actually helping in the conduct of the experiment. I am also especially grateful to the late Christopher Kalff for his kindness and assistance both with the experiment and with the data analysis. Finally, acknowledgments are expressed to Ralfo Bakola who helped with the design of the second experiment's 3d models.

I want also to express that I feel fortunate for being during my studies part of "Space Syntax Ltd", that gave me the chance to gain valuable practice experience, to obtain through practice useful insights for my research and to take my mind off the academic work at times that it was necessary. I express my gratitude to the people working there for putting up with my academic demands especially regarding the time schedule and also for being valuable friends and partners. Special thanks are ought to Jorge Gil for helping with Mapinfo program problems.

Finally, I feel debt of gratitude, because their support contributed to this thesis in more personal ways, to many friends. Dr Ben Croxford for his intellectual help and emotional support and for his constructive critique of the first stages of this text. My closest friends during the London years: Claudia, Sam, Dora, Thomas, Anisha, Patrick, Wafa, Yiannis and Anna for filling up nicely the energy batteries at no-work times. Wafa especially for helping with UCL formalities at a crucial moment. I finally wish to express gratitude to the two close friends in Greece, Evie Kirana and Prof. Dimitris Hatzichristou who acted as the link with the academic world when I was back in Greece and supporting and motivating me at a very difficult stage of the thesis writing.

I am especially grateful to my family for always being at my side and supporting every single decision of mine.

Finally, to Grigoris for his love.

List of Illustrations

List of Tables

Chapter 1 Introduction

Could the three-dimensional scale have an effect on the intelligibility of the city?

Scale in architecture and urban design

This thesis is trying to investigate the issue of the three-dimensional scale of the built environment as an urban design and spatial cognition problem. It attempts to question whether the three-dimensional scale of the city should derive not just from policies at the level of densities and environmental decisions but also whether it should be considered based on the effect it has on people's understanding of the city and use of space. There is a necessity to understand the interaction of the three-dimensional scale of the built environment with the people moving in it. The starting point of this research is the attempt to understand the three-dimensional scale as an urban problem, a perception problem and a spatial cognition problem at the same time.

The built environment around us consists of different three-dimensional scales, from big metropolises to small villages. There are places with different scales, like traditional villages with a small, cosy scale or big metropolitan cities with the imposing scale of the skyscrapers. In contemporary urban design the scale of a place is mainly considered as the outcome of policies and economic or environmental procedures. In the past and present, it has always been the contingent outcome of technology and of the properties of materials. In most planning decisions, the guidelines for building heights or width of streets are based on desirable population densities, land use and the minimal dimensions for ventilation and the exposure of streets to the sun.

High population density has led to the creation of high-rise buildings in big metropolises and low density has kept a small scale in villages. Issues of aesthetic quality play an important role in many cases, especially regarding the preservation of small, traditional scales. On the other hand, there are cases, like London, where although the population was increasing, the preference for low density development has led to a medium scale which is unusual for a metropolitan city.

In London again, for example, the issue of the three-dimensional image of the centre of the city has been approached by taking an extra factor into account. Within the last few years there have been discussions on the London skyline. Major developments that have been taking place in the centre of the city all these years, have respected the “view corridors” which were established to protect the view of Saint Paul’s cathedral. High density and high rise development took place in specific areas which were outside the view corridors. However, in the last few years the need for more built space in the centre of the city has led to the construction of high rise buildings. The discussion still focuses on issues like view restrictions or aesthetic quality but it now seems that environmental sustainability of these buildings and of the urban environment around them is most important.

On the other side of the prevailing policies, in the cases that scale has been taken into account discursively and consciously in planning decisions, concepts like “human scale”, “in or out of scale”, “harmonious scale” and “scale in context” are often mentioned. These terms refer both to the urban three-dimensional scale of buildings, the relation of dimensions of public spaces or squares, the relation of building heights to street width and so on but also to the architectural three-dimensional scale which refers to the form properties of buildings, the relation of the parts to the whole, the relation of buildings elements to the whole façade, the relation of the size of a building to the size of the adjacent one and many more. The approach is mainly aesthetical and it has rarely been investigated how people respond to scale properties not only aesthetically but cognitively as well or whether concepts like “human scale” or “scale in context” have a cognitive effect beyond the affectionate one.

Research questions of this study

In this general context a few research questions have been formed. Does the three dimensional scale of the built environment affect the intelligibility of the city? Does it affect the way people use the city and move in the city? Does scale affect movement and path choice in an urban environment? Is there a specific scale of the cities that would make people’s navigation in the built environment easier? Would this be more view of the sky? Would it be same building heights? Would it be the use of scale as a landmark by creating distinctive elements by manipulating their scale properties?

The starting point of this research is the attempt to understand scale as an urban and cognitive problem. The main research question is whether the three dimensional scale affect the intelligibility of the city. The interest is in the interaction of the three-dimensional scale of the built environment with people moving and living in it. A theory that investigates into the interaction between people moving in a city and the built environment is space syntax (Hillier & Hanson, 1984). Space syntax particularly examines the interaction of space with people moving in it by approaching this interaction as an urban and cognitive problem. Therefore, the investigation of the interaction of the urban three-dimensional scale to people moving in the urban environment will step on the trails of space syntax.

Space syntax is a theory and a set of methodological analytical tools that study the urban network systems which has been originated in University College London by Hillier and Hanson (Hillier & Hanson, 1984). The theory is based on cognitive grounds and therefore the spatial analysis, that it introduces, sheds light into navigation and wayfinding problems (Kim, 2001; Penn, 2003; Conroy Dalton, 2005; Hoelscher and Broesamle, 2007; Broesamle, Mavridou and Hoelscher, 2009). The space syntax tools, which take into consideration only the two-dimensional spatial layout, as on a plan representation, can reveal existing patterns of pedestrian movement or predict patterns of pedestrian movement in design proposals (Hillier, et al., 1993; Karimi, et al., 2007).

In this way, the theory can argue on the effect that the spatial configuration has on pedestrian movement. It advocates that the main factor that affects the way people move and navigate in cities is the relations of spaces as these emerge in the urban network (Hillier et al., 1993). Although space syntax theory has managed to account for many successful studies and real life projects regarding the spatial analysis of urban networks and the facilitation of navigation in cities (Karimi et al., 2005; Karimi et al., 2007), the fact is that the third dimension is a missing part of its approach.

Space syntax is a useful platform for the quest of this thesis since the interest is on the way people navigate in cities. The experience gained from the two-dimensional spatial analysis can be used as a starting point to expand the research to the third dimension and relate it to scale. Therefore in the experiments that will be conducted for this thesis, space syntax's ideas and concepts will play a crucial role.

The second issue regarding the research question that needs to be clarified is the concept of intelligibility. The word intelligibility, as it stands, has been first used by space syntax in Hillier's book "Space is the Machine" (Hillier, 1996). Intelligibility is defined as the attribute of a network or a system to give enough and useful information at the local level from which one can create the global image. This means that if someone is aware of the small pieces and the information given is good then one can put the pieces together and grasp the whole part. This means that the knowledge of small areas or streets as one moves around in a city, can help the creation of the global map of the city. What is important for space syntax is that "good" information that is necessary to put the pieces together is only the syntactic information which refers to the street connections and spatial relations.

Intelligibility is then measured as a correlation of the connectivity, which is a local property, to integration, which is a global property (Hillier & Hanson, 1984). The better the correlation of connectivity to integration the more intelligible the system or the city is. The more intelligible the city is, the easier it is for pedestrians to navigate and find their way in it.

However, the origins of the concept intelligibility are found further back to Kevin Lynch's book "The image of the city" (Lynch, 1960). Lynch had first used the term legibility and imageability to define the attribute of a city to have such a visual quality that "its parts can be recognised and can be organised into a coherent pattern" (Lynch, 1960, p.9). The term is similar to this of space syntax although space syntax considers that the important information to create the "whole image" is spatio-structural and Lynch considers it is visual and cognitive. He differentiates though five specific urban elements: paths, edges, districts, nodes and landmarks. The buildings belong to the element "edges", as they create a boundary according to Lynch.

The way that the term intelligibility is used in the current research is a combination of both Lynch's definition and space syntax's syntactic approach. What is common with Lynch's approach is the importance that the visual image of the city, as three-dimensional scale in this case, has in the intelligibility of the city and in navigation and wayfinding. What is different from Lynch's approach is that by assigning buildings in his "edges" category it is believed that he puts emphasis only the boundary and in this way he creates a duality between space and form by differentiating the two elements. In this thesis space and form will be approached together as the elements of the three-dimensional scale of the city which creates the three-dimensional image of the city that is considered as an important visual quality.

Another issue that is different from Lynch's approach is regarding the people's level of acquaintance with the city. In Lynch's work a city's imageability was constructed through extended experience, through the everyday interaction between the city and the people living in it. On the other hand, space syntax's definition of intelligibility is not involving the user's experience of the city, it is considered to be totally depended on the properties of the city and not on the level of familiarity of the people with the city. In the current thesis, the experiments are involving people who are first time users of the urban environments where they are navigating. The user's experience of an environment in relation to the intelligibility of this environment is an issue that needs special attention and to be further studied however, for the current thesis intelligibility will be approached through the user who is not familiar with the urban environment.

The fact that the relation of space and form is considered an important visual element of the city doesn't mean that characteristics of space like its syntactic intelligibility are left out. The importance of the spatial network and its effect on navigation and wayfinding is considered a strong element that will be tested in combination to the three-dimensional image. Space syntax's intelligibility and other properties are tested opposite scale qualities in both experiments that have been conducted for this study (Chapters 4, 5 and 6).

However, the term intelligibility as it appears in the research question and is developed in the thesis combines two more characteristics of space syntax's and Lynch's terms. Space syntax is defining intelligibility as an attribute of the built environment which although it has cognitive grounds it remains an environmental attribute. Lynch's term involves the human more actively, his imageability is an attribute of the environment but the way that this attribute is perceived and communicated with people is also important as it plays a role in the imageability. This thesis' intelligibility is a dual process involving both the environment and the human. It is about how people read and understand the environment which has to do both with attributes of the environment but also with how people read and understand these attributes. It is considered equally important whether the people perceive the system as intelligible or comprehensible based both on its image and its spatial qualities. This comprehensibility of the environment can be mainly measured by questionnaires. The outcome is expected to be a feedback on the way that space and form are related to create an intelligible world and on the way that this three-dimensional world interacts with people.

The three-dimensional scale which is considered both as a visual and spatial quality will be named cityscape scale in this thesis. Cityscape scale will be defined as a relation of form to space. Cityscape scale intends to describe the complex relation of what a human mind perceives when walking down a street which is a combination of architectural forms juxtaposed in a specific formal configuration which creates the urban form and the space that surrounds the urban form. It is suggested that the urban form is much more than the sum of its constituent architectural parts; it is a relation of these parts to the space they create. Therefore, the perception of scale of the urban environment is not simply the perception of the architectural forms, of the objects, that this environment consists of. Perception of the cityscape scale is actually the perception of the relations of forms and space created among these forms. This relation will not be approached through a map, a plan or a section representation but through an image representation. This is the image as it appears in front of the walking observer. The only way to study such a representation, if not in real life, is through images-pictures depicting a three dimensional static world or, if interested in non-static representations, then it is only through movies or virtual environments.

Outline of the study

Chapter 2 of this research introduces an investigation of the concept of scale in the existing literature and research. Three approaches are identified, the first looks into “formal scale” which examines scale as an attribute of form, the second one is “experiential scale” which investigates how scale is experienced through the studies of perception and spatial cognition and the last one is “configurational” scale which is scale as defined in this research. The current definition of scale introduces the cityscape scale, which is scale as a relation of form to space in an urban environment. Scale as such a relation is also approached as a missing element in space syntax theory looking into the relations of space and how these affect the way people move in the cities.

The investigation into the research question will be approached with the simulation of real life navigation and wayfinding in virtual environment experiments. This means that the effect of the three dimensional scale on the way people move and navigate in cities will be tested in controlled and easy manageable virtual environments. The use of virtual environments raises criticism and questions therefore Chapter 3 is examining the use of virtual environments as a scientific methodology and more specifically as a methodology for the studies of issues related to the built environment and to spatial cognition and perception. The advantages and disadvantages of such a methodology will be investigated and special attention will be given to the main argument against the conduct of virtual experiments which is the transferability of results in real life.

The two virtual experiments are presented in the next chapters. In Chapter 4, the first virtual experiment is described that took place in an immersive virtual environment where participants had to navigate in two groups of six small urban environments each, with the same layout within each group but with different three-dimensional scale properties. The first environment was with same buiding heights, the second with different heights, the third was double scale of the first, the fourth double scale of the second, the fifth was like the first but with doors and windows and the sixth like the second with doors and windows added. One group had an intelligible layout and the other a non-intelligible one according to the space syntax definition (Hillier, 1996). The term intelligibility as it is defined in space syntax is included in this investigation as it is tested opposed to the navigation performance of the participants and to their perception of environmental properties which may be affected by the three-dimensional differences. Space syntax's intelligibility is an attribute of the layout which remains constant no matter how the three-dimensional image of the environment changes. The experiment questions whether the three-dimensional scale affects the space syntax's idea that intelligible environments are easier to navigate than non-intelligible ones. Also, it investigates whether the three-dimensional visual differences of the environments are making an environment more comprehensible and more navigable according to the participants' perception.

Chapter 4 continues with the qualitative analysis of participants' comments regarding the differences of the environments and how these differences affect their sense of navigation or their perception of the built environment's differences. The findings of this analysis have pointed towards important aspects of the perception of the three-dimensional scale in an urban environment. The main finding is that the changes of the three-dimensional scale properties are affecting the perception of properties of space. In other words, the changes of the properties of form are affecting the perception of properties of space which stay unaltered.

Based on the findings of this first experiment, a second one has been set up which is described in Chapter 5. This experiment was also testing navigation and wayfinding skills in virtual environments with the same layout but different three-dimensional properties. A syntactic property of the urban layout was also used in this case for the design of the environment. This is the syntactic hierarchy of streets. According to the space syntax theory the representation of an urban layout, called axial map, rates axes corresponding to whole streets or parts of streets according to their value of integration in the urban system (Hillier & Hanson, 1984). This value of integration has been found to be correlated to the pedestrian movement that an axis attracts. Higher integration means higher volume of pedestrian movement therefore higher population densities and finally in order to accommodate the higher population densities, higher buildings.

When studying many cities' axial maps it becomes clear that many of the main or high streets of these cities are the most integrated (Hillier, et al., 1993; Karimi, Mavridou and Armstrong, 2005; Karimi et al., 2007). In many cases these axes also host higher buildings. Therefore the second experiment is based on this assumption. Four environments with exactly the same layout and four different scale properties were designed. The first had all buildings with low heights varying between 6-8m, the second with bigger heights varying between 12-16m, the third with heights correlated to the integration of the street on which they were found and the fourth with heights inversely correlated to the streets on which they were found. The participants had to complete navigation, wayfinding and direction tasks and their performance was rated with relevant measures.

Chapter 6 presents the analysis and the findings of the previous experiment. The analysis is both quantitative and qualitative based on the replies of a questionnaire. The findings point to the direction that scale differences cannot be related to navigation, wayfinding and direction performance of the participants but can be related to the micro-behaviour of path choices. What becomes apparent from this analysis is that integration plays the main role in path choice with correlatedness, having building heights correlated to integration, coming second. This finding reinforces the idea of established schemata which in the specific case justifies the environment with the heights correlated to the integration of the streets. Participants seem to find this environment easier to navigate and also their tendency to error was smaller.

The final two chapters, 7 and 8, present a discussion and the conclusions respectively. The discussion in Chapter 7 brings into light the findings of both experiments and discusses the issues that they raise. Also, the methodology is discussed in the same chapter taking into account issues that have been raised in the experiments. Chapter 8 presents the implications of the findings on design, the improvements that can be done if the experiments are replicated and the possible direction of future research.

At the next chapter the concept of scale as it is found in the existing literature and research is presented.

Chapter 2

Scale in the studies of space and form

Abstract

This chapter looks into the notion of scale as it can be found in the existing literature. The notion is examined through studies of the built environment, visual perception and spatial cognition. After looking into the definition in the existing literature, the notion of scale as it will be approached in this thesis will be presented. The section is divided in three parts; the first one examines the notion of "formal" scale which presents scale in general as an attribute of form, the second one is "experiential" scale which looks into how scale is perceived, cognized and finally experienced and the third one is "configurational" scale which is the definition of scale that this research suggests. This is scale as a relation of form to space and as a missing element from the syntactic theories of spatial configuration.

Introduction

Scale has a very wide meaning and can be found in many references and fields. This research will focus on scale as an attribute of the built environment. In order though to study scale as such, it should be first examined in a wider sense.

This chapter investigates into the notion of scale as this appears in the relevant literature. The first question that is raised is whether scale is an attribute of form as size, colour, shape etc. The answer is not clear as scale cannot characterise a single object but becomes a property of an object when this is compared to something else. However, there is something about scale that relates to forms. Therefore the first section is looking into this notion of scale that is named formal scale. This type of scale can also be called mathematical scale as it is usually defined with mathematical relations.

Some writers have defined scale on the basis of perception like Cullen (1961) who states that scale is the inherent claim to size that the constructions makes to the eye. So scale is the way that the size of an object is perceived by the human eye. This idea introduces another notion of scale which will be called experiential scale. It is scale as it is perceived and experienced by people. This scale is sometimes found in the literature with the name visual scale.

Finally, turning to the built environment literature we can see that the reference is to the formal or mathematical notion of scale and also to the experiential or visual scale. The last section will present the types of scale that are found in the literature of the built environment and will investigate into a phenomenal gap of the notion of scale in these studies. The argument will point to the lack of a notion of scale as a relation of form to space. This notion of scale is named configurational scale as it defines a configuration of forms and spaces in the built environment.

Formal Scale

The first question that is raised when studying scale is whether scale is a property of form. Scale is not one of the direct attributes of form as size, colour, shape etc.

but an attribute of forms' hierarchy since scale has a meaning of existence only when comparing more than one forms. In any case scale relates to forms and to their properties and mostly to size and therefore it can be defined as a property of form.

As such an attribute scale has been studied since ancient classic writers and philosophers up to our days. All literature on scale concurs that scale is relations. Scale is defined as the relation of something to: either a standard (meter, foot, tatami, Modulor etc.), or to the human body (Plato, Vitruvius, DaVinci, Modulor, foot metric system), or of things among themselves (Pythagoreans, Golden section, Fibonacci series etc.) which usually appear with mathematical relations. Therefore the question of scale brings back the philosophical question of relations.

Scale is closely related to size and proportions however there is a distinctive difference among the three. Size is defined as the physical dimensions of length, width and depth of a form. While these dimensions determine the proportions of a form, its scale is determined by its size relative to other forms in its context. While proportion retains to an ordered set of mathematical relationships among the dimensions of a form or space, scale refers to how we perceive or judge the size of something in relation to something else. Therefore, when dealing with the issue of scale, we are always comparing one thing to another, we put an hierarchy on things according to their size.

So generally speaking scale is about the comparison of sizes. The comparison of sizes can be done in two ways: either by measuring the size based on a standard or by juxtaposing the objects based on the visual size hierarchy. As it has already been mentioned this differentiation introduces two different types of scale, the mathematical and the visual. When we compare sizes based on a standard we refer to the mathematical scale of objects which is objective and absolute. The mathematical scale is the one that derives when measuring sizes. Meaning that by using a standard which is common to all measuring, we describe a real attribute of the object in comparison to other objects. If the standard is a pace and we measure the distances from home to the super market and from home to work then we can with relative accuracy and objectivity define the two distances and make a judgment on their length.

In the case that we compare sizes by juxtaposing the objects based on the size hierarchy we refer to the visual scale. Visual scale doesn't refer to an objective measuring of a size and its comparison to another but to the direct comparison of one or more objects as they appear to the observer's eye. Ching (1996) has particularly pinpointed that this type of scale is in the interest of designers and he defines it as a type of scale which refers not to the actual dimensions of things, but rather to how small or large something appears to be in relation to its normal size or to the size of other things in its context. Visual scale relates to the optical illusions since the way that they eye or the brain make judgments on object's sizes highly depends on the other objects which are in its context, on the observer's position and on other issues that create the illusion. Optical illusions will be further discussed in the next section on scale and spatial cognition.

Visual scale is of interest in the studies of space and the built environment in relation to its use from people. The mathematical scale can be accurate and useful for the designer but if one is interested in the way that the human-user understands the environment then it is the visual scale rather than the real which describes better what the human mind perceives. Visual scale will be further presented in the section of scale and perception.

Scale and proportions are closely associated as they both represent relations. The issue of the proportions of forms was one of the major questions in the antiquity. Proportion is a concept tightly related to scale, it is a relation among things and refers to the equality of ratios therefore it is a normative relation, while scale refers to the quantitative comparison of two similar things and it is a descriptive relation (Ching, 1996; Terrance, 2004). So proportion refers to the equality of ratios therefore it is a normative relation, while scale refers to the quantitative comparison of two similar things (ratio a : b : c) and it is a descriptive relation. Scale is attempting to describe a relation of sizes and not to set how this relation should be. The proportion systems of the antiquity were attempting to define size relations which would be considered harmonic or of high aesthetic value and ideal.

From the antiquity until the Renaissance the issue of proportion was present in many theories and practices of form (art, architecture and music). The main concern was to recreate the perfect proportions of nature into the human made forms. The Pythagorean philosophers (Euclid, Philolaus) and later Plato (Timaeus, translation of 2000) were referring to divine proportions and had developed their proportional systems as the Golden Ratio. Vitruvius in his "Ten Books on Architecture" (translation of 1999)had referred to scale and proportions in architecture, and to symmetry and harmony in relation to the human body; a concept that was later used by Leonardo DaVinci to define the divine proportions to be used not only in architecture but in art as well.

In the history of the issue of proportion there were two distinct paths: the systems of proportions and the concept of proportion (Terrance, 2004). First, the systems of proportion were developed by the Pythagoreans, Plato, Vitruvius, Fibonacci, Da Vinci and others and even more recently by Le Corbusier (1948; 1958) and Van der Laan (1983). The proportions based on the human body, called anthropomorphic proportions (Ching, 1996), were first introduced by Plato, then Vitruvius and later studied by Leonardo Da Vinci. They were all pursuing rational and objective principles as generators of form. According to Padovan (1999) the proportion systems were developed to create an ordered complexity since order and complexity are twin poles of the same phenomenon. The issue of proportions is in many cases strongly related to this of order and complexity (Arnheim, 1977; Ching, 1996; Padovan, 1999) as it is assumed that the application of proportions is introducing an order, preferably the same order as in nature, in the complexity of the design process. As Ching argues (1996) a proportioning system establishes a consistent set of visual relationships since underlying any such system there is a characteristic ratio which is transmitted from one object to another.

Second was the concept of proportion, where the question of what are the natural limits to growth was seen as models, even guidelines, for human design (Terrance, 2004). These attempts were mostly looking into nature, plants and animals, trying to understand the evolution of forms. The idea was that growth could not exceed specific proportions. Aristotle was studying proportions in this direction. Plato, in

Timaeus (translation of 2000), introduces the mathematical theory of proportion: two things, called the extremes, are united by a third, the mean. According to Padovan (Padovan, 1999), proportion is a matter of classification and of relative scale and the function of proportion is binding things together (uniting separate elements to make an integrated whole).

The result of the study of proportions was the development of geometrical and arithmetical proportion systems which were applied to the design of forms until the Renaissance, and perspective along with it, arrived to shift the importance from the observed/object to the observer/subject (Padovan, 1999). It was then realised that actually all these perfect forms were never perceived by any human eye and mind in the same way as they were designed. The idea of "good" proportions started fading without though disappearing. Even in our days there is research on issues of architectural composition and good proportions (Wittkower, 1949; Arnheim, 1955; Van der Laan, 1983; Weber, 1995; March, 1998; Padovan, 1999; Weber and Amann (eds), 2004).

In modern times there have been attempts to abort the symbolism and divine attributes from proportions. In this direction Meiss (1990) and Ching (1996) are presenting their categories of proportions.

Meiss (1990) differentiates two types of systems of proportions: systems commensurate with sizes, having a common denominator between them, and systems incommensurate with sizes in which the different sizes have no common measure. Commensurate proportions are the proportions which are related to a standard, either inch, foot, thickness of a wall or diameter of a column. However, the use of a grid in the modern architecture, assumed by many as a proportion system, cannot be in this sense a commensurate proportion system according to Meiss. The difference between the proportion systems and the modern use of a grid is that the use of the grid allows the design of any dimensions, as long as the grid is respected, while the use of proportions allows only for preferential relationships, for example the ratio of 2:3. Incommensurate proportions are those that some basic geometric figures have which establish ratios that are easy to draw geometrically but impossible to measure with precision (like the Φ number of the golden section).

Ching (1996) presents three different types of proportion: the material proportions, the structural proportions and the manufactured proportions. The material proportions are the natural limits of the materials due to their inherent strengths and weaknesses. The structural proportions are the proportions of architectural elements due to the structural attributes they perform; for example a column should be thicker if there is more load on top to carry. The manufactured proportions are those imposed by prefabricated mass-production of architectural elements; for example the proportions of bricks. For Ching (1996) the modern proportion systems are not anymore reproductions of metaphysical numbers but they are the result of the natural abilities of materials and of the modern methods of production. However, he categorises the proportions of the past in the following categories (naming them theories of proportion): the golden section, the orders, the renaissance theories, the modulor, the “Ken” (Japanese tatami), the anthropomorphic proportions and the scale defined as affixed proportion used in determining measurements and dimensions.

Consequently proportions are a specific type of scale. The main difference though between scale and proportions or the proportion systems is that scale relations don’t try to reproduce a relation of sizes existing in nature or an ideal mathematical order, as proportions and proportion systems do, but to describe the relation between two or more sizes. Therefore scale defines relations and as it has been already mentioned these relations can be the relation of an object to the human body, to a standard or of things among each other. On what follows each one of the scale relations is defined.

Scale as relations of objects’ sizes to the human body appears in the literature in three ways. The first is as a unit for measurement, the second is as a source of divine and ideal proportions and the third is as a module for ergonomic design.

The measurement of sizes based on the human body dates back to antiquity. In the Greek ancient world distances were measured based on paces while in the United Kingdom the “feet” measurement is used up to nowadays in everyday life. The body was an easy measurement unit since it was anytime available to be used and at the same time a “universal” unit since the differentiations that could exist from one body to another wasn’t of big importance as accuracy was not the point.

The human body and its proportions, has been the inspiration of many of the proportion systems from the antiquity to the Renaissance (Plato, Da Vinci). The body in these cases wasn’t a measurement unit but the source of ideal proportions which should be recreated and applied to any human creation whether it was art or architecture.

The human body as a modular scale was not introduced until the moment that ergonomy occurred as an issue. And this discursively preoccupied the modern architecture (Le Corbusier, 1958). It was at that time that the issue of ergonomy explicitly appeared. Ergonomy’s goal was not to reproduce the proportions of the human body but to create relations between the human body and the human creations in order to make them easy to use.

The modern movement and its persistence with ergonomy brought the matter of scale and proportions based on the human body into the light but this time in a more functional way as opposed to the metaphysic way of the past. Le Corbusier (1948;1958) was the first one who brought the anthropomorphic proportions in the discussion in the modern movement. The stress was still on rational mathematic or geometrical relations based on the human body but the reasoning was not symbolic, as in the ancient and renaissance world, but ergonomic and aesthetic at the same time.

According to Meiss (1990), the drawing of analogies between the human body and architecture, were done in three different senses; in the symbolic sense, in the geometric sense and in the ergonomic sense. In the symbolic sense anthropomorphism is found in the design of the orders where all columns have base, body and head or any other parallelism like seeing the temples as the human body. In the geometric sense, there are the proportions that imitate the human body’s proportions which are reflected in Leonardo Da Vinci’s “Vitruvian man” fitting his body in a circle. Finally, in the ergonomic sense the anthropomorphism was drawing on the relationship of size, form and movement. This relationship Meiss defines as characteristic of the human scale.

Meiss (1990) by defining human scale as the relation of size, form and movement, he is utilizing movement as the human activity that defines the use of a form. He is not defining, as it would be expected, the usability of form as the factor that defines its size but movement stating in this way that movement precedes use. Meiss raises in this way a very important issue in design, this of the human scale.

Le Corbusier (1958) was preoccupied with the issue of human scale. For Le Corbusier architectural scale was relations between the parts and to the whole and all these with respect to the human body. He created a standard, the Modulor, to be used in the design process. "It is essential to have a scale since otherwise the eye will drown in an ocean of arbitrary dimensions. This scale must be a geometrical series, because the eye appreciates relationships." (Le Corbusier, 1958 p.128). With the term scale Le Corbusier is referring to specific relations or geometrical series that he named “human scale”. Le Corbusier’s Modulor (1948;1958) was defined as a harmonious measure to the human scale universally applicable to architecture and mechanics. This would actually be a standard tool to make the design process easier and not a norm on the scale architects should build. Although the Modulor defines normative relations, and in this sense it is a proportions system, and ranges of preferred sizes, it doesn’t define which of this ranges should be used, therefore it doesn’t define the scale, in which architects should build. The Modulor can be applied in any range of sizes, from a small residence like the Villa Savoye up to a block of flats like the Unité d’ Habitation, not defining in this sense a specific scale. However, Le Corbusier is referring in his second book to Chandigarh’s Court, mentioning the 'mistake' they made in the beginning with the scale of the court and it ended up to be built 'to the scale of giants' so they chose lower Modulor values to bring it back to 'human scale'. For Le Corbusier the Modulor is a set of relations that can be applied to several levels of sizes that he defines as scale. In this way, the human scale is a scale that is close to the human body’s dimensions but in general Le Corbusier’s human scale definition is closer to Meiss' definition that human scale is related to the ergonomy of objects rather than to their sizes.

However, nowadays there is a common ground, especially in lay language, that human scale is defined as the small 'cosy' scale, stating mostly the range of sizes rather than the relations. Le Corbusier's human scale mostly refers to the discovering of the reference to the human body's proportions as you 'zoom-in' in building's elements. This is what is happening with most of Le Corbusier's buildings, like the Unite d'Habitation in Marseille, or his Cité Radieuse, which are not sized in what is – popularly - called a human scale but the human body is found as a measure and a standard at each level of design as we 'zoom-in' at the building's elements.

Licklider (1965) has a totally different opinion on what human scale is based on how this is perceived. According to him there are three kind of scales; the physical, the proportional and the human scale. The physical is the building's visual scale (physical dimensions) determined by the structural behaviour and the system of construction. In this sense scale is a visual quality. The proportional scale is the proportional system used in the organisation of space and forms, usually ratios and geometries of scientific or religious significance (Roman, Greek, Chinese, Hindu, Islamic architecture) or the module, which is for him the simplest and most limited proportional system (like Wright's honeycomb or Le Corbusier's module). Finally, human scale for Licklider is the scale as perceived by humans. In this sense, size is a relative rather than absolute quality of visual experience; the spectator carries a standard size, from view to view, which is their body and this creates an unavoidable standard for the measurement of the environment. Licklider here introduces human scale as a visual experience based on perception and this differentiates him from Meiss or Le Corbusier who used the human body as a standard to define human scale. Scale as an experiential quality will be in detail introduced in the next section of this chapter.

Finally, Maertens (1884) in his book "The optics of scale" (cited in Blumenfeld, 1953) has presented some norms on the way that scale should be used in architecture based on the optic array, in the same book he differentiates the “intimate human scale” and the “public human scale” and introduces two more types of scale the “superhuman scale” and the “extrahuman scale”. In superhuman scale is any design that makes objects or spaces to appear large or larger than they are. Superhuman scale is a scale that goes beyond the normal human, but it is definitely related to it, so as to develop the feeling of grandeur out of its contrast to what is found or expected as normal. Extrahuman scale is the scale of great bridges, airfields, hangars, dams, reservoirs, power stations etc. Extrahuman scale relates with objects that are perfectly right at scale which is however neither human nor superhuman. It is a scale more related to phenomena of nature, to rivers, lakes, mountains and valleys. While superhuman scale has a symbolic character, extrahuman scale has a utilitarian character.

It has been indicated that scale as a relation of objects to the human body is related to ergonomy, it allows the use of objects by humans and therefore it can be defined as the interface of objects with people. Human scale in this sense can be considered as people’s interface with the built environment. Architects’ intuition has put human scale in the spotlight but hasn’t managed to make its importance discursive. Based on the hypothesis that scale is people’s interface with the built environment, human scale is important but its importance is not lying in the production of low-rise buildings and narrow alleys. Its importance is lying in the application of the human scale to the interface between humans and the built environment. A simple example is the design of the handle which is people’s interface with the door, its size and scale is what allows and helps people to use the door. If this handle were too big or too small for the human hand people wouldn’t be able to interact with it. In a building the doors and windows are playing the same role as they make the building intelligible and people’s interaction with the environment is enabled through an interface which can be scale.

Scale can be a user’s interface with the environment not only in a physical way but in a mental way as well. People’s interaction with buildings is not only physical, restricted on the ground floor, but furthermore they interact mentally with it, by perceiving images of the built environment and the information that this offers. Part of the information that they receive and makes buildings comprehensible to them is related to scale. For example the existence of windows on a building's façade automatically gives to the human mind information about its size as a straight comparison of sizes takes place subconsciously in the mind. The size of a window is familiar and this is used as a reference for the size of the building which is unknown. Therefore scale is creating an interface, a way that people and environment can exchange information and interact. As seen above scale is relations, relations between parts and wholes of forms. Human minds perceive scale as a relation between parts and wholes and this makes buildings intelligible to them (Orr, 1985). For Orr, scale is the aspect in architecture that makes buildings intelligible to people, it gives to users a sense of how to relate to the building, and it does so in a way that either attracts them and reinforces their values or repels them and contradicts their values.

The need of measuring sizes in a way that they could be used in international transactions and would be universal, accurate and invariable had led to the introduction of metric standards. In this way the newcomer systems of measurement were defining an arbitrary but common language on exchanges. At the time the metric systems were appearing as a common language in an emerging globalisation culture world. Before the universal system, the traditional units were based more on things close to people's understanding or human scale. In Malaysia the walking distance between two villages could be "three rice cookings" since everyone in Malaysia knows how long it takes to cook rice. This however would mean nothing to any French citizen. New scale relations were introduced which could be used and understood by everyone equally. Traditional measures were not targeting precision but a language commonly understood by people. Science and later on industrial development demanded for extreme precision that traditional measures could not give. This could be now understood with the parallel to the use of local currency and the conversion that one has to make when travelling abroad of the country of origin. This conversion was common practice for sizes before the universal standards.

Metric system originated in the ideology of "pure reason" introduced after the French revolution. As Alder (1995) points out "As mathematics was the language of science so would the metric system be the language of commerce and industry" meant to unify and transform the French society (Alder, 1995, p.41). Gabriel Mouton was the first to suggest in 1670 the creation of a metric system based on the size of the earth. This system was adopted (though with a small variation) one hundred years later in 1791 by the French academy of sciences weights and measures committee.

Although the standards had in many cases still reference to the human body there was an important difference in the standardisation process. In this case there was not only one unit of measurement defined, like the foot, the arm, the pace, but a whole scale of units was defined with a base unit, its decimal subunits and multiples of ten of the main unit. This was giving the opportunity not only to use a standard but also to measure in accuracy. Scale as a decimal transition from a smaller unit to a bigger unit is introduced.

In this context, scale moves on from human scale and is defined simply as scale since it is no longer measured based on the human body but on the newly introduced standards. This appears to have affected design which in combination with the properties of the new materials they lead to the creation of new construction scales.

The third type of relation that scale introduces is relations of things among each other. The context is a notion that is very important when studying scale and this is because comparisons and judgments of sizes are very much affected by the existence of other sizes in the neighbourhood. So scale properties can be defined besides by the human body or standards by things among each other. In what follows we can see that most writers agree that scale is size relative to other sizes.

Cullen (1961) is referring to scale in relation to context, since for him scale of a building is not independent of the environment in which the building is embedded. As it has been seen already, Cullen states that scale is not size but "the inherent claim to size that the construction makes to the eye" (1961, p.79) and this always depends on what the construction is juxtaposed with.

Scale is often implicitly related to context (Forty, 2000; Orr, 1985). Context is here described as the integration of the building into the existing environment. In this sense what is suggested is that any new design should be harmonious with the existing which also means that any new scale must be harmonious to the existing scale. This means that a specific relation between the sizes of the objects in the neighbourhood should be achieved. The same idea is common within the urban morphology studies with the term "contextual" architecture (Whitehand, 1992).

Moore and Allen (1976) define scale as relative size. They advocate that scale can be relative not only to human size but also to the whole, to other parts, or to a usual size. The relation to a usual size is what has been earlier on defined as a relation to a standard and the relation of whole to parts is the relation of things among each other. They also state that "as shape has to do with the meaning of individual things, scale has to do with their physical size, and therefore their importance and their meaning in relation to something else" (Moore & Allen, 1976, p.17).

Ching (1996) defines scale as affixed proportion used in determining measurements and dimensions. He argues that scale is perceived size relative to other forms. "While proportion refers to the mathematical relationships among the real dimensions of a form or space, scale refers to how we perceive the size of a building element or space relative to other forms" (Ching, 1996, p.299). He differentiates two types of scale: the generic scale and the human scale. The first is the size of a building element relative to other forms in its context and the second is the size of a building element or space relative to the dimensions and proportions of the human body.

Thiel (1997) states that scale is the most elusive concept characterising the visual "scene". According to Thiel one of the problems is that the word itself, "is involved in environmental experience, is generic and encompasses a number of separate but related issues as size and extent, ratios in representation, operational appropriateness, structural design validity, conventional size expectations, psychological situational responses, and the ethics of sociological symbolism" (Thiel, 1997, p.270). This is the interest of the current thesis to study scale as an environmental experience, as related to size, ratios and psychological situational responses, in other words scale as a complex and relative characteristic of the built environment.

Another concept related to scale that is used in design practice and is found in the relevant literature is that of “harmonious scale”. This usually refers to scale in harmony with the surrounding scales. This imposes a type of order in the scale relations. According to Meiss (Meiss, 1990), the perception of the environmental qualities is based on some factors of coherence like repetition and similarity. He argues that common scale, even the comparative size of elements, is an effective factor in grouping by similarity according to the Gestalt law. However, he doesn’t define what common scale means but it can be assumed that it is similar sizes.

A concept that is crucial to be studied is that of hierarchical scaling. Hierarchical scaling is the recognition of a hierarchy of sizes in the environment which is giving a sense of order. As mentioned earlier, scale can be considered as the interface between the user and the environment. In this sense we cognise the environment through our interaction with it. A tall blank wall can be cognised, with respect to scale, in a different way than if doors, windows and texture are present. People can estimate these elements due to experience even if they cannot estimate the size of a whole building. The interface at the ground level is the principal way people physically (and mentally as well) interact with a building. The more accessible and pluralistic the information of this interface is, the easier the interaction with the building for the user will be. And such an interaction is the recognition and comprehension of the size. This is the way that elements like doors and windows work but also this is how texture on surfaces works.

Arnheim (1977) refers to the hierarchy in the way smaller parts create a whole. He argues that there are two ways of relating parts to wholes: the first is in coordination, as with windows of a façade that form a row, and the second is in a hierarchic subordination, as in the relation of the single window to the row and all to the façade. Hierarchic subordination as Arnheim calls it is actually hierarchical scaling and he argues that this helps the viewer to grasp the size of a large object. In this way the perception of size turns out to be a highly dynamic process since, he argues, the building is not actually having a size but it acquires its size from its relation to the adjacent objects, from its position in the hierarchy. Therefore he concludes that size is a matter of internal relations.

According to Mikiten, Salingaros and Hing-Sing (2000), hierarchical scaling seems to enable intelligibility of the built environment. Their thesis is that the brain and the mind are having a fractal nature and that the mind is using fractal encoding as a way of coding of related thoughts into a single fractal entity. They believe that environmental structures need to be fractal to satisfy the human brain. All systems in the body and the brain are “tuned” to recognize different kinds of fractal hierarchies. For this reason the mind seeks to shape the environment according to the same rules for structural connectivity. Fractals define a scaling hierarchy that is complex at every level. A fractal connects several different levels of scale and creates in this way a hierarchical linking. Substructures in forms create subscales that make possible the linking of forms. When a form appears with hierarchical scaling it encodes complexity in a simple fashion (the algorithm is very short). Based on this concept they propose that what appears to be complex processes in the human mind and its interactions with the environment could be very simple in a fractal sense. Our mind appreciates fractal structures, because the visual information is presented as a coded pattern, and this is the reason for like or dislike of specific environments.

Experiential scale

The previous section was preoccupied with the scale as an attribute of form and of the built environment. This section is dealing with scale as it becomes perceived by the human mind; this is an experiential aspect of scale. The fields that will be studied are those of: perception, experimental aesthetics and evaluative image of the city.

As we have seen in the previous section, scale can be defined in two distinct notions, this of mathematical scale (which is mostly approached by proportions and proportion systems) and of visual scale. Many researchers, authors and philosophers even from the early years after the Renaissance had started realising that applying scale as mathematical relations on objects does not represent what the eye perceives and the mind grasps. Therefore, it is very important to differentiate two types of scale; the formal one or mathematical which is the scale as an attribute of forms' comparison defined with mathematical relations and the visual scale which is the scale of objects as these are perceived by the eye. The research in this field is investigating whether scale as mathematical relation is perceived as it is described by this mathematical relation or not.

Many of the writers presented in the previous section have defined scale on the basis of what is perceived and not as an absolute comparison of commensurate sizes. As it has already been stated Licklider (1965) has defined human scale as the scale as perceived by humans. In this sense, size is a relative rather than absolute quality of visual experience; for him the spectator carries a standard size, from view to view, which is her body and this creates an unavoidable standard for the measurement of the environment. Also, as seen above, for Cullen (1961) scale is not size but “the inherent claim to size that the construction makes to the eye” (1961, p.79). And finally Ching (1996) argues that scale is perceived size relative to other forms, he claims that although proportion refers to the mathematical relations among the real dimensions of a form or a space, scale refers to how the size of a building element or space is perceived relative to other forms.

The research on the perception of scale is limited only to objects and not to the environment. Research on the perception of objects' scale is Konkle and Oliva's (2010) study which relates the representation of sizes of objects on a paper to the frame of space around the depicted object and Cheng and Boulanger's (2004) study on the perception of objects' scale relative to distance in three-dimensional online visualisations. Most of the studies of perception are investigating into the perception of size and the perception of distance or depth. These two are considered to be closely related to scale as scale has been defined as relative or perceived size and distance or depth affects the perception of size. Coeterier (1994) argues that all three, perception of size, depth and distance are integrated in perception of space. Space is not meant as void but as the environment surrounding us, as in spatial cognition.

What is apparent from all the studies is that perception of size is not and cannot be accurate as for example perception of colour or perception of shape. The perception of metric properties like size and distance is relative and always depends on other properties of the environment or other objects in the environments or even on perceptional cues.

An important cue, on which size and distance perception are based, is size constancy. Size constancy (Eysenck and Keane, 2003) is the tendency for any given object to appear the same size whether its size in the retinal image is large or small. Size constancy depends on our experience of the world. Therefore there is a relation between size and distance which changes accordingly and therefore keeps the size constant. For example, if an object's retinal image is very small, the object may be judged as big if it is also judged that it is far away. Therefore according to Kilpatrick and Ittelson (1953) there is the size-distance invariance hypothesis according to which for a given size of retinal image, the perceived size of an object is proportional to its perceived distance.

Size judgments also depend on information on familiar size. Familiar size can be used to make accurate assessments of size regardless of whether the retinal image is very large or very small (Schiffman, 1967). In the built environment, for example, the size of a door can be easily estimated as its size is usually standard and familiar. Based on the size of a door or a window the size of the building can be roughly estimated. In the everyday world, objects which act as a measure for the overall estimate of the environmental sizes and distances are the cars, the pavements and even other people.

Another cue on size is the horizon (Bertamini, Yang and Proffitt, 1998). The horizon is considered to give a cue for size estimation in the sense that objects that stand on the line connecting the observer to the horizon are at eye-height then they are considered to be approximately the same height as the observer given that this connecting line is parallel to the ground.

Furthermore, perception of size is affected by other factors like whether the observer or the object is static or moving. In real life cues to depth are often provided by movement, either of the observer or of the objects in the visual environment (Eysenck and Keane, 2003). Furthermore, there are the monocular cues, the binocular cues and the oculomotor cues. Monocular cues to depth are linear perspective, aerial perspective, texture, interposition, shading, familiar size, image blur and motion parallax. Binocular and oculomotor cues to depth are convergence, accommodation and stereopsis (Eysenck and Keane, 2003).

Based on the size-distance invariant hypothesis by Kilpatrick and Ittelson (1953) described above, perception of size depends closely on distance or depth. Eysenck and Keane (2003) differentiate two types of depth; the first is an absolute distance which refers to the distance from the subject-observer to the object and the second is a relative distance which refers to the distance among objects. They support that the judgments of relative distance are more accurate than those of absolute distance.

Norman (2002) names the above two types of distances the egocentric distance perception and the exocentric distance perception. Egocentric distance perception or frame of reference as it is usually called is the perception of distance of a person from an object. In this case, the subject uses her own body to indicate the position of an object. Exocentric distance perception is the distance between two objects in an environment. This allocentric frame of reference is used by someone to indicate the position of an object in relation to another object. Levin and Haber (1993) support that exocentric distances are overestimated by 20-40%.

The whole issue of the relativity of the perception of size and distance which are never perceived as they really are, brings in the discussion the topic of visual illusions. Visual illusions (Eysenck and Keane, 2003) are the cases when perceived images differ from real images. The visual illusions have been much studied in perception. Some of the illusions are related to size or space perception. Optical illusions are actually cases or situations where the human eye can be tricked and see something different than what happens in reality. Examples of such optical illusions are the Muller-Llyer illusion or the Ebbinghaus illusion.

In Muller Llyer illusion there are two double ended arrows as seen in figure 2.1. One arrow has the fins pointing to the opposite direction of the line and the other arrow has the fins pointing towards the line. The illusion is that although both lines have the same length, the line with the fins pointing the line looks longer than the one where the fins point to the opposite side. This illusion shows the difference on the perception of the length of the vertical line depending on the direction of the fins on the edges.

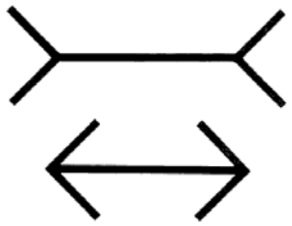

Figure 2.1 The Muller Llyer illusion. The line on top looks bigger than the line at the bottom although they have the same length.

The Ebbinghaus illusion (figure 2.2) is again based on size perception. There are two circles that are surrounded by other circles. In the first case the surrounding circles are smaller than the central circle and in the other case they are bigger. What the human eye perceives is two different sized circles and in particular in the first case the central circle looks bigger than in the second case. In reality they are exactly the same size.

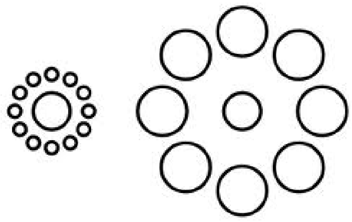

Figure 2.2 The Ebbinghaus illusion. The circle in the middle, looks bigger on the left side than that of the right side although they are the same size.

What these illusions show is that perception of size is very much affected by the neighbouring, adjacent or within the same context objects. This is exactly what scale is about. In real environments where the existence of many objects creates a complex environment the perception of sizes and distances is easily tricked.

However, for many researchers of perception the illusions work due to internal processes dealing with experience and expectations. According to Gregory (1970; 1980) many visual illusions can be explained based on the constructivist theory assumption that internal processes, like experience and expectations, interfere with senses perception and affect what is finally perceived. According to constructivist theories, the formation of incorrect hypotheses and expectations leads to errors of perception. However many of Gregory's arguments (1970; 1980) have been refuted by later research (De Lucia and Hochberg, 1991) or with illusions like the Ebbinghaus illusion (Aglioti, Goodale and De Souza, 1995).

Gibson (1979), on the other hand, advocated that visual perception works independently collecting information without any internal process being necessary. For Gibson there is a different explanation why illusions work. The reason is that the view of the illusions is usually two dimensional and static. He believes that movement gives extra perceptual awareness. Gibson has introduced the importance of the environment in perception. Until then almost all experiments on visual perception that had been done were focusing on the visual perception of a motionless observer observing static objects. Gibson stated that the human always moves in the environment or the objects that are found in it are moving and therefore the movement and the environment are very important elements for visual perception. He supported that the environment and particularly in what he calls optic flow pattern, there is very important information which the human eye can collect through visual perception without any processing of the information from the mind being necessary. Gibson named this approach to perception "ecological" in order to stress that the first function of perception is to facilitate the interaction between the human and the environment.

Gibson (1979) has also introduced the importance of the change of texture gradient in the information supply. As he noticed when the observer or the objects are moving then they tend to present a change of texture density. Their texture becomes more subtle or sparse or totally disappears as they move away from the observer. Gibson supported that the observer receives this information in the optic array, as he called the structured quantity of light that reach the eye, and in this way the perception of depth is perceived.

Gibson's statement was possibly the first differentiation between the perception of an object and environmental perception. As Ittelson (1970) has also stated the tradition in the psychology studies until the '70s was the focus on object perception and then it shifted into environmental perception without though changing the explanatory system. The differentiation between object and environmental perception was later thoroughly studied and given more importance by other scientists like Ohno. Ohno (2000) made the important distinction between object perception and environmental perception in the perception studies. Ohno argues that the first is object centred and uses focal vision whereas environmental perception is subject centred and uses ambient vision.

The differentiation between object and space is also found in cognitive studies of visual reasoning (Kozhevnikov, Hegarty and Mayer, 2002; Kozhevnikov, Kosslyn and Shephard, 2005) where individuals are separated into those who construct detailed representations of objects' properties such as size, shape and colour (called visual imagery) and those who construct representations of the spatial relations between parts of an object or between objects (called spatial imagery).

Gibson's differentiation is extremely important regarding the perception of the built environment where the observer is never static. The perception in the built environment involves a continuous interaction between the environment and the observer which is based on movement. Movement includes pauses, shifts of points of view and changes of distances.

The above mentioned points are important for the understanding of scale and its approach in the current research. The first issue is that distances and sizes cannot be perceived accurately and that the wrong estimation of distances and sizes is possibly based both on expectations and experience and on the lack of adequate information from the environment. A way to overcome the inadequate information is movement. This introduces the second issue to be taken into account which is the importance of movement on the perception of the built environment. This also explains the difference between estimation of perceived and traversed distance that has been observed in experiments, with traversed distance estimations to be closer to real distances than perceived distance estimations (Witmer and Kline, 1998). A third issue is that estimation of an object’s size seems to be affected by other objects in the surroundings, as the optical illusions show, which has big importance regarding the built environment and the perception of scale.

A research field that is also investigating into issues related to the perception of scale is experimental aesthetics (Molnar, 1974; Crozier, 1980; McManus, 1980; 1997; McManus, Cook and Hunt, 2010). Experimental aesthetics is the field that examines the perception of aesthetics norms and rules and targets to find out whether there is any psychological reasoning behind them. One of these rules and norms are the proportion systems.

In the first half of the 19th century the question of the validity of the proportion systems, which originated in the Renaissance, had as result the concept that “proportion if it is to survive, must be refounded on the basis of explicable psychological phenomena instead of unfounded metaphysical dogma” (Padovan, 1999, p.271). Therefore proportions had also been studied as purely psychological phenomenon within the science of experimental aesthetics which was founded by Gustav Theodore Fechner (1876) as cited in Nasar (1998) and developed by others among who Friedrich Herbart (Padovan, 1999). There were attempts within this field to investigate with experiments if there is actually objective preference for specific proportions. The experiments were testing the participants’ preference of cards with specific proportions, like the golden section. Although the findings showed that there may be a preference of specific proportions over others, all these experiments were based on the application of specific proportions on cards and may not be able to explain more complicated aesthetic experience.

Later on similar experiments, by Woodworth (1938) on preference for specific proportions showed that there is no preference for ratio 1:2 or for the Golden section (Meiss, 1990). Similar experiments by McManus (1980; 1997; McManus, Cook and Hunt, 2010) pointed towards individual differences in the aesthetic preferences rather than towards specific proportions or dimensions.

On the steps of experimental aesthetics a field within environmental psychology emerged which is named environmental aesthetics or evaluative image of the city. According to Nasar (1988) environmental aesthetics derives from the merging of empirical aesthetics and environmental psychology. The main aim of this field of study is to understand environmental influences on affect and to translate this understanding into environmental design that is judged favourably by the public. It mainly deals with order and complexity.

This field studies the evaluation that inhabitants or visitors make for specific urban environments. The findings of such research create the evaluative image of the city which is based on people's affection for specific environments and not on architects' or designers' opinion on what is aesthetically preferable.

According to Nasar (1998), the evaluative image of a city may involve environmental perception, cognition (mental activity) or may arise from the meaning of the form. Therefore the study of evaluative image may seem to be something as apparently subjective and qualitative as community appearance and evaluation.

In Nasar (1998) it is argued that importance of a setting (or building) is expressed through scale and quality of execution. He states that although the effects of scale are anecdotally obvious, they are inadequately tested besides some evidence from way-finding and cognitive studies (Appleyard 1969; Carr and Schissler 1969, cited in Nasar 1998) and that the size of a building or public space is historically strongly linked to its social significance.

Other than that there is no reference to scale in such studies. However, some references to order and complexity can be related to the issue of "in or out of scale" or to "harmonious scale" which is usually mentioned. In several evaluation exercises residents reported that they liked areas for their visual order, referring negatively to chaos and the lack of uniform style (Nasar, 1998). Additionally to this, a research by Groat (1983) has shown that preference of people for specific buildings increases with compatibility of these buildings to neighbouring ones.

In studies (Nasar, 1998) investigating into perceived order it appears that some of the factors that are important for the perception of an environment as ordered are: clear structure, differentiation of parts and congruence of form. However, other research (Nasar, 1998) shows that perceived ordered should be accompanied by a satisfying degree of visual arousal and complexity. People's interest and arousal increase with environmental complexity.

One of the most widely studied theories in environmental psychology is the mystery/complexity/legibility/coherence model of Rachel and Stephen Kaplan (1989). The theory postulates that people will have two basic needs in environments: to understand and to explore. Moreover, these needs might refer to what is immediately perceptible, or might refer to what might be perceptible if one moved to another location. When the two needs are crossed with the two levels of immediacy, four variables are created. The four variables were called "informational variables". The labels used for the informational variables are coherence (immediate understanding), complexity (immediate exploration), legibility (inferred understanding) and mystery (inferred exploration). All four informational variables were suggested as predictors of environmental preferences.

When qualitative analysis of people's judgments is involved, issues of aesthetics are raised. It is very clear that scale can also be the object of aesthetics, however this is a very wide issue and not in the direct interest of this thesis. However, a differentiation that Berleant provides for aesthetic experience is presented here. According to Berleant (cited in Nasar, 1988) there are three models of aesthetic experience: the first, (called the active model) the phenomenological or of the aesthetics of pragmatism, advocates that the objective world of classical science is not the experiential world of the human perceiver. The second model supports that the environment is not wholly dependent on the perceiving subject but it also imposes itself on the person engaging it in a relationship of mutual influence. Finally the third model (called the participatory model), the aesthetics of engagement, presents the environment as a field of forces in continuous interaction with the organism. Berleant's models are important because they present the aesthetic experience as something more than just a subjective opinion but consider that there is an interaction between the human and the environment.

What most of the research on scale demonstrates is that there is indeed a gap between the objective scientific world and the perceived world. The case of perception of sizes and of scale pinpoints that they never get comprehended in their pure mathematical dimension but they are relative and also based on the human observer. At the same time theories of space like space syntax advocate of a more interactive relation between the human and the built environment (Hillier & Hanson, 1984) considering that the organism and the space are in a type of relation closer to the second model of mutual influence.

Configurational scale (or scale of the built environment)

This section will attempt to focus on scale as an attribute of the built environment, to bring together all that have been discussed in the previous sections and suggest a definition of scale that will be used in this thesis.

The scale of the built environment is a very complex attribute as it is not just about two or a few juxtaposing objects but about a pluralistic and diverse environment. In the first section an ontological approach of scale has been done and its definitions from the past up to now have been presented especially through several normative ideas and theories of form, art and architecture. In the second section an epistemological approach has been done which presented how scale has been studied in the field of perception. The present section will attempt to identify and focus on the particularities that the notion of scale of the built environment raises.

In the past scale has been mostly identified with proportions and proportion systems. In the last years scale has been studied on its own share in the studies of the built environment. However, within the studies of the built environment scale hasn't got a clear definition or distinction and it ends up to be used with different meanings. In what follows we will attempt to differentiate the types of scale as these appear in the built environment studies. The differentiation is clearly connected to different fields of the built environment and in particular architecture, urban design and geography.

In the literature of the three fields of the built environment mentioned above there can be identified three types of scale: architectural scale, urban scale and spatial scale.

Architectural scale is the scale as it appears in the architecture literature and mostly refers to the scale of a building. Architectural scale deals with size relations of buildings' parts to the whole or relations of buildings among themselves. Such relations are the relation of the elements of a façade to the whole façade, like the windows or doors to the whole building or the dimensions of a building or the relation of the sizes of buildings. Architectural scale also looks into the size relations of the interior of buildings, the relation of rooms' dimensions, the relation of objects in a room to the rooms' dimensions and so on. This type of scale is usually studied with plan, elevation or three dimensional drawings of buildings. Architectural scale is very much identified with proportions. It is more common when talking about a building not to talk about its scale but about its proportions.

Urban scale is the type of scale that appears in the urban morphology literature and it studies the building's fabric, the two-dimensional and three-dimensional form of the city. It studies the scale of streets, squares, parks, urban blocks and other such elements of urban environments. This type of scale although it studies the three-dimensional form of the city this is done in a fragmented way which means that the media used are usually isolating a two-dimensional image of the form. It is either cities' plans that are studied which have the two horizontal dimensions of urban elements or elevations or sections, as street sections, which are isolating one horizontal and one vertical dimension. There has never been a study of the three-dimensional form of the city in the same representation and even more in a perspective representation.

Urban scale is usually studied with block structure maps, plans of urban environments and street sections like for example in Jacobs (1993). The urban scale, as block structure, is often defined as urban grain as by the British Ministry of Communities and Local Government. Their definition for the urban grain is: “Urban grain is the pattern of the arrangement and size of buildings and their plots in a settlement; and the degree to which an area's pattern of street-blocks and street junctions is respectively small and frequent, or large and infrequent (Communities and Local Government Publication, 2000).

What seems to be the main interest in the studies of urban morphology is the morphology of the city as this appears on a city map or an aerial photo of the city from above and not the morphology as this appears in front of the eyes of a pedestrian in the city. Cullen (1961) is one within the urban morphology field who is actually referring to the pedestrian experience, naming it “serial vision” which is the unfolding of the town’s scenery as one moves through and experiences it. However, what he is mostly interested in is the emotions that serial vision will evoke to the pedestrian. As Levy (2005) describes, within urban morphology there is need to “widen the corpus of analysis to embrace more fully the diversity of modes of representation, including three-dimensional, perspective and video recording so that the range of aspects of form and of the senses is captured”.

There are cases where the three-dimensional representation has been achieved and studied as is described by Holtier, Steadman and Smith (1999) for the Smallworld GIS software. However, still in this case what is studied is not the three-dimensional form of the city but the three dimensional arrangement of the data of the city.

Finally, spatial scale is the type of scale that appears in the geography literature. This is an abstract notion of scale denoting the extent, spatial or temporal, at which a phenomenon takes place. In this sense, there is the neighbourhood scale, the city scale, the state scale and so on. It is referred to the size of a spatial phenomenon (Montello, 1993; Paasi, 2004; Mansfield, 2005; Sayre, 2005) as an abstract notion, not as the void between buildings but as the space of the neighbourhood, of the city, of the state. This is the area to which the phenomenon of the neighbourhood or of the city or of the state takes place.

The notion of scale is encountered quite often in the studies of geography. However, it must become clear that this notion of scale although it refers to a category of scale of the built environment it is not in the interest of this thesis. In particular none of the three types of scale described above are what this thesis will attempt to study however, the first two, the architectural and the urban are very close to the scale that will be here defined and examined.

In order to define the notion of scale as this will be studied in this thesis there are two issues to take in mind. The first is that in both the existing literature and in the perception studies there is a latent accordance, which never becomes explicit, that scale is a relation of form to space. The second is that the interest is in the perception of the scale of the built environment as it is perceived by a human pedestrian observer and not as it is described in two-dimensional representations.

The study of the scale of the built environment cannot be just the study of the scale of forms. It must also include the relation of the buildings with the space that surrounds them. In the studies of perception that have been studied in the previous section it was clear that the perception of size is in close relation to the distance of the objects between them or from the distance of the observer from an object. This distance is the size of space and it is apparent that it affects the perception of the size of objects. Therefore, if scale is the perceived size of an object that depends on the other objects in context it also depends on the size of the space that creates the context.

Therefore, the scale of the built environment refers to the metric relation of buildings and to the space among them. The current studies of scale in architecture usually isolate the building from its surrounding or when many buildings are studied together the approach is two-dimensional.

In urban studies the issue of the relation of form to space becomes again apparent without though being explicit. The block structure maps, the street sections representations depict form and space and actually study the relation of the two.

What is missing though in these studies is, as has been already mentioned, the combination of all three dimensions, the two horizontal and the vertical in one study. It is usually either the plans or the sections-elevations that are studied. This leads to a fragmented view of the built environment and to a view that represents absolute attributes of the built environment and not the built environment as it is perceived by the human eye.

The urban studies by examining the relation of the built to the unbuilt with two dimensional representations they never capture the complex relations in their total character. These relations depend on all the dimensions of the buildings, the dimensions of the space and the dimensions of the human among them. This last is an issue that stresses the importance of space in the scale of the built environment even more. This is the fact that the observer with the body that she carries she becomes very much part of the space, she is immersed in it. In the case of small objects the observer is watching the setting, is outside of what is happening. In the real environment the observer is part of the setting, she is not just watching the relation of object to space but she is taking part in it with her body, physical activity is involved therefore kinesthetics becomes a crucial factor of perception.

The two points presented above, first that there are not studies of scale with representations of the built environment which depict what the human eye perceives and second that scale relations should include the dimensions of buildings, of space and of the human body, brings us to the next point that is important for the definition of scale in this thesis. This is that the interest in this thesis is in the study of scale as this is perceived by a human observer walking on a street. The two dimensional representations that are used in urban studies can help the study of the attributes of the built environment but they don't provide a representation that is close to what the human eye perceives when moving in the built environment. The importance of movement for the perception of the built environment attributes was stressed earlier on through Gibson's ideas (1979). This thesis is not interested in scale merely as an attribute of the built environment but on the way that scale is also perceived and then affects decisions on movement and use of space. Therefore scale is not studied through a morphological approach but through a cognitive approach which is then expected to shed light in the morphological research.

Within this direction an urban theory that attempts to represent the way that the human mind perceives the urban environment and makes movement decisions will be examined in detail. This theory as it has already been presented in the introduction is space syntax developed in University College London by Bill Hillier and Julienne Hanson (Hillier & Hanson, 1984). Space syntax is a theory within the urban studies that examines the configuration of space as it is created by the imposed forms. In this case space is meant as the void created among buildings. The interest for space syntax is on the way this configuration of space affects pedestrian movement (Hillier, et al., 1993).

There are two issues that make this theory interesting for this thesis. The first is that space syntax has brought into the discussion the importance of space considering the configuration of urban space to be a crucial factor which affects movement decisions. The second is that it is interested in the configuration of space not just as an attribute of the urban environment but also in the way that the human mind cognises this configuration. These two subjects are very close to what this thesis attempts to study regarding scale; however, there is one main drawback in the theory which is that all space syntax research is based on the two horizontal dimensions. In the space syntax theory and approach the third dimension, the vertical, is not taken into consideration. Space is studied on its two dimensions based on block structure maps. In its endeavour this thesis will also attempt to investigate into scale as a missing element of space syntax theory.

Beyond this drawback there is also one more point that differentiates space syntax from the approach this thesis attempts to create. Space syntax studies the configuration of space mostly topologically. It is not interested in the metric attributes of the environment and it doesn't take into account the dimensions of buildings or of blocks or of streets. It is interested in the way that buildings are juxtaposed to create a configuration of space and then studies this configuration topologically. It is actually breaking down the configuration of space into smaller parts and then studies the relations of these parts. The way it breaks down the unique space to smaller parts is based on human perception. Each smaller part is based on the “perceivable” area by a human observer.

The research on scale could not be based by definition than on metric attributes as scale is relative to size and size is measured metrically. However, beyond the mathematical relations governing scale and size there is also the visual scale as has been defined above. Therefore scale can be simply approached by its visual attribute as a three-dimensional configuration. Consequently the interest is not on the metric relations that define scale but on the visual three-dimensional configuration that is encountered in urban environments and also defines scale.

Finally, there is one more issue that makes space syntax theory important for this thesis’ argument. This is that space syntax is interested in a moving observer. The interest is on the way a moving observer moves in space and how the configuration of space affects navigation and wayfinding. For this reason space syntax has been found in the interest of spatial cognition studies.

Based on what has been described above, the notion of scale as it will be studied in this thesis can be presented. Scale is defined as the relation of form to space. Form in the case of the built environment is the buildings which are superimposed the one next to the other. Scale is the relation of the buildings among them but also the relation of the buildings to the space that surrounds them. The space among buildings defined also as distance, absolute or relative, becomes a geometric element which participates in a complex relation of sizes. The scale of the city is therefore defined both by the size of the buildings and of the space that they create.

This thesis is not interested in studying scale in a morphological way but to focus on the way that the human mind perceives the scale of the urban environment and the effect that scale can have as an element of the built environment on the people who move and live in it. Scale as defined in this thesis is called cityscape scale and intends to describe the complex relation of what a human mind perceives when walking down a street which is a combination of architectural forms juxtaposed in a specific formal configuration which creates the urban form and the space that surrounds the urban form.

Before summing up this chapter a last mention should be done to several attempts to generate quantitative methodologies of three-dimensional form or three-dimensional space which are considered to be related to scale. What these methods of quantification are attempting to do is to translate into mathematical relations, relations of form or relations of space. The approach in almost all of them is not cognitive and therefore is considered to be different than the current study's approach.

Quantification of form is capturing in mathematical relations, the relation of the parts of buildings among themselves and to the whole building or relations of buildings. The simplest way of quantification of form is the perimeter or the area of a façade. However, usually complicated methods are used which are trying to capture also the level of complexity of the urban environment. Information theory and information aesthetics are some common methods of quantification in this direction (Moles, 1966 ; Krampen, 1979; Haken and Portugali, 2003).

On the other hand there are attempts of measuring three-dimensional space properties (Teller, 2003; Turner, Doxa, O'Sullivan and Penn, 2001). These two researches are attempting to include the third dimension (heights of buildings) in the quantification of space that is done by the space syntax methodology in two dimensions. The method each one suggests though is different, Turner et al. are suggesting visibility graph analysis used in three dimensions and Teller is actually analysing open spaces by creating spherical projections and calculating their sky opening.

Summary

This chapter investigated into the issue of scale as this appears in the existing literature and research. The chapter is divided in three sections each one defining a different type of scale. The first defines formal scale, the second defines experiential scale and the third configurational scale.

Formal scale defines scale as a property of form. All literature coincides that scale is relations either of something to the human body, or to a standard or of things among each other. Scale is strongly related to size and proportions however it is differentiated from size as this has to do with the physical dimensions of the objects and from proportions as they refer to a retained set of mathematical relationships. Proportions is defined as a normative relation while scale as a descriptive relation.

Scale is defined as relative size and it is often mentioned in the literature as perceived size therefore bringing in the definition of scale the importance of perception. Due to this definition two different scales can be introduced, one is mathematical scale which is the scale as metric relations, objective and accurate, and the other is as visual scale which is scale as perceived which is objective and relative.

The issue of proportions has prevailed for many years in the literature and in the interest of researchers, philosophers and scientists. Since the ancient times philosophers and mathematicians were trying to find the perfect proportions in nature and recreate them in artefacts. Proportions were thought to have divine properties until Renaissance and then the modern movement arrived to shift their importance towards the issue of ergonomy. Ergonomy was and still is promoting the use of proportions in order to make designed artefacts compatible to the human body, to make things easy to be used by the humans.

The scale relations as relations of objects to the human body stopped to be the prevailing ones with the need for global, universal and accurate descriptions. The metric standards were introduced and brought a new definition of scale more precise and mathematical.

Possibly the most important definition of scale is the one considering scale as a relation of things among each other which stresses the relativity that is inherent in the concept of scale and the importance that the context has for the concept. The scale of objects is relative to other objects found in the neighbour. The context in which an object lays affects the scale of both the object and of the context.

When having an imposition of many objects the issue of hierarchical scaling is considered to be important. According to the literature it helps the user to grasp the size of the objects and it makes the environment more intelligible. Hierarchical scaling is defined as the existence of many sizes that cover a varied range of sizes and are organised in a way that create a hierarchy. In the built environment such elements that create hierarchical scaling are considered to be elements like the windows, the doors, the pavements, even the cars and many more.

The second category introduces experiential scale which is scale as perceived by the human mind. Many references in the existing literature define scale as size as perceived by the human mind. Therefore this category focuses on the existing research on the perception of size, distance and scale. As there is not research looking into the perception of scale, the perception of size and distance is considered to give important insight into how perception of scale might work.

The cues that are considered to affect perception of size and distance are size constancy, familiar size and the horizon line. All these show how the human mind works and grasps distance and size and can give us a cue in how perception of scale also works.

Regarding the perception of size, the optical illusions are an important research concept that helps the understanding of scale perception. This is because many illusions are based on the effect that the context has on the perception of sizes. An important input on the issue of illusions is that by Gibson (1979) who explains that illusions work due to the lack of movement and due to the fact that most of them concern two dimensional views. These two issues become even more important when the focus is the perception of environmental properties and Gibson puts them in the centre of environmental perception. Especially movement will be considered a crucial issue and will be a main factor for the research on scale in this thesis.

Three points that can be concluded from the research on experiential scale can be, first, that distances and sizes cannot be perceived accurately and metrically, second, that movement is an important factor for the more accurate perception of environmental factors and third is the importance of the context for the perception of metric attributes like size and distance. It can also be said that size, distance and depth are metric attributes and are not perceived as they are while scale is a relative attribute and not metric and is therefore totally based on perception.

Finally, the chapter ends by presenting the concept of configurational scale which is scale as an attribute of the built environment and incorporates the configuration of built forms and empty spaces along a street. Configurational scale studies scale as visual relations and not as mathematical relations. A configurational type of scale is introduced in this thesis and is called cityscape scale which describes the complex relation of what the human mind perceives when walking down a street which is a combination of architectural forms juxtaposed in a specific formal configuration which creates the urban form and the space that surrounds the urban form.

It is clearly denoted that cityscape scale is different than the types of scale that are found in the existing studies of space and the built environment like the architectural scale which study the scale of buildings, the urban scale studied by urban morphology and looking into the scale of urban grids in representations of street sections or of block structures and finally spatial scale which is studied by geography and looks into the extent of spatial and temporal phenomena.

The next chapter will present and discuss the methodology that will be used in this thesis for the study of scale.

Chapter 3

Methodological issues: Built Environment, Spatial Cognition and Virtual Environments

Abstract

The two experiments of this research that will be presented in the next chapters are conducted in virtual environments. Therefore, this chapter attempts to discuss virtual environments as a methodology for the study of issues related to the built environment and spatial cognition.

The chapter will also attempt to explain why virtual environments are chosen as a scientific methodology, the types of virtual environments that exist and the possibilities and restrictions that they offer. All these are presented in relation to the issue of embodiment and the relevance or effect of this to the research on scale.

Finally, research on spatial cognition in virtual environments and whether the results can be transferred to reality are presented. This research includes, perception of size, of distance, navigation and wayfinding in virtual environments and the differentiation this has from the real cases.

Introduction

The two experiments which will be presented in this research, took place in virtual environments. Therefore this chapter will attempt to present how they are used in scientific research. Specifically it will attempt to present virtual environments as a widely used methodology for the studies of the built environment, spatial cognition and of the human behaviour in general.

A virtual environment is an interface between the real world and the digital world. It can then be from a computer's desktop to a totally immersed virtual world, a replica of the real world where someone can be fully immersed and experience it with the use of the right technical means. A virtual environment can be conceived by a human mind or automatically created by a computer (although again guided by a human mind). In either case it cannot be created without a computer's input. A human mind can conceive the environment but a machine is necessary to create it as it is computer simulated. The reason for the creation of a virtual environment can be leisure, education, information, research and facilitation of interaction (especially distanced). A few indicative applications of virtual reality are telemedicine, telepsychiatry, education and distance learning, training, flight simulators, games, architectural and interior design, new kinds of exercise equipment, underwater exploration, assessment of surgical skills, collaborative work and much more (Lombard and Ditton, 1997; Lányi, 2012). In research where investigation in real situations is difficult or dangerous the simulation of real situations through virtual environments offers the area for trials and experiments, like in medicine or flight simulation.

Virtual environments are either replications (simulations) of real environments with the use of technical media or totally new imaginary creations. These technical media are usually computers and the environments are digital environments. The reason they are called virtual is because they are trying to imitate the construction and structure of our built and physical environment.

Virtual environments are widely applied in sciences because they offer the possibility to isolate attributes of the study and keep invariants and change variants. In this way the human response at each of these attributes is observed. A virtual environment is created by the researcher with specific attributes which can be systemically varied according to the questions set. Therefore they offer advantage in comparison to real environments.

However, the use of virtual environments brings a lot of objections. This chapter will attempt to bring to the front the discussion on the use of virtual environments and examine the arguments of both sides. The upper goal is to argue and explain the final decision to use virtual environments as the methodology for the experiments in this research.

In the first section the advantages and disadvantages from the use of the virtual environments as a methodology in scientific research will be presented, then in the second the transferability of the results of virtual experiments to reality will be discussed and in the final section the use of the virtual environments in the studies of the built environment, of spatial cognition and environmental perception will be presented.

Advantages and disadvantages from the use of the virtual environments as a methodology for scientific research

One of the possibilities that virtual environments offer are for the possibility they give for controlled conditions. This means the control over the presented stimulus (Van Veen, Distler, Braun and Buelthoff, 1998; Rizzo and Kim, 2005) which allows the separate exploration of single conditions. The experimenter can easily manipulate the parameters by testing separately each condition in the same environment with the same participants. This control over the stimuli and the parameters that virtual environments offer gives two big advantages to the research which is the reproducibility of the experiments and the possibility for systematic research (Van Veen, Distler, Braun and Buelthoff, 1998; Lányi, 2012).

A second advantage is the fact that they offer interactivity between the participant and the environment (Van Veen, Distler, Braun and Buelthoff, 1998; Rizzo and Kim,

2005) which is very difficult in many real cases either due to safety conditions or due to the difficulty to isolate just the participant and the environment. The level of interactivity is not the same in all types of virtual environments with some set ups being more advantageous, like a head-mounted display, than others, like a desktop display. However, the fact that interactivity is part of the virtual environments set up is a fact the last years.

Another important advantage of the virtual environments is the behavioural tracking and the performance recording (Rizzo and Kim, 2005). Indeed the participants' behaviour and performance is easier observed in a virtual environment and can even be done with more technical means which leaves less space for objective interference from the experimenter or biased observations. Also the performance is easier quantified in virtual environments due to the media of technology at every stage.

Finally, virtual environments offer the advantage of safe conditions and low risk. Therefore they have been used as a tool for therapy of psychological phobias since they create replicas of the situations that cause stress to the patients and help them to overcome the fears in a safer, in their perception, environment. It offers the opportunity to the patients to face their fears in an environment which is not real but which offers the same reactions and emotions, it gives the opportunity to the therapist to control the environments and also the opportunity to the patient for habituation (Juan and Perez, 2009).

Some of the criticism of the virtual environments as a scientific methodology is based on the level of perceptual realism that they can offer. The perceptual realism in virtual environments improves continuously but in no case can represent truthfully a real environment. In many cases although the environments can reach a very good level of realism especially due to the capabilities of photorealistic software, it is difficult for this to be supported by the rest of the equipment necessary for the virtual environment experience. Even in the case of super machines that can support the realistic representations, the cost of these machines is extremely high and therefore difficult to find.

Beyond the technological issues related to the perceptual realism there is also the issue of the desired level of detail. Due to the same technical problems as above the researcher in many cases has to choose an abstract model of reality with smaller level of detail. In some cases this happens to create more controllable conditions. If the level of detail is reduced there are fewer factors to take into account and better control of the desired variables. However, an optimum between detailed and non-detailed environments should be reached as it is considered that detailed environments help people participating in experiments to transfer their spatial knowledge from the virtual environments to the real world (Wallet, Sauzeon, Rodrigues and N'Kaoua, 2011).

Important part of the criticism on the use of virtual environments in scientific experiments is based on the participant's experience of the virtual and how this can be compared to the real experience. This issue is related to a big discussion in the field and raises many questions some of which will be discussed below. These are the issues of presence, immersive and non-immersive environments, of the phenomenology of the virtual environments and of the virtual environments and embodiment.

A virtual environment has a basic difference from a real environment and this is that it is two dimensional and therefore cannot be lived in. Even in the case of three dimensional virtual environments, which are met very often, what is meant is a three dimensional representation and not an environment with three dimensions. Therefore virtual environments can be perceived by the senses, and are mostly a visual experience although some of them offer and additional sensory information as sound, or conceived as three dimensional by the mind but not lived as three dimensional in the same sense as real environments are.

The virtual environments experience is the subject of study of the field of phenomenology of virtual environments. Phenomenology is defined as the study of phenomena as these appear to human consciousness. The main aim of phenomenology is the approach of issues through a subjective view; the interest is not on patterns that appear in the world independent of the consciousness but in the ones that are created through consciousness. Based on these the mind creates a conscious experience which is the object of study of phenomenology.

In the case of the virtual environments there are two realities a real one and a virtual one. On one hand there is the experience of the participation to a real world situation where a virtual world is created and experienced as an experiment, a game or leisure and on the other hand there is the experience of the virtual world as such. Therefore when speaking about phenomenology of virtual environments we speak of two distinct things.

One of these two experiences can be more intense or more "lived" than the other. Usually the experience in the real world is more intense since the body plays a very important role in the way people experience the world. And the body is always in reality. In the virtual world the body has a subsidiary role and the question is if there can be a phenomenology of virtual environments without the participation of the body.

In the virtual world it is only the mind that participates in the experience, the body participates less or in an out of the ordinary way compared to the way it has learned to participate in similar circumstances in the real world. This mind is however formed in a real world body, it carries the knowledge and the experience of a body, it is embodied, and therefore could be considered that it is also the body, through the embodied mind, that participates in the virtual experience. The body has played its role in the formation of the perception and it has no active role anymore. The next question would be how the participation of the body could be more intense, more realistic and after all does it need to be? Is it the body or the mind that needs to be convinced for the participation in the virtual world?

Therefore phenomenology of virtual environments consists of these two types of experience which is necessary to separate as they take place in different settings with different levels of bodily participation. In a virtual environment's game, the active body is using a joystick or keyboard and it doesn't walk. There is however the embodied mind that can grasp the idea of walking, that understands this move, its effect on the body and how it works. This embodied mind however can even go further of the body's capabilities and create more moves, like flying, that the real body wouldn't. In any case, in a virtual environment, there is a mind and not a body that takes part. This mind though is trained within a body and works with the restrictions that it poses.

The degree of distinction of the two experiences defines the level of presence in a virtual environment. According to Witmer and Singer (1998), presence, as a virtual environments term, is defined as the subjective experience of being in one place or environment, even when one is physically situated in another. In virtual environments this means that one experiences more of the computer-generated environment rather than the actual physical locale.

Lombard and Ditton (1997) define presence as the perceptual illusion of non-mediation. They argue that presence is what happens when participants forget that their perceptions are being mediated by technology. They give six conceptualizations of presence of which in our interest are presence as realism and presence as immersion. The term perceptual indicates that the phenomenon involves the senses, cognition and affection and non-mediation refers to the lack of any medium in the communication with the communication environment. The illusion of non-mediation occurs when a person fails to perceive the existence of a medium in the communication environments and responds as if it were not there.

There have been reported many factors that affect presence. According to Lombard and Ditton (1997) factors that affect presence are image quality, image size, dimensionality, proportion of user's visual field, motion, colour, and camera techniques, all named as visual display characteristics. Then there are also aural presentation characteristics and stimuli for other senses like olfactory output, body movement (vection), tactile stimuli and force feedback. For Fontaine (1992) presence is a matter of focus. Loomis' (1992) theory advocates that presence is affected by the set of devices mediating the interaction with a virtual environment.

The real world experience can also be related with the room conditions, like if it is cold or warm in the room, if there are other people around or noise. It is also related with the participants' bodily condition and functions. If the participant is hungry, this is a real condition that may affect the experience. Therefore the goal is to provide the best possible real conditions, to make the real experience as more unattractive, not interesting and comfortable in order to take the participant's mind away of it and make it focus on the virtual one. No matter if a game or an experiment is taking place, what is desired is the participant to be fully immersed in the virtual world, to be transferred with the mind to the virtual world and forget about the body which is in the real world.

Ijsselsteijn (2002) differentiates two variables that determine user's preference: media characteristics and user characteristics or as Slater and Wilbur (1997) have defined them "external" objective determinants of presence and "internal" subjective determinants of presence. The first refer to the apparatus or system used to create the virtual experience and the second to characteristics of the user.

However, a major or the primary cause of presence according to many researchers is interactivity (Lombard & Ditton, 1997; Ijsselsteijn, 2002; Navarre et al., 2005; Witmer and Singer, 1998). Lombard and Ditton (1997) define interactivity based on Steuer's (1995) definition where an interactive medium is one in which the user can influence the form and/or content of the mediated presentation or experience.

Viciana–Abad and Poyade (2010) support that presence is not important only in the sense that it increases the participant's experience of the virtual, but also in the fact that many studies support the idea of a positive correlation between presence and task performance indicating though that for certain tasks, a lower level of presence may imply better performance.

Presence and the virtual experience have mostly to do with the equipment used for the creation of the virtual environment. So it can be either a computer screen and a mouse or a head-mounted display and body sensors. It can be a new experience or a usual one depending on the acquaintance of the player-participant with it. Usually, experienced participants are preferred as the attempt is to take participants interest and mind away from the experience of the real world and equipment.

Presence is related to the level of immersion that a virtual environment can offer. Virtual environments are usually characterised as immersive and non-immersive. This distinction is mostly related to the apparatus used for the creation of the experience. The apparatus consists of the visual display and the movement aids. The visual display can be a desktop display, a screen projection, a CAVE or a head mounted display (HMD). A CAVE is a room-sized cube where the virtual environment is projected on all the walls of the room. A head mounted display is an apparatus worn on the head where the world is projected on two small screens in front of the participants eyes, like wearing glasses, that gives stereoscopic vision of the environment, senses head movement and adjust the image accordingly. From the head mounted display, to CAVE, to screen projection and finally desktop display the experience is considered less immersed.

There have been many studies comparing the several display modes. A study conducted by Sousa Santos, et al. (2009) comparing a head-mounted display versus a desktop display for a navigation task resulted that although users found the head-mounted display interaction intuitive, natural and more enjoyable, most performed better with the desktop setup. However, they attribute this outcome to the possibility that most of the participants were accustomed to the desktop configuration which is used for game interaction while most of them had never used head-mounted display before.

On the contrary a study by Ruddle, Payne and Jones (1999) testing navigation in virtual building with head mounted display and desktop display resulted to participants using the head-mounted display navigating the building significantly more quickly and developed a significantly more accurate sense of relative survey distance. Also they noticed that there was no difference between the two types of display regarding the distance the participants travelled and the mean accuracy of their direction estimates. However, again, like in Sousa's study, the participants were engaged to more natural behaviour with the head-mounted display like looking around and stopping for shorter intervals to choose direction.

The movement apparatus is the mode used for the movement in the virtual environment. This is usually a joystick, a keyboard or a mouse as in classic video games or rarely a more sophisticated glove with sensors or a whole body outfit with movement sensors. In many cases there is physical walking (either real or on a treadmill) translated into movement in the virtual world which is considered to enhance the immersiveness in the environment. However, in any case the most common instruments for measuring presence are subjective questionnaires (Viciane-Abad and Poyade, 2010).

The benefits of using a walking interface to navigate in virtual environments was tested by Ruddle and Lessels (2009) in an experiment where participants had to complete a navigation task under three different "walking" conditions. In one case they were physically in a room while viewing the virtual world in a head mounted display, in the second case they were moving physically but were pushing a button to translate the rotation and in the third case the display was on a desktop therefore there was not at all body based information. The results indicated that in the first case they performed better than the second and third bringing to the forefront the benefits of the implementation of the walking interface to virtual environment applications.

Immersiveness has less to do with the perceptual realism. For example high quality photographs or films may provide a higher resolution of detail for applications such as an architectural walkthrough but a head mounted display will actually convey a more realistic sense of the depth and size relationships in a virtual environment (Riener and Proffitt, 2002).

Transferability of results to real environments and real life

One of the biggest issues in the criticism that virtual environments have raised was on the transferability of the results in real life. The transferability of results is regarded in two different ways. One has to do with the transferability of the knowledge acquired in the virtual environments to real ones and the second has to do with the transferability of the results of the research done in virtual environments to similar real situations. Much of the research in spatial cognition regarding real and virtual environments is focusing on the transferability of spatial knowledge from a virtual to a real environment. The reason is that the use of virtual environments has found welcoming ground in research regarding people with learning difficulties. Therefore virtual environments are widely used to train people in safe conditions.

Beyond this the interest is also in the transferability of navigational patterns, wayfinding strategies and direction skills from virtual to real environments. In other words, in this case virtual environments are used in order to discover patterns or behaviours which would be the same if the experiment took place in real conditions.

First, the transferability of knowledge gained in virtual environments which were used for training or teaching purposes will be discussed and then the transferability of results.

Witmer, Bailey and Knerr (1996) have concluded after an experiment in real and virtual environment that virtual environments can be effective training media for learning complex routes in buildings but also leave a hint that they should not replace real environments but should be used in cases when the real world site is unavailable for training.

According to Richardson, Montello and Hegarty (1999) the transferability of the knowledge of the training from a virtual environment to a real one depends on the extent of similarity between the virtual and real situations like the level of interaction and the provision of multimodal (visual, auditory, proprioceptive) or unimodal information.

According to Cromby, Standen, Newman and Tasker (1996) during an experiment one group of students with learning difficulties performed a shopping task in a virtual supermarket and a second group performed a different learning task in a different virtual environment. Then both groups performed the shopping task all together in a real supermarket and it was found that although there was no difference between the two groups the first time, on repeating the task in the real supermarket the group with the virtual supermarket training were significantly faster and more accurate than the other group without the virtual supermarket training.

During an experiment by Chabanne, Péruch and Thinus-Blanc (2003) in both virtual and real environment, where the virtual was used as training for the real, it was confirmed that spatial knowledge acquired from a virtual environment can be transferred to the corresponding real-world environment. Even more in this case the tendency to compress large distances and to extend longer ones both in virtual and real environments was confirmed.

In some cases transferability is related to special characteristics of the virtual environment like in the case described below that it is related to perceptual realism. A study performed by Wallet, et al. (2011) was designed to test the effect of the perceptual realism of a virtual environment with two conditions, detailed and undetailed, on the transfer of spatial knowledge on passive and active navigation. Passive navigation is considered the navigation when the participant is watching a pre-recorded video of the route while active navigation is when the participant is moving along the route. The results indicated that the detailed virtual environment helped the participants to transfer their spatial knowledge from the virtual environment to the real world, irrespective of the navigation mode.

Chabanne, Péruch and Thinus-Blanc (2003) argue based on previous research, that while studies have shown that people learn the layout of virtual environments more slowly than the layout of equivalent real-world settings, the spatial mental models that people elaborate are similar in both structure and accuracy. They also refer to several studies that reveal good transfer of spatial knowledge between virtual and real environments.

In the second case of transferability, a research that is not testing transferability of knowledge from virtual to real environments but the equivalence of navigation tasks in complex real-world and virtual buildings is that of Koenig, Crucian, Dalrymple-Alford and Duenser (2011) who tested the navigation performance of a group of participants in a real environment and a group in the same virtual environment after showing them some landmarks. Although they indicate that further research is needed the results pointed that there were no significant differences or effects between the two groups.

The above case of conducting experiments both in real and in virtual conditions is the best way of testing the issue of transferability. This is what Van Veen, Distler, Braun and Buelthoff (1998) suggest, that the way to overcome the transferability issue is to reconstruct part of the experiment in real environments as well as in virtual. If the results gained in both the virtual and real environments are similar then further experiments can be performed in the virtual environments and the results will be considered transferable. Of course the drawback of this method is that it makes necessary the need for virtual environments that are modelled after real environments which serves only for specific type of research questions.

In the same mode, a study by Conroy (2001) has shown that patterns of pedestrian movement in the same virtual and real environment are quite the same. In an experiment that took place in the real Tate gallery in London and in a virtual replica of it, the real pedestrians and the virtual participants were having the same movement strategy in both cases resulting to similar movement patterns. Even more these patterns were found to coincide with the ones occurring from the spatial analysis of the gallery using the space syntax methodology.

A study of Richardson, Montello and Hegarty (1999) of navigation in real and virtual environments showed that the performance of the participants in the virtual environment was poorer than those who learned the environment from real navigation or from a map. More specifically virtual environment learners were more susceptible to disorientation after rotation.

Although navigation in virtual environments in comparison to navigation in real environments has a restricted field of view, restricted viewing scale, possible room effects, a lack of proprioceptive feedback and of physical effort, research suggests that the effects of all the above have a relatively small magnitude compared to the structure of the environment (Colle and Raid 2000; Waller, Loomis and Haun, 2004).

Virtual environments as a methodology in the studies of the built environment, spatial cognition and environmental perception

Virtual environments have been widely used in the study of the built environment in several fields. These include computer automated design, modelling, spatial analysis, in engineering for the simulation of buildings' responses to environmental conditions (earthquake, wind) and of course as a visualisation tool. However, their use is keep increasing as a methodological research tool in regard to people's responses to attributes of the environment.

One of the fields related to the built environment studies where virtual environments have been used as a methodology is that of spatial cognition. In these studies the virtual environments have been widely used especially for research on navigation and wayfinding due to the difficulty of separating stimuli that are tested in such studies in the real environment and in recording participants' behaviour which is particularly important in this type of research. Virtual environments have been also used in research related to the perception of environmental properties like size, distance and so on, and the transferability of such researches' results in real environments.

The studies which use virtual environments as a methodology can be separated in two categories: those that are trying to test factors that affect the performance, perception or cognition, in a virtual environment and those that are testing whether the results gained in a virtual environment are the same as in a real one. In the second case the virtual environments are used as a methodology that offers the opportunity to conduct research which would otherwise be impossible to conduct in real environments and in the first case the virtual environments as a methodological tool which can replace reality is questioned. There are cases when the patterns are the same in both real and virtual environments and other cases when the patterns differ.

The virtual environments in this thesis are used as described in the second category. The question is to study the effect of a variable, which is scale, on people's behaviour in conditions that would be impossible to recreate in real environments. The validity of the use of virtual environments as a methodology for the study of scale is considered to be granted through the research that is presented in the current chapter and show that virtual environments have been used for similar studies bringing to the front both successful results and critical negative issues. Whether the use of virtual environments as a methodology for studying scale issues is successful or not will be presented in the general discussion in chapter 7 after the presentation of the experiments.

In almost all studies of environmental perception or spatial cognition in virtual environments there is not research regarding scale but there is research relevant to it concentrating on perception of distance and size. In many cases, some of which presented below, it is found that perception of distances and sizes are underestimated in virtual environments (Henry and Furness, 1993; Lampton, McDonald, Singer and Bliss, 1995; Witmer and Kline, 1998).

Lampton et al, (1995) conducted an experiment for the estimation of a small distance with three types of virtual environments apparatus, in the first case with head-mounted display, in the second case with binocular omni-oriented monitor and in the third case with a computer monitor. They have concluded that for distance perception between the participant and a moving figure most participants called out before the figure had closed the specified given distance while in real environments they called out after the figure had closed or passed the specified given distance. It is apparent then that not only the participants underestimate the distances in virtual environments but they have also been overestimating the distances in real environments.

Henry and Furness (1993) conducted an experiment of navigation in a real and in a virtual museum gallery with architects as participants in order to test dimension evaluations and orientation. The participants were tested in three different virtual settings, one with a desktop display, one with head-mounted display with head position tracking and one with head-mounted display without head position tracking. The results indicate that the participants underestimate the dimensions of the gallery in all settings of virtual environments than in the real gallery.

Contrary, in a desktop display experiment by Ruddle, Payne and Jones (1997), participants who navigated in a virtual building and were asked to judge directions and distances, not dimensions in this case, were showing similar results to those found with the real building, after overcoming initial disorientation.

In Willemsen, Gooch, Thompson and Creem-Regehr (2008), an experiment is presented where the imperfect viewing conditions in head-mounted displays has been tested as the reason for distance underestimations. Given the results of the paper, the restricted field of view of head-mounted displays and their imperfection in binocular image are not the cause for the underestimation of distance perception.

As seen above, in most studies the apparatus type of the virtual environment and the restrictions that each provides do not seem to account for the wrong distance estimations. Factors that affect the wrong estimation are suggested by Witmer and Kline (1998) to be either visual cues that affect perceived distance or visual, cognitive and proprioceptive factors that affect traversed distance.

In an experiment conducted by Witmer and Kline (1998), they have found that participants underestimate distances both in the real and in the virtual environment but the underestimates are more extreme in the virtual world. In order to test for visual factors affecting distance estimates they have applied different textures on objects and found that textures don't affect distance estimates. Also, in order to test for proprioceptive factors they tested different movement methods to conclude that moving via treadmill didn't improve distance estimates over moving with joystick.

On the other hand and regarding texture Naceri, Chellali and Hoinville (2011) have different findings. In their investigation towards factors that affect distance estimation they conducted an experiment in virtual environments using head mounted display, testing depth perception in three environments with different level of cues, in a dark room, in a wireframe and in a lit textured room. The participants had to evaluate the egocentric distance to spheres in two different cases: first case, the apparent size of the sphere was held constant and in the second case it co-varied with distance. In the first case it was found that participants estimated depth more accurately in the lit and textured virtual environment. More specifically the error was small in distances up to 55cm and increased with distance above the 55cm. In the second case there were mostly individual differences. The above experiment indicates texture and good viewing conditions as a factor affecting distance estimations.

A factor on which the wrong distance estimation is often attributed is the sense of disembodiment usually being the case in the virtual worlds. In an experiment conducted by Mohler, Creem-Regehr, Thompson and Buelthoff (2010) in a head-mounted based virtual environment testing distance judgments a rendering of the user's own body was applied. It is considered that the view by the participants of a representation of their own body brings back the relation to the body and creates a sense of embodiment. It was found that participants who could see a representation of themselves made more accurate judgments of absolute egocentric distance to locations ranging from 4 to 6m away than did participants who saw no avatar.

Beside studies like the ones presented above that are investigating into the estimation of distance comparing virtual and real environments and factors that affect the estimates in virtual environments, there are also studies in virtual environments attempting to find the factors that affect perception of distance. In this case virtual environments are used as a tool for predicting behaviour in the real world. Such a use of virtual environments is supported by Cubukcu and Nasar (2005). They conducted an experiment which was testing a previous research finding on the effect of the segmentation of built form along a route on the perceived distance of the route. The findings confirmed the previous research. The more buildings there were along a path the highest was the perceived distance.

In another study by Osmann and Berendt (2002) which was testing also the perception of distance in different environmental conditions it was found that this was related to the number of turns along a route. The distance of the route with the fewer turns was underestimated while the distance of the route with more turns was overestimated confirming results gained in a previous similar experiment in real environment by Sadalla and Magel (1980).

Also, Belingard and Péruch (2000) conducted an experiment testing estimation of distance and direction in three different cases in virtual environment: in free condition, in occluded travel condition and in complete occlusion. The difference between these cases is based on the difference between what they call procedural and configurational type of spatial representation. The first is the spatial representation based on perception and is created when people can see unoccluded (this is the free condition) the space of which they make the representation. The second representation is based on cognition and is created when people cannot see the space of which they make the representation because there are occluded objects. Their findings show that distances errors were lower in the free and occluded travel condition than in the complete occlusion and even more the distance errors were the same in the free and the occluded travel condition.

Regarding the perception of size the three cues for size judgment that apply in real environments apply also in virtual environments. These three cues are, the horizon ratio, the eye-height cue and the relative size cue (as relative to other object's size) (Dixon, Wraga, Proffitt and Williams, 2000). A good indicator in real world studies is the eye height-horizon cue. This works also in immersive virtual environments as effective eye height scaling can occur in immersive virtual environments but not in non-immersive virtual environments. In non-immersive virtual environments Birgham (1993a; 1993b, cited in Dixon Wraga, Proffitt and Williams, 2000) suggested that familiar size is better indicator than horizon ratio. In non-immersive virtual environment observers did not associate the depicted horizon with their own eye height which caused the object sizes to be ambiguous. This was not due to the reduced field of view as experiments in immersive virtual environments with reduced field of view had the same result as the non-restricted.

One study that is related to scale is that by Glennester, Hansard and Fitzgibbon (2009) that was conducted in an immersive virtual environment was testing the perception of the size of objects in a room that was expanding from one test to the other. The finding of the study was that the observers failed to notice the expansion of the room around them and were consequently making gross errors when comparing the size of objects. The failure to notice the change in a room's size is an outcome that wouldn't be expected to happen in a real environment. The sense of embodiment in virtual environments is again questioned.

Summary

The current chapter has presented the use of virtual environments as a methodological tool for research in the field of spatial cognition and environmental perception. Virtual environments have been used for the conduct of the two experiments presented in the current thesis and therefore some issues regarding their use in research should be first discussed.

The use of virtual environments in research has widely expanded as they offer advantages which are not possible in cases of real environments. These include the controlled conditions, the interactivity, the behavioural tracking and performance recording and the safe conditions in low risk.

In the experiments of this study the virtual environments were chosen most of all for the ability to produce controlled conditions. The intension to create environments which would be stripped off from unnecessary noise that would only obstruct the effect of the desirable variables could only be done in virtual environments. The ability to keep constant several characteristics of the environment, as the layout in the specific ones, and change others, as the scale, limits the opportunity to find such environments in the real world. The virtual environments would give the prospect to test different scale conditions easier, faster and in a controlled manner.

Beyond this, the interactivity and the behavioural tracking are also important as virtual environments would give the opportunity to participants to freely navigate in the environments without any obstructions and distractions. The recording of data that would be done automatically is also offering a case where clear and accurate data are collected.

Of course, besides the advantages offered, the disadvantages could not be neglected. As it has been described above, these include the perceptual realism of the environments, the desired level of detail and the participant's level of experience. Although three dimensional representations nowadays can give a quite satisfying level of perceptual realism and detail, the fact that it is not easy to find mechanical settings that can support such representations has lead to an intermediary solution. Given the available mechanical settings, the time schedule and the cost, a medium level of perceptual realism has been applied in the experiments' virtual worlds.

It has been presented above how the participant's experience in a virtual environment is related to the phenomenology both of the real and of the virtual. The prevailing of the one over the other defines the level of presence in the environment. Presence is an important characteristic of the virtual environments which relates to their success as a methodology. The higher the presence, the more the experience is transferred from the real world to the virtual and the more successful the setting the experimenter is intending to obtain is considered to be.

Factors that affect presence have been described to be on one hand the media characteristics like the apparatus, the visual display, the devices mediating, the room conditions and on the other hand the user characteristics, like individual differences or the user's acquaintance with the apparatus. Finally, an important factor of presence is the level of interactivity.

Presence is closely related to the level of immersion created in the virtual environment. The virtual environments are categorised in immersive and non-immersive, a distinction mainly based on the type of apparatus used. A head-mounted display and CAVE apparatus are considered to create an immersive virtual environment while a desktop display or a screen projection are considered non-immersive.

In the current experiments two different modes of apparatus have been used. One experiment has been in an immersive virtual environment with the use of a head-mounted display and the other in a non-immersive virtual environment using a big screen projection. The experiment included two different modes as it is not clear in literature whether there is any clear advantage of the use of one over the other. Both experiments included questionnaires asking about the use of the apparatus in order to get participants' feeling about it.

Another important issue regarding virtual environments as it has been described above is the transferability of the results. The virtual environments are divided in two groups depending on what is transferred. In one group the transferability concerns knowledge that is acquired in the virtual environments and whether this can be transferred in real environments and in the other group transferability concerns the transfer of the results acquired by the study conducted in virtual environments, like whether navigation performance and movement strategies that were observed under specific conditions in virtual environments would be the same in real ones. Transferability has been proved to be successful in both types of experiments and is related to the level of interaction, on the media used and on perceptual realism.

For this thesis the second type of transferability is in the spot as the interest is to test conditions in virtual environments that can elucidate what happens in real environments. However, transferability of the results gained by the current experiments will not be tested in the current thesis. This is considered to be the focus of further research on scale. In the current thesis the virtual experiments will be used to shade light in the effect of scale on navigation and wayfinding. It can be the focus of next research to test in real environments the findings of the current experiments. In any case the fact that previous research, as described above, has shown that transferability of results from virtual to real environments is successful, cannot be neglected and therefore will be considered to possibly be the case in the current research.

Finally, looking into studies using virtual environments for the investigation of spatial cognition and environmental perception again two different categories of studies have been separated. In the first category there are studies that are looking into factors of the virtual environments as a medium that affect the performance in perception and cognition and the in the second there are studies that are testing cognition and perception performance under different conditions irrelevant of the medium (which in the specific case is the virtual environment but it could be the real as well).

In the first category factors that are mentioned to affect performance are the apparatus, the level of immersion, the level of detail of the environment and the sense of embodiment. These factors will be brought back in the general discussion of the thesis in chapter 7 in relation to the finding of the experiments. What will be questioned is whether findings that occur are due to the medium used. The findings point to the direction that the sense of embodiment plays a role, the use of texture remains questioned and the apparatus has probably minor role.

In the second category factors that have been found to affect perception of distance have been reported to be the segmentation of the built form along a route, the number of turns along a route and the level of occlusion of the distance that is questioned. These effects give some clues on how the perception of scale may be affected by environmental factors.

The reasons for the decision to use virtual environments for the current research have been explained. The questions that this chapter raises on the use of virtual environments will be addressed again in the general discussion chapter after the presentation of the virtual environment experiments and their findings.

In what follows the first experiment in virtual environments will be presented.

Chapter 4

Perception of environmental differences while navigating in virtual urban environments with three-dimensional scale differences

Abstract

This study was set up to test how changes in three-dimensional scale are perceived by people navigating in virtual environments. The participants were asked to navigate in six virtual urban environments which had the same spatial layout but different properties of scale or proportion. The environments were set up in two groups with different layout each. One group had a space syntax intelligible layout and one had an unintelligible layout. Both groups had different visual legibility due to the differences in the three-dimensional scale. The participants had to fill in a questionnaire regarding the perceived differences of the environments.

The qualitative analysis of the questionnaires and the study of the participants' paths in the virtual environments are presented in this chapter. A main hypothesis for the perception of scale has been created through this study. This is that the perception of differences of scale properties of form affects the perception of both geometrical and topological properties of space.

Introduction

An experiment was set up in order to investigate how the three-dimensional scale differences of the built environment are perceived by people and affect the way they move in the urban environment. The methodology used to investigate this issue is that of the navigation in a virtual environment as it has already been described in the previous chapter where the advantages of the conduct of experiments in virtual environments have been presented. In general, it can be summarised here that virtual environments provide the possibility to separate and manipulate independent variables and the perception of each variable in a more controlled way than in the real environment. Therefore, the main reason that this experiment was conducted in a virtual environment was that it is hard to separate and manipulate scale as an independent variable in a real environment.

The experiment that is presented in this chapter was conducted in order to examine if and how scale differences of the built environment are perceived by people navigating in urban environments and in order to help create a hypothesis on the effect that scale may have on perception and navigation. The perception of the three-dimensional scale is studied on people while navigating because movement is an important factor altering and informing perception as it has been already presented in chapter 2. Therefore the interest in this study is on perception while moving.

The objective of this virtual experiment was to examine if and how differences of the three-dimensional scale of the built environment are perceived by people moving in it. The aim was to produce systemic variations of an urban environment regarding the building heights and the overall scale and then examine whether these variations were perceived by the participants and in which way they were affecting their judgment of the environment's properties.

The analysis of this experiment is based on the qualitative and interpretative analysis of the participants' comments while navigating and on questionnaires given after navigation. The comments are helping to build up a hypothesis to be tested in the next study. This type of investigation where quantitative research is grounded by prior use of qualitative is a possible case in research (Murray, et al., 2000).

The virtual worlds

The worlds were designed in such a way to present variations in buildings heights and scale within the same urban layout. This means that the virtual worlds that have been designed have the same urban layout, this is same plans and same block structure, but different building heights and overall scale. Therefore, the visual qualities of the environments vary for someone moving on the street level and looking at the street image. On the other hand, while looking at the plan representation the worlds seem to be identical. The worlds have the same plan configuration but different visual and formal properties.

There are in total twelve worlds which can be divided in two groups of six worlds each. The differentiation in the two groups is based on the two different layouts that are used. The two urban layouts have been designed and published by W. Hillier in the book “Space is the Machine” (Hillier, 1996) and are presented in figure 4.1. These two layouts have been chosen due to a main property that they have, according to space syntax theory, which is called “intelligibility” and has already been presented in the introduction and is further explained below.

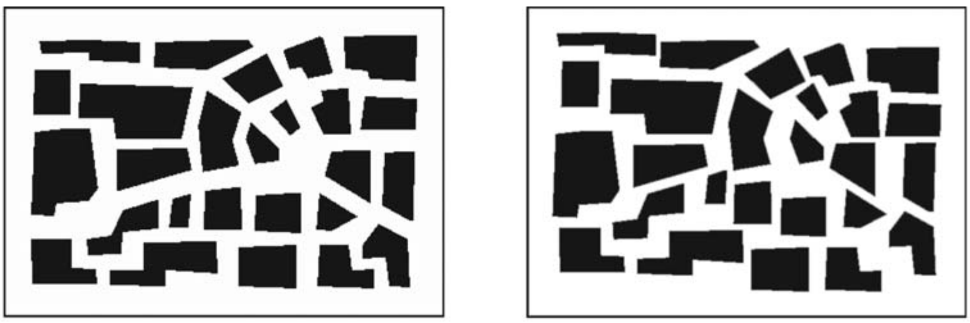

Figure 4.1 The original layouts as presented in Space is the Machine, the intelligible on the left and the non-intelligible on the right.

These two urban layouts are constituted by the same number and size of blocks. However, according to space syntax there is a main difference that has as a result that these two layouts are demonstrating different navigation patterns. The difference in the layout is that the blocks in the second layout (figure 4.1 right) are slightly shifted. This misplacement creates a different space configuration as it is obvious in figure 4.1. The difference in the spatial configuration can be represented with a space syntax measure that is based on the topological properties of each urban layout and is called "intelligibility".

The "intelligibility" of a system, in general terms, is used in urban studies to judge how easy may be for an urban system to be "read" and understood by its users. In space syntax, as it has been already mentioned in the introduction, there is a specific and "in house" developed definition of "intelligibility" (Hillier, 1996) which is defined as the ability of an urban system to give to the pedestrian information for its overall configuration by seeing parts of it at a time. In lay terms this would mean how easy it is for a pedestrian walking in this urban system to grasp its overall layout or global structure by navigating on the streets and perceiving only the local structure at a time. This is the way people meet cities and urban environments. One comes across small parts of the city at a time when walking around. One only sees a local configuration, where the eyes reach, and a couple more streets like where one has come from, where one is going and some intersections that denote the existence of more streets, in a few words, the connections of the streets. As one walks in the city and interacts with small localities he is starting to build a cognitive map of the layout of the city by putting these bits together. "Intelligibility" of the system is the property of the spatial configuration of a system to give good information to the pedestrian to build the whole image from the smaller pieces. Therefore, according to space syntax, "intelligibility" is a measure that derives from the topological properties of the space configuration of a system (Hillier, 1996) which is denoted by the relation between connectivity and integration of a system.

The connectivity of a space is a local property and a property that can be seen from each space, as described above, one walking along a street can see the connected streets to it. Integration is the depth of a space from all other spaces of the system and, opposed to connectivity, is a property that cannot be seen from that space. Therefore, according to space syntax intelligibility of a system means the degree to which what can be seen from a space is a good indicator to what cannot be seen. An intelligible system is one where well-connected spaces tend to be well-integrated.

Space syntax research has shown that an intelligible system is easier to navigate than a non-intelligible one (Conroy, 2001; Haq and Zimring, 2003). The difference in intelligibility in the experiment's environments is achieved just by a slight movement of the blocks which is however enough to change the space configuration. The change of the space configuration changes its topology. This means that the relation of local elements to the global system changes and therefore the "intelligibility" of the urban system changes.

Space syntax measures the change of the topology by using graph theory. The nodes of the graph are pieces of the unique otherwise space of the system. The way the unique space is broken down to pieces is based on the human perception of this space. In other words, each piece of the broken down space is a unity which can be instantly and statically perceived by a human standing at a single point. This unity is called by space syntax axial line and is defined as the longest line of sight. The pieces of the space and their connections, called axial map, can be represented as a graph which is different in each of the two cases. The topology of the graph of the system defines the "intelligibility" of the system.

The reason that an intelligible and a non-intelligible world have been used in this experiment is to examine if there is any interrelation between intelligibility, navigation patterns and perception of three-dimensional differences. Considering that, disregarding scale differences, an "intelligible" urban system is easier to navigate than a "non-intelligible" one then it would be expected that the same pattern would prevail even when having scale differences.

The layouts used for the virtual environments are not exactly the same as the original ones in "Space is the machine" (Hillier, 1996) but are slightly modified. In "Space is the Machine" all the side edges of the layouts are flat walls but in the current experiment the edges are treated in the same way as the rest of the environment with the creation of extra blocks leading to dead-ends. This modification is done in order to make the world look more realistic and avoid having a flat distinctive wall around the urban system indicating its edge. Figure 4.2 shows the modified urban worlds.

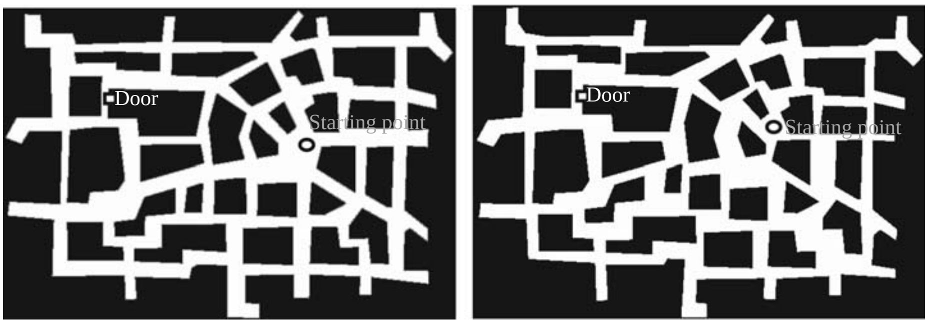

Figure 4.2 The modified layouts used for the virtual experiment. The small white square on the left side of each world shows the location of the object the participants had to find and the dot on the right side the starting point.

As mentioned above two groups of environments, one based on the “intelligible” layout and one on the “non-intelligible”, have been created. Each group had six different environments. The differences among the six environments are related to the scale, proportions and building heights. The diagram in Figure 4.3 sketches out the differences among the six environments. The code names are A1, B1, C1, D1, E1 and F1 for the “intelligible” virtual worlds and A2, B2, C2, D2, E2 and F2 for the “non-intelligible” virtual worlds.

Visually the virtual worlds were very simple, without textures, landmarks or any other detail that would add cues to the environments other than the scale. The virtual worlds consisted of buildings forms and shapes. It was only environments E and F that had extra detail with facades constituted with windows and doors which again were all the same for all buildings without differentiations in the windows and doors.

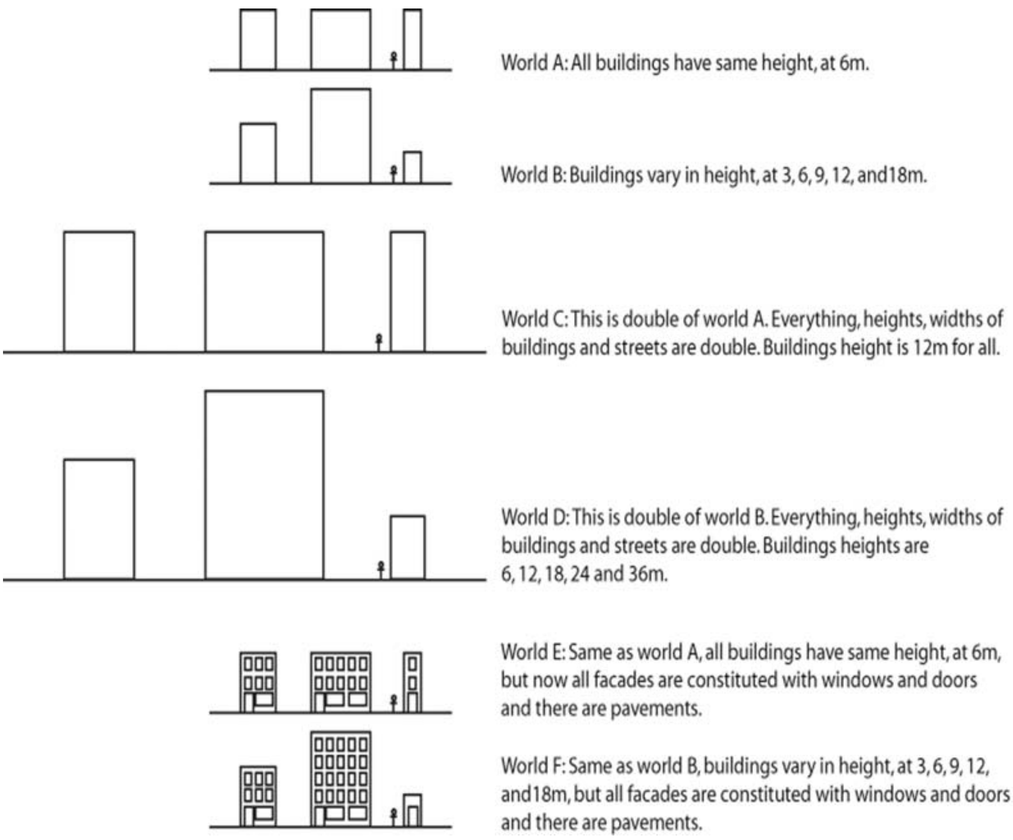

Figure 4.3 Sketch diagram of each of the six worlds.

Virtual worlds A1, A2, B1 and B2

The numbers in the naming of the world denote the “intelligible” system for 1 and the “non-intelligible” system for 2 while the letters denote the differences in scale meaning that worlds A have same scale properties, the same goes for B worlds and so on.

In worlds A1 and A2, all the buildings have the same height which is 6 meters. There are no doors or windows on the buildings. In worlds B1 and B2, the buildings have different heights and these are 3, 6, 9, 12, an 18 meters. The height of each building is randomly attributed. Again, these worlds have no doors or windows. (Figure 4.4).

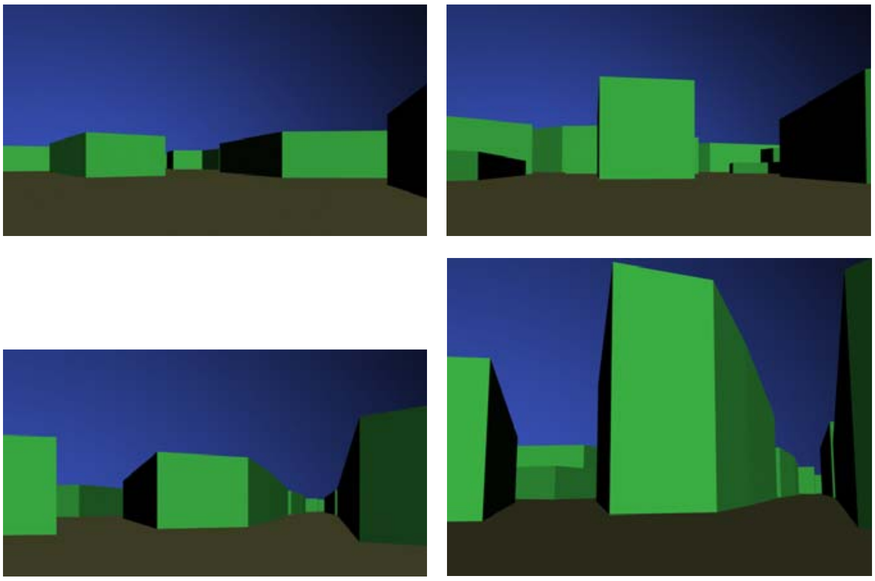

Figure 4.4 Screenshots of Worlds A1, B1, A2 and B2.

The design and comparison of results of worlds A1 and B1, both “intelligible” but with differences in building heights, is expected to test how environments with the same spatial configuration but different heights will be perceived. Furthermore, it is expected to test whether the differences in building heights will enable or disable the perception of ease of navigation and wayfinding. The comparison of A2 and B2, both “non-intelligible” but with differences in building heights, will attempt to test the same questions but having as starting point the “non-intelligible” worlds which are already considered to be more difficult to navigate.

Virtual worlds C1, C2, D1 and D2

In worlds C1 and C2, everything is double size of worlds A1 and A2. As a result, all the buildings in C1, “intelligible”, and C2, “non-intelligible”, have the same height which is 12 meters. Width and length of roads are double than in worlds A1 and A2. Worlds D1 and D2 are double scale of worlds B1 and B2 respectively. Therefore, the heights of the buildings in D1, “intelligible” and in D2, “non-intelligible” are 6, 12, 18, 24 and 36 meters. None of the worlds C1, C2, D1, and D2 have windows or doors. The size of each of the small scale worlds is around 260mx400m and the big 520mx800m.

The comparison of the results of worlds A to C and B to D is expected to test how environments with the same spatial configuration and same proportions but different scale will be perceived. The difference in scale in the case of environments C and D is not just an absolute change of scale meaning that every dimension is double but it is also apparent in the relation to the human body. This means that in a real world even if all things around got double the human body would still keep its usual dimensions and would act as a standard. This is also expected to happen in the experiments.

The second question that is tested with the comparison of A to C and B to D is whether the double scale in both “intelligible” and “non-intelligible” urban environments has any effect on the perception of ease of navigation and wayfinding.

Finally the comparison of C, same heights, to D, different heights, is testing how the differences in proportions from one world to the other are perceived when the scale is double. These results are compared to the ones from the comparison between A and B to test whether there is a difference between small scale and big scale.

Virtual Worlds E1, E2, F1 and F2

Virtual worlds E1, E2, F1 and F2 are exactly the same as worlds A1, A2, B1 and B2 with extra feature that the buildings have windows, doors and there are pavements. Actually, E1 and E2 have buildings with same height which is 6m, and F1 and F2 have buildings with different heights which are 3, 6, 9,12 and 18m. The doors, windows and pavements are designed in order to introduce hierarchical scaling and give a sense of familiar size (doors, windows and pavements sizes) to compare to the buildings size. In all cases, the ground floor was constituted with doors and big windows (like shop windows) and all the floors above with sliding windows. Each floor was considered to be 3 meters high which resulted to have 1 floor buildings (3meters building), two floors (6meters building), three floors (9 meters) and so on (figure 4.5).

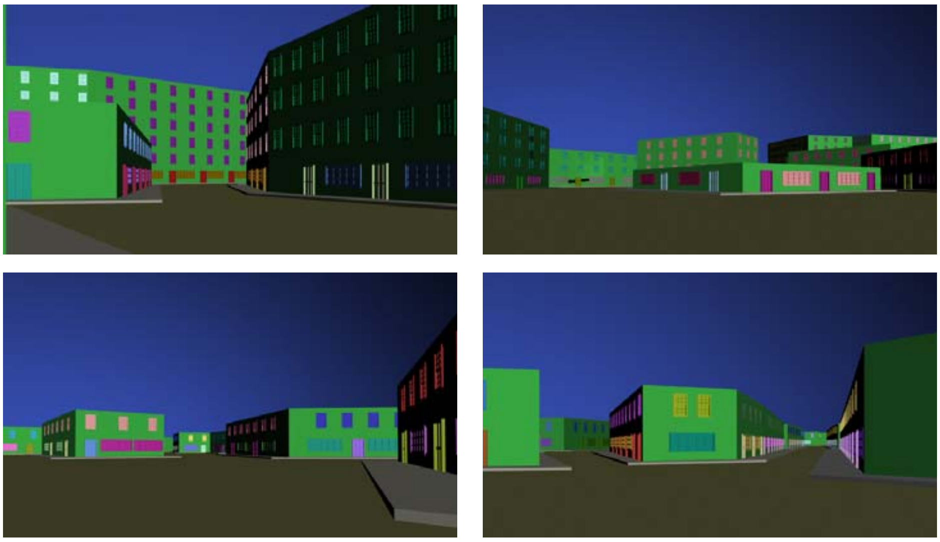

Figure 4.5 screenshots from virtual environments E1, E2, F1 and F2.

The comparison of the results of worlds E to A and F to B is intended to test how environments with the same spatial configuration and the same scale but different proportions in the sense of scaling hierarchy and familiar size elements will be perceived. Also, the comparison is intended to test if the perception of navigation and wayfinding is affected when there are clues of familiar size.

The Apparatus

The experiment took place in the VR Lab of the Bartlett School of Graduate Studies in University College London. The apparatus that was used was a head-mounted display system with head tracking with which each participant was visualising the worlds in three dimensional projection and a three dimensional mouse to move in the worlds. The apparatus of this experiment is considered to give an immersive experience of virtual environment.

The software used for the navigation in the virtual environment is called “Candle” (initially authored by Nick Dalton and next version by Chiron Mottram) and was developed in the VR Lab of the University College London. The head mounted display system used for the experiment is called “Arthur AR Prototype Display system” or “AddVisor™ 150”. This is a helmet like apparatus with two miniature flat panel displays (figure 4.6). The displays are full colour 1280*1024 pixel computer screens, one in front of each eye and each giving a slightly different view so as to mimic stereoscopic vision. The horizontal field of view is 54 degrees horizontal by 29 degrees vertical. The head movement tracking system used was “Motion Tracking by Ascension” with an “Inertia Cube by Intersense”. The position and orientation measurement system was called “The Flock of Birds”. The walking speed was always constant and approximated with normal walking speed at 7km/h.

Figure 4.6 The head mounted display system.

The models were drawn in two dimensions first in “Autocad 2005 by Autodesk” and then the three dimensional models in “3d Studio Max v.7 by Autodesk”. The extracted data, which were the position of the object in the virtual world, were saved twenty times per second as an ASCII text log file. These data files were then imported in “Mapinfo Professional v7.5” in order to visualise and manipulate the data.

Participants

The participants in the experiment were twenty two English speaking unpaid volunteers who corresponded to a school-internal announcement. Eleven of them participated in the experiment with the group of “intelligible” worlds (A1, B1, C1, D1, E1, F1) and the other eleven in the group with the “non-intelligible” worlds (A2, B2, C2, D2, E2, F2). In the “intelligible” group, 55% of the participants were female and 45% male while in the ‘non-intelligible” group, 45% were female and 55% male. In the “intelligible” group, half of the participants (55%) were in the ages of 30-35 years old and 27% younger, 25-30 years old, while in the “non-intelligible” group almost all of them (73%) were in the range of 25-30 years old. The participants’ occupation was representing a bias towards researchers and architects, 91% of the sample being researchers in Group 1 and 60% in Group 2. Architects were also 45,4% of the participants in Group 1 and 64% of them in Group 2. At the current stage, individual differences are not in the interest of the research but in future steps these could be studied in order to test individual differences among architects and furthermore differences between visualisers and verbalisers (Kozhevnikov, Hegarty and Mayer, 2002; Kozhevnikov, Kosslyn and Shepard, 2005). Table1 shows the statistics for each group.

	“Intelligible” Group		“Non-Intelligible” Group
Sex	55% female		45% female
Age	55% 30-35yrs old	27% 25-30yrs old	73% 25-30yrs old
Occupation	91% researchers		60% researchers
Architects	45.5%		64%

Table 4.1 Statistics of the participants in the experiment.

Experiment Procedure

The experiment was conducted after the approval by the University College London's Committee on the Ethics of non-NHS Human Research. The participants were first handed a "Participant Information Sheet" informing them about the nature of the experiment, that their participation is voluntary and they can pull out at any time should they wish and that the collected data will be stored in accordance with the Data Protection Act 1998. Then if they agreed to proceed they were asked to sign the "Informed Consent Form".

After the task was explained to them the actual experiment was starting. First they had a test navigation to get used to the apparatus. The test virtual world had different layout than the virtual worlds of the actual experiment. During the test navigation they just had to "walk around". When they felt comfortable with the apparatus the actual experiment started.

The starting point was a small city-square in about the centre of the world. The task was to find a purple sliding door on one of the buildings and if it was found then they were asked to go back to the starting point. The participants knew from the beginning of the experiment about the return to the starting point task. In this way the return task was expected in all rounds because otherwise if it was not announced the first time it would be unexpected in the first round but expected in the next rounds changing in this way the degree of attention between the two. The door is indicated in figure 4.2 with a small square. They were starting from the same point in all environments, which is in about the centre of the world, which is indicated with a white dot on the modified plans of figure 4.2. The door is at the same place in all virtual worlds. Before they start the navigation they were asked to turn around and have a 360^{o} look around the starting point and then start moving. They had ten minutes to complete the task in each virtual world and five to ten minutes interval between each navigation.

During some of these intervals the participants had to answer questions related to the differences of the urban environments where they had previously navigated and to the ease of navigation. The questions were answered some at the intervals between the navigations and some at the end of all navigations. In order to avoid any bias caused by the order of the virtual worlds in the experiment and the acquaintance of the navigation, the order was different for each participant but organised in such a way to allow for the same questions to be answered.

For example the first participant would start from virtual world A, the second from B, the third from C and so on. However, the aim was always to keep worlds A and B and C and D continuous for the questions to be possible to be replied. So if B was first then A would be second or similarly if D was first then C would be second. In the same way, pairs A-B and C-D were always continuous with no importance which comes first. In any case, all worlds had passed from the first, second, third and so on place of the order of the experiment.

This change of order slightly affected the way the questions were replied. So if the pair A-B was first, the first question would be replied after the completion of these two experiments. However, if the pair C-D was first, then both first and second questions would be replied after all four environments (C, D, A, B) were completed. If the pair E-F was first, all questions of the questionnaire would be replied after the end of all navigations. This change of order of the questions was considered as a factor decreasing any bias based on the alert in attention the first question would cause. For example, when the first question was asked after the completion of the first pair of worlds, this alerted the participants to look for differences in the following worlds. Although, according to this change there were at most only two participants executing each order the experiment's design couldn't be done differently. The reason is that each pair, like A-B and B-A or C-D and D-C, had to be continuous in order for the questions to be asked properly. A possible way to overcome this issue would be with more participants.

Questionnaire

The questionnaire, which can be found in Appendix A, consisted of two parts. In the first part there were questions on personal data like sex, age, occupation, previous experience in immersive environments and previous experience in non-immersive environments like computer games.

The second part of the questionnaire consisted of questions related to the experiment. The first two questions were regarding the perception of changes between virtual worlds. The first question was whether the participants had noticed any difference between worlds A and B (A1 and B1 or A2 and B2 depending in which group the participant was) and the second about the differences among the four worlds A, B, C and D (again A1, B1, C1 and D1 or A2, B2, C2 and D2 depending on which group the participant was). The third question was regarding the perception of ease of navigation and asked the participants whether they had found any of the six environments easier to navigate and to explain why. The purpose of this question was to identify how the participants had perceived the intelligibility of the environments in a conscious level. The final question posed the question of the level of difficulty in moving around in the virtual environment. If they found a difficulty they were asked to explain what it was. The purpose of this question was mainly to identify cases in which the difficulty in navigation was not due to the properties of the environment but due to the nature of the experiment being virtual and problems related to the apparatus.

Dependent measures

The collected data from the navigation were the x, y, z coordinates of the position of the participant. The data was collected 20 times per second. The coordinates were then mapped to give the route of each participant in each virtual world.

The routes of the participants will be tested in correlation to the space syntax measure “integration” of the spatial configuration of the virtual worlds indicating properties of the layout disregarding the scale and building height differences. These will be tested opposite current space syntax hypotheses regarding navigation and wayfinding.

Most important part of the analysis will be based on the qualitative analysis of the questionnaires. By looking into the participants’ answers and comments, common issues regarding the perception of the scale differences will be sought which will help to create a hypothesis on how these differences are perceived by people navigating in a city.

Axial Analysis of the Virtual Worlds

After having seen the visual and formal properties of the virtual worlds, the spatial configuration analysis of each of the two layouts will be now presented. The analysis is based on the space syntax measures and will be used to study the results of the participants' paths of the experiments.

In figure 4.7 the space syntax spatial analysis of the two layouts, the "intelligible" and the "non-intelligible" are presented. The axial analysis is a form of analysis of a spatial layout which is based on the representation called axial map. An axial map consists of the longest lines of sight that pass through a convex space. In the sequence, based on graph theory and assuming that each line is a node of a graph, several measures which measure properties of the graph can be calculated. One such measure is called "integration" and it is measuring the relative depth of each line to all the other lines of the system. Practically speaking this means that it measures how easy it can be to get from one line to all the other lines. The line which is in such a location in the graph, or equally the urban system, where the trips to all other lines are easy is considered to be integrated to the system. The level of ease and difficulty is measured by step distance defining as one step the transition from one line to another.

A value is assigned to each line using an algorithm calculating the relative topological distance from this line to all other lines. This value represents its level of integration in the system. All the lines are then coloured according to their integration value from red for the most integrated down to blue for the least. The result is the axial map of figure 4.7. The colour spectrum used is from red to orange, yellow, green and finally blue. This map gives very good information on the spatial layout of the urban system. This information is useful since it has been tested that the integration value of a space-line-street is a good predictor of the accumulated pedestrian movement that this space may accept (Hillier, et al., 1993).

In other words the people in an urban environment are using mostly the integrated streets.

The two layouts used in this experiment have been used before in another virtual experiment conducted by Conroy Dalton (Conroy, 2001; Conroy Dalton, 2003) where it was revealed that the participants were indeed using the most integrated roads. There was a correlation in pedestrian movement and integration values of axial lines.

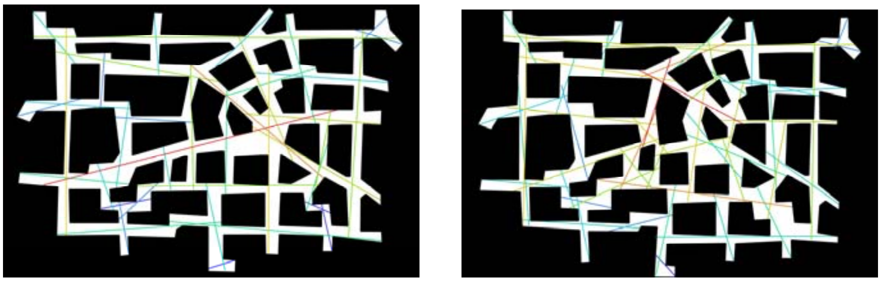

Figure 4.7 Axial analysis of the two layouts used for the experiment, “intelligible” left and “non-intelligible” right.

The way to create a correlation between pedestrian movement and integration values is to introduce in the analysis “Gate Counts”, a common method in space syntax (Hillier et al, 1993). Gate counts are virtual invisible gates crossing the axial lines. The number of people who cross such a gate during an experiment’s navigation are counted and the number of pedestrians/participants crossing this virtual gate is plotted in a graph against the value of the integration of the axial line crossing the same gate. For the “intelligible” layout it has been shown that the correlation is high when for the “non-intelligible” it is low.

The question posed now is to test whether this pattern remains when scale differences are introduced in the virtual urban environments.

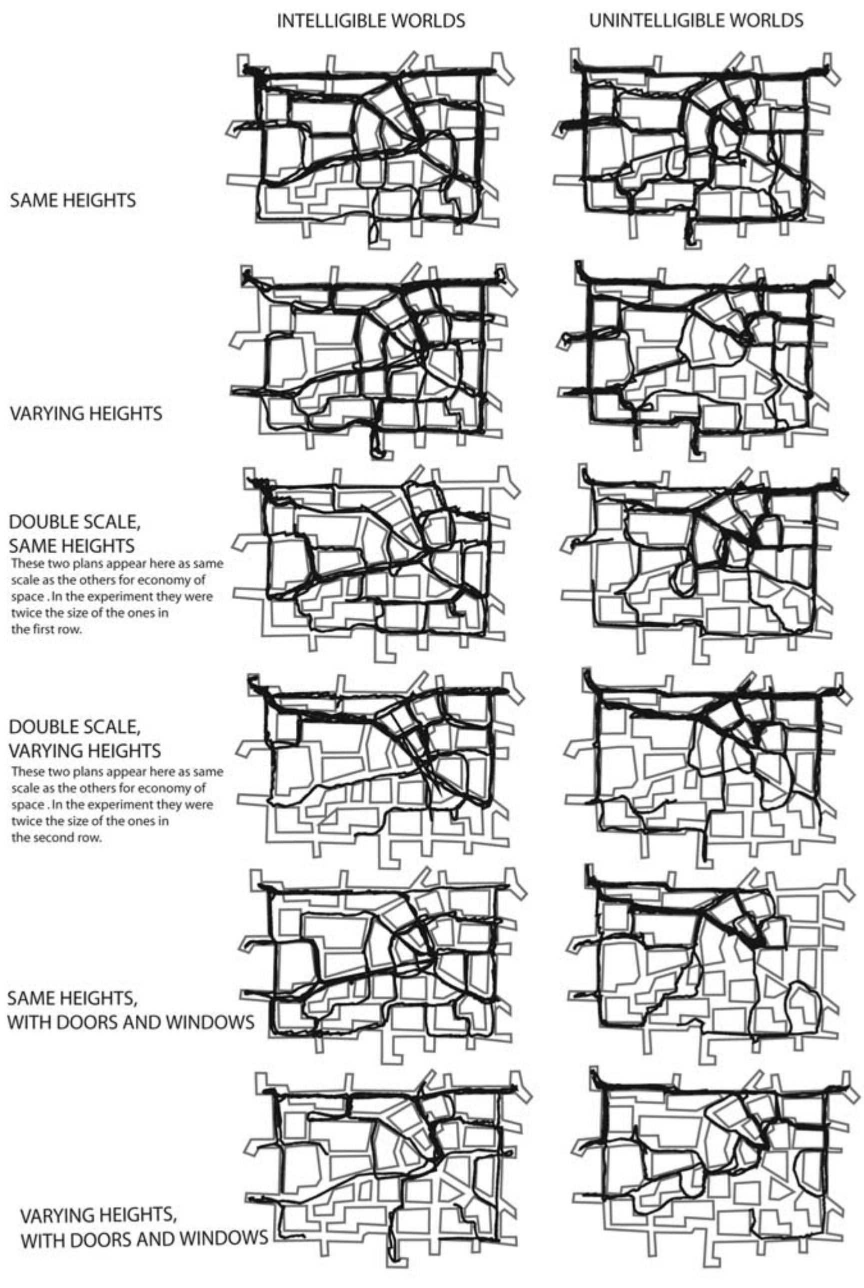

Figure 4.8 The paths of the participants in each of the 12 worlds.

Paths of Participants

Figure 4.8 illustrates the paths of the participants in each world which have been drawn using the x, y coordinates of the raw experiment data. There is no clear and strong pattern immerging from the visual comparison of the paths.

The scattergrams between gate counts and integration values have been created presenting the relation between the number of participants counted at a gate and the integration value of the axial line crossing this gate. This relation is measured by the correlation coefficient of the scattergram. The correlation coefficient for each world is illustrated in Table 4.2.

As one can see in the table the correlation coefficients are very weak and therefore cannot be considered statistically proved. However, it seems that the environments with the same heights, A, C and E, appear to have a stronger correlation than the ones with varying heights in both “intelligible” and “non-intelligible” environments. The only exception to this is the intelligible double scale worlds (C and D) which have about the same correlation coefficient. The stronger correlation in same height environments can mean that these are easier to navigate. If according to space syntax an “intelligible” environment is easier to navigate due to the fact that the correlation of pedestrian movement to syntactic properties is high then in the same sense a same height environment is more “intelligible” than a “non-intelligible” one.

It is interesting that although previous research (Conroy, 2001; Haq and Zimring, 2003) has shown that pedestrians find it easier to navigate in intelligible environments (and this is the case for both real and virtual environments), this is not strongly supported in this experiment. Two hypotheses are suggested to explain this phenomenon which would need to be further studied.

The first hypothesis is that pedestrians’ performance is affected by the three-dimensional scale of the built environment. Therefore, their performance is not dependent only on the intelligibility of the environment. This is the object of this research and will be studied in more detail in the second experiment presented in chapters 5 and 6. In the second experiment it will be tested whether navigation and wayfinding is affected by the three-dimensional scale.

The second hypothesis is that participants' performance may be affected by the type of navigation. This means that people may be having different strategies of choosing routes or navigating in environments depending on the task in question. In real cases, the same person could be choosing a different route if would need to go from home to work, another route if would go for a stroll and another route if would be looking for a grocery shop. The navigation strategy that the same person would use would be different in each one of these cases. Also, the navigation strategy for the same task would be different for a first time visitor of the environment and for someone familiar with the environment. Besides intelligibility, navigation is affected by all these issues. It should be mentioned that in both Haq and Zimring's (2003) and in Conroy's (2001) researches the findings involve first time users of the environments. In the current research the correlation of people choices and integration values are based on the recurrent navigation of participants in the same layout. However, having said that, this hypothesis is not in the interest of this research and will not be further studied.

	World A	**World B**	**World C**	**World D**	**World E**	**World F**
Intelligible	0.20	0.16	0.10	0.11	0.17	0.10
Non Intelligible	0.10	0.01	0.13	0.10	0.31	0.01

Table 4.2 Correlation coefficient of the scattergrams between gate counts and integration values.

Hypotheses deriving from Questionnaires Analysis

The findings presented in this section are based on the analysis of the questionnaires and on the comments the participants were making during the participation in the experiment and on their comments on the questionnaire (which can be found in Appendix C).

The present experiment considers the configuration of space as being the invariant in six different environments and scale and proportions being the variant. Knowing that people's movement decisions in these environments are not affected by differences in the configuration and that the layout is the same, we can test the effect of scale on the perception of the urban environments. However, since scale is not one specific property but depends on various relations among elements, different environments had to be recreated with each one approaching and examining a different kind of relation.

A basic finding is that changes of forms can affect the perception of both geometrical and topological properties of space. Geometrical properties of space are so related to the forms creating this space that we cannot actually isolate the study of geometrical attributes of space from the study of forms. For example, it seems that the perception of the length of a road is strongly related to the heights of the buildings along this road, or to the distance of the buildings etc.

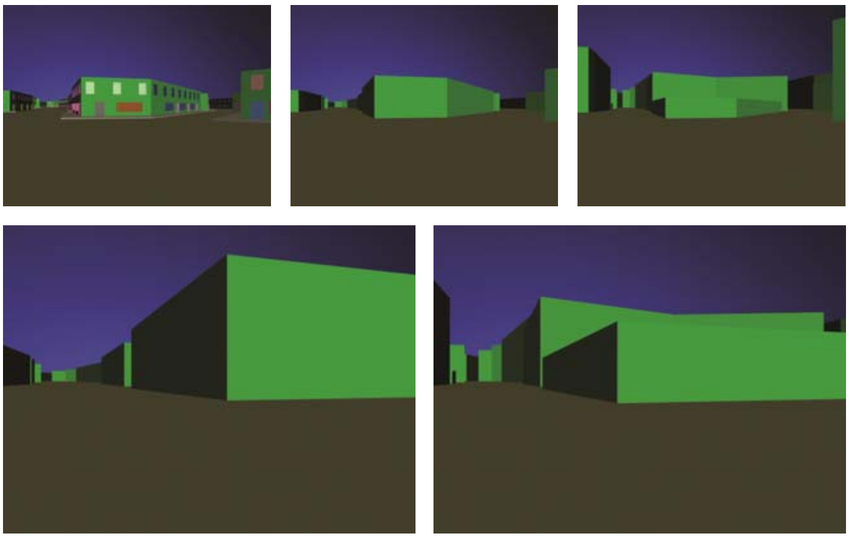

Figure 4.9 Top row, three views from the same point with different three-dimensional scale configurations. Middle row, two views of another point with different three-dimensional scale configurations.

Figure 4.9, on the top row, illustrates three snapshots each one taken in a different virtual environment. The snapshots are taken from the same point and towards the same direction in all three environments. The difference in the perception of the length of the road in each case can be noticed. The second row illustrates another two snapshots of the same street, one in environment with same heights and one in environment with different heights. The fact that the length of the street is perceived as being different in each case though it is the same, can be paralleled to the Muller-Llyer illusion, illustrated in figure 4.10.

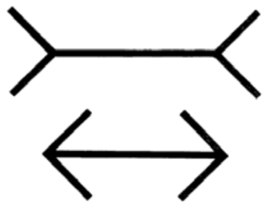

Figure 4.10 The Muller-Llyer illusion indicating how the length of a line may be perceived differently depending on the angle of the edge fins.

Regarding the topological properties of the environments, it seems that they are not perceived as being the same when the buildings heights configuration is not the same. The six environments had exactly the same topological properties and they were not perceived as such. The different building heights configuration or scale was jeopardising the recognition of the environments as being the same topologically.

However, in any case, the different building heights configuration and scale affect the perception of the environments in different aspects. The way it affects the perception of the environments will be presented next.

The filtering of the questionnaires' answers is presented in Table 4.3, Table 4.4 and Table 4.5. It becomes apparent that 59% of the participants realised that the environments A and B were different and did mention a difference while 27% of them realised that they were different but could not tell or remember what the difference was. Between those who realised the difference most of them mentioned the building heights (85%) which however is exactly half of the total participants, quite low for a difference that would be thought of as striking.

Other than building heights, 38% of the participants considered that the layout was different (reminding that each participant was navigating in the same layout either intelligible or not-intelligible), 30% of them mentioned that the shape of buildings and blocks was different, 23% of them thought that the varying building heights environment was more irregular than the same building heights environment and another 23% of them found the streets in the varying heights environment narrower than in the same heights one.

	Similarity between environments A and B			**Similarity between environments A,B,C and D**		
	Intelligible	**Non-intelligible**	**Total**	**Intelligible**	**Non-intelligible**	**Total**
Exactly the same	0	18%	18%	0	0	0
Different but cannot tell/remember what	27%	27%	27%	9%	18%	14%
Different	64%	55%	59%	73%	82%	77%
Other	9%	0	4,5%	18%	0	9%

Table 4.3 Percentage of participants giving each answer for the questions A and B of the questionnaire.

Differences between A and B mentioned by participants	Percentage of participants (out of 13)	Percentage of participants (out of 22)
Heights	85%	50%
Layout of the worlds	38%	23%
Shapes of the buildings and blocks	30%	18%
B more irregular and confusing than A	23%	14%
Streets were narrower in B	23%	14%

Table 4.4 Differences that were mentioned by the participants who identified environments A and B as different (in the middle column as percentage of the 13 who identified differences and in the right column as percentage of the total number of participants).

Differences recognized between A, B, C and D	Percentage of participants (out of 17)	Percentage of participants (out of 22)
Heights but not scale	88%	68%
Streets and open spaces geometrical properties (length, width, bigger open space)	47%	36%
Bigger size (or scale) environment	35%	27%
Layout of the worlds	24%	18%
Buildings shape difference	12%	9%

Table 4.5 Differences that were mentioned by participants who identified environments A, B, C and D as different (in the middle column as percentage of the 17 who identified differences and in the right column as percentage of the total number of participants).

The difference between the small and big scale worlds were more striking and therefore 77% of participants mentioned that the environments were different with a small percentage of 14% finding them different but not being able to tell or remember what the difference was. Among those who found the environments being different most of them (88%) mentioned as difference the building heights. They didn’t recognise the difference in the overall scale but only that the buildings were higher. However there were only 35% of the ones recognising differences who managed to notice that there was a difference in size or scale. These were only a 27% of the total number of participants. 36% of all participants considered that there were differences in geometric properties of the environments like the length of the streets, the width of the streets or that there were bigger open spaces. 18% of all the participants thought that the layout was different and 9% believed that the shape of the buildings was different.

Summarising the questionnaires’ answers and comments the differences in perception can be identified in seven thematic groups; perception of distance and geometric properties of space, perception of order and structure, perception of spatial similarity, perception of three-dimensional scale, perception of hierarchical scaling, recognition of landmarks and finally perception of environments’ “navigability”. Further research can be conducted to test each one of these differences separately and more thoroughly. In what follows each thematic group is presented and a sample of participants’ comments is reproduced in order to highlight how each difference was perceived.

i. Perception of distance and geometric properties of space

The streets in the environments with same building heights were perceived as longer or wider than in the ones with varying building heights. As it has been presented above the building heights configuration seems to affect how geometrical properties of space are perceived. A parallelism to the Muller-Llyer illusion (presented in detail in chapter 3) has been made in order to illustrate how in the same way that small changes in a shape, like the angle of the edge fins, may affect the perception of the length of the line, the building heights configuration may affect the perception of the length of streets. However, it is interesting to point out that the difference of the length of the streets was not noticed by participants in the double scale environments as it will be presented further down.

Finally, regarding another geometrical property, the angle of incidence between streets, it was noticed that in the detailed environments with the same building heights the streets were considered to be more angular than in the detailed environment with varying buildings heights.

A sample of participants' comments regarding the perception of geometric properties were:

> *"there was a distinctive broad alley" (mentioned by a participant as difference between A1 and B1, however the width was the same in both cases*)
>
> *"wider streets (in A1 than B1) made it sometimes easier to make your decision where to go and to navigate"*
>
> "there were more narrow paths (in B1)"
>
> "the streets were more angular (in E2 than in F2)

Regarding the perception of distance many participants mentioned that in the environments with varying building heights they found the roads longer than they expected. This means that the initial perception of a street's length as short due to the varying building heights was creating an expectation which was not met when the participant started actually walking along this street and therefore the street eventually felt longer. This is the difference noticed already in research, as mentioned in chapter 3, between perceived and traversed distance (Witmer and Kline, 1998).

ii. Perception of order and structure

The environments with varying building heights were perceived as less ordered than the environments with the same buildings heights.

The following are typical comments:

"the one with different heights was more confusing"

"the street network structure seemed different, the first (the participant means A1 with same heights) was more regular and the second (the participant means B1,different heights) more irregular"

"last one (B1) had lots of irregular spaces"

iii. Perception of spatial similarity

In the few cases that the environments were identified by the participants as being the same were only when the building heights were the same. The same building heights irrelevant of the scale being small or big were enabling the recognition of the spatial configuration as the same. Furthermore, in the cases of environments with the same building heights when the layout was identified as the same, the participants had learned their way to the target. They were using the same route in all experiments to find the door and then go back to the starting point.

A sample of participants' comments were:

"the second and fourth (A2 and C2) were exactly the same. The first and third (B2 and D2) could also be identical but it was too hard to tell"

"the 1st, 3rd, and 5th (B1,D1 and E1) were more or less indistinguishable in terms of visual qualities" (we must remark that this participant didn't identify any differences related to the forms, like different heights or double scale)

In one case that the environments A, C and E were identified as the same, it was due to a wide alley according to a participant's comment. Looking at the intelligible plan in figure 4.1, this alley is the one starting from the central city-square and leading towards the left and down side of the image. Of course this wide alley had the same width in environments A and E and was wider in C but what was constant was the metric relation (or proportion) of this alley to all the others in all A,E and C environments. What was identified in all cases as the same was the existence of an alley which seemed to be wider than others in the environment. However, this alley had the same width in environments B and F as in A and E but was not recognized as such due to the varying building heights. Similarly, the width in environment C was the same as in D but again was not recognized as such.

iv. Perception of three-dimensional scale

The bigger scale (double) was mainly not recognized as such. The assumption is that this is related with the virtual character of the experiment and the issue of embodiment. It would not be expected in a real world experiment that participants wouldn't recognise the difference between two environments of which one was double, or at least bigger, than the other. In this case the lack of embodiment of virtual environments can be questioned. Possibly because of the indirect participation of the body and of the lack of contextual cues the change in scale is not perceived.

The perception differences mentioned above, of geometrical properties and of order, were only perceived as such in the small scale environments and not in the big ones. A possible reason is that in the big environments the participants' visual field was mostly filled by a built wall with not much view of sky and buildings' skyline. In a sense the differences in buildings configuration were taking place out of the immediate visual field of the participant. Considering that the gaze stays put heading forward both in the small scale and in the big scale environment it is clear that the amount of information taken regarding the buildings' skyline is bigger in the small scale environment than in the big scale environment. Therefore, the building heights differences were not strongly perceived in the bigger scale environments and consequently didn't affect the perception of the properties in the same way that they were affected in the small scale environments.

v. Perception of hierarchical scaling

It is not clear whether the hierarchical scaling with the addition of pavements, doors and windows in the environments was helpful or not. Some participants found it helpful and others confusing. A sample of their comments was:

"too much detail"

"too cluttered with windows etc."

"windows and doors didn't make any difference"

"the fifth one (F2) was easier with pavements, doors and windows with colours and varying building heights"

"the last two (E2 and F2) with doors, pavements and windows, seem to give more information about the form of the space"

"the last two(F2 and E2) were probably easier because there were pseudo-real building elements rendered in the scene"

vi. Perception of environments "navigability"

Some participants believed that same height environments were easier to navigate. It is interesting that couple of them found this opposed to their expectancy. According to their comments the same height environments made them feel that the visual field was wider. Possibly this was due to the fact that the same height buildings were quite low as well (6m) offering in this way much of sky and buildings skyline view. A sample of comments:

"(E2) seemed easiest although there was little building height variation"

"the very last one (E2) was easier, despite the wall height being constant, because there seemed to be more (longer) visibility available which somehow made it easier to navigate and remember the path"

"the one with the low buildings was easier to navigate because you could see around better"

The view of the sky and the skyline besides being latent in many of the participants comments as a navigation aid, it was also explicitly mentioned by some of them. They believed that they were aided in navigation if they could see the sky. Although the participants are mentioning the view of the sky, it is considered that what must be helpful for them is not the view of the sky itself but the view of the border, of the edge between the sky and the buildings, this is the buildings skyline.

> *"too difficult to navigate because I could not see the sky always" (talking about the big scale environments)*
>
> *"higher walls in the 4th environment (D1) made it more difficult to navigate because I couldn't always see the sky"*
>
> *"the fifth one (E2) was the easier one, the walls were quite low, not so high, there was no other obstacle when one's viewing the sky, the streets were quite vast"*

Beyond the participants who found the same height environments easier to navigate there were other participants who characterised the differentiation in building heights interesting and helpful.

> *"there was a lot of building height variation which at least made the journey more interesting"*
>
> *"certainly, the differentiation in the height of buildings was helpful in navigation"*
>
> *"environments with buildings of different size and streets of differing widths were easier because I could tell the difference between them – easier to orient myself"*
>
> *"the last one is easier to navigate because it gives more information about where I stay in that environment such as the height of the building"*

vii. Recognition of landmarks

It was interesting that participants characterised the very few areas with very low buildings (3m) as "squares". They considered these areas like open spaces because they could see the higher buildings at the back of the low buildings. The participants were saying, for example, that:

> *"in worlds B and D there were more squares"*

"low building in a square"

Furthermore, these "squares" or low buildings were recognised as landmarks that aided navigation. Consequently the environments with squares were perceived as easier for navigation.

"…look in the distance above lower buildings to think where to go and where I had been"

General Conclusions

This chapter has explored the perception of three-dimensional scale differences in small virtual urban environments. The interest is specifically in the perception of the three-dimensional scale as it is perceived by pedestrians walking through cities.

In order to investigate the issue of the perception of three-dimensional scale, the methodology used was that of navigation in virtual urban environments. The environments had the same spatial configuration but different visual properties of three dimensional scale and proportions. The principle finding of this experiment is that differences of the formal properties of buildings, specifically three dimensional scale and building heights configuration, affect the perception of both geometrical and topological properties of space. Geometrical properties of space like length and width of roads which were constant were perceived as different depending on the heights of the buildings along the roads. Also, although the environments had the same spatial configuration, therefore they were topologically the same, they were not perceived as such.

Also, the findings point towards the creation of a hypothesis that specific building heights configuration aid navigation. In the specific experiments it was concluded that such configuration could be a same building heights configuration or a low building heights one that would allow for more sky and buildings skyline view.

The findings of the experiment also bring up a relation and interaction between the perception of space and the perception of form. Therefore a study of three-dimensional scale should not look into form and space independently from each other and this consists one of the main points of this thesis.

The findings of the experiment presented in this chapter set and open up many questions related to the issue of three-dimensional scale. One question that derives from the findings is whether three-dimensional scale affects beyond the perception of the environmental properties mentioned above, also navigation and wayfinding in urban environments. Grounded on the findings of the current experiment, the one that is presented in chapter 5 has been designed which investigates exactly this question whether scale differences affect navigation and wayfinding in urban environments.

Chapter 5

Navigation, wayfinding and survey knowledge performance in virtual environments with different building heights configuration – Part 1

Abstract

Following up on the knowledge acquired from the findings of the first study in virtual environments a second experiment has been set up. This experiment is designed to investigate participants' performance in navigation, wayfinding and survey knowledge in four environments with exactly the same plan configuration but differences in buildings heights configuration. The four environments are: first one with low buildings of varying height, second one with high buildings of varying heights, third one with building heights correlated to the "integration" of the street on which they are found and fourth one with building heights inversely correlated to the "integration" of the streets on which they are found." Integration" is used and defined as can be found in the space syntax literature. The third case is actually reinforcing established schemata of urban environments since the high buildings are on the integrated streets (main streets) and the low ones are on the segregated (back alleys). The fourth case is opposed to established schemata since the low buildings are on the integrated streets (main streets) and the high buildings on the segregated ones (back alleys).

This chapter presents a description of the experiment set up and the next one the findings.

Introduction

The first study experiment has led to the hypothesis that scale properties of the built environment seem to affect the perception of properties of space such as the length of the route, the order of the layout and the perception of ease of navigation and wayfinding. The current research is taking this issue further attempting to address the question whether scale is playing any role on navigation and wayfinding performance irrelevant of what participants perceive of the environmental properties. Therefore this chapter is looking into objective dependent measures testing navigation, wayfinding performance and survey knowledge.

In order to examine the above question an experiment in a virtual environment was set up, once more, which took place in the VR lab of the Centre for Cognitive Science of the University of Freiburg in Germany. The experiment which will be presented in this chapter was designed based on the hypotheses that were created on the pilot study presented in the previous chapter.

The hypotheses that arose from the pilot study were based on the participants' perception of differences of scale properties. There were two main hypotheses created from that research. The first one is that the perception of length of a street is affected by the configuration of form heights along this street. This means that the perception of length of two streets with the same length depends on the height of the buildings along them. If the buildings are low the street will be perceived longer than in the case when the buildings are high. The second hypothesis is that low height environments are perceived as easier to navigate than bigger height ones. People perceived the virtual environments with small height buildings as more ordered and more intelligible, in the sense of understanding the layout, than the virtual environments with buildings of bigger height.

The new experiment is set up taking these hypotheses into consideration and attempting to examine further three variables. These are:

- The cognition of route distances in virtual urban environments with the same layout and different building heights configuration. In this sense the experiment will be a judgment exercise of distances that are not instantly perceived. The participants will be asked to estimate the distances of routes that they will walk along. The routes will be exactly the same among participants but the building heights along the routes will be varying from one case to the other. The question asked is whether the distance estimation is affected by the built form in each case.

- The ease of navigation in relation to the building heights configuration. This will be a navigation task. Participants will be asked to navigate in environments with the same layout and varying building heights. The navigation performance will be tested with navigation performance and survey knowledge measures and questionnaires.
- The effect of the correlation of building heights to the space syntax measure "integration" (Hillier and Hanson, 1984) on navigation. This is again a navigation task. The participants will be asked to navigate in an environment where the building heights are correlated to the "integration" of the street and in one where building heights are inversely correlated to the "integration" of the streets. Performance is assessed with several navigation measures and with questionnaires. Further explanation on the "integration" measure and the way it is applied in relation to building heights is given in the next section.

Based on the above variables there are three questions that this experiment will attempt to reply and which will help the investigation of the thesis main research question:

- Is the estimation of a route distance affected by the buildings heights configuration?
- Are navigation and wayfinding in virtual urban environments affected by the three-dimensional scale?
- Is the navigation performance affected by the building heights when these are correlated to the syntactic "integration", according to the space syntax term (Hillier and Hanson, 1984), and when they are inversely correlated?

In what follows, the description of the virtual worlds, the participants, and the procedure of the experiment will be presented, then the dependent measures of the analysis. The main findings of the experiment will then be presented in the next chapter.

The virtual worlds

Four different virtual worlds were designed for the experiment. The worlds were designed in “3dStudio Max” by Autodesk. The four worlds have all the same layout but each one has different building height properties. The size of the world is approximately 680m X 705m. The layout which is imaginary but trying to resemble an urban layout is presented in figure 5.1 and 5.2.

The variations of building heights configuration among the four models are (figure 5.4):

- One model has high buildings, 12m, 14m and 16m height randomly assigned to buildings.
- One model has low buildings, 6m, 7m and 8m height randomly assigned to buildings.
- One model has heights correlated to the syntactic integration. The height of the buildings is correlated to the integration value of each road. The roads with higher integration are having higher buildings than the segregated ones. There are three building height ranges corresponding to three integration values ranges. The heights for each range are: 4m, 5m and 6m for the low buildings, 10m, 12m and 14m for the medium height buildings and 19m, 22, and 25m for the high buildings.
- Finally, the last model has the inversed correlation. In this case, the height of the buildings has a negative correlation to the integration. The integrated roads are having lower buildings than the segregated ones, this is again low buildings have 4m,5m,6m height, medium 10m,12m,14m and high buildings 19m,22m and 25m.

Figure 5.1 The layout of the models.

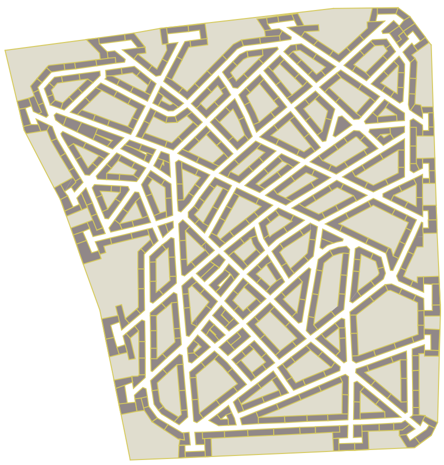

Figure 5.2 The layout of the models with the buildings illustrated along each street.

The way that the heights were assigned to the last two models will be explained. The axial map of the layout of the virtual worlds was drawn and analysed by space syntax "integration" value. The way that an axial map is designed and analysed is already presented in chapter 4 (“Axial Analysis of the Virtual Worlds” section). The integration values of an axial map are grouped in ranges and a colour is assigned in each range. Usually 7-12 ranges and colours are used. However, in the current case, in order to avoid having a highly complex environment in building heights only three ranges would be sufficient. In figure 5.3 the simplified map with only three ranges is presented. The three ranges, corresponding to three colours, red for high integration, green for medium and blue for low. In the sequence, a different building heights configuration was assigned to each of the integration ranges. For the correlated model red means high buildings, green for medium and blue for low. For the inversely correlated red means low buildings, green medium and blue high.

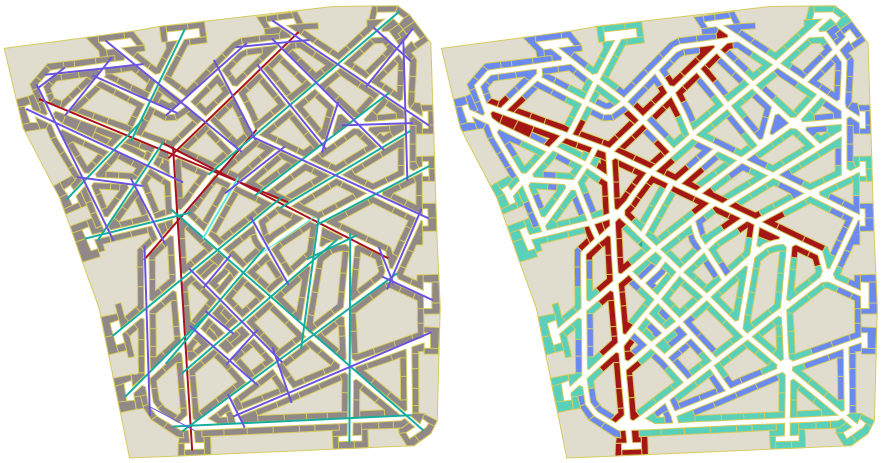

Figure 5.3 The axial map with the three syntactic integration ranges (left) corresponding to three different buildings height ranges (right). In the syntactic map red is for the integrated, green for the less integrated and blue for the segregated. The colors on the right image represent red for high buildings, green for medium and blue for low in the case that the model is correlated and red for low, green for medium and blue for high in the case of the inversely-correlated model.

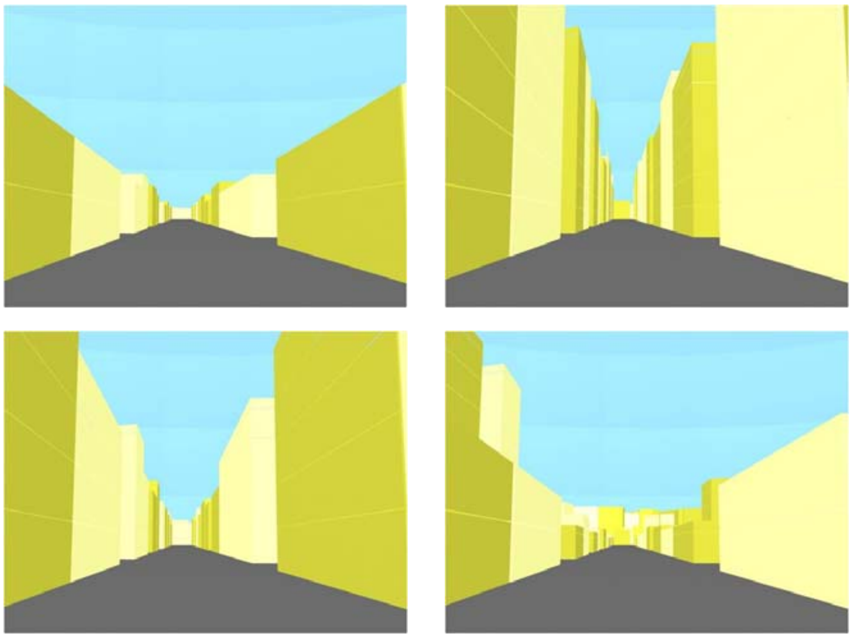

Figure 5.4 Aspects of the 4 models from the same point. Model with low heights (top left), with high heights (top right), with correlated heights (bottom left) and with inversely correlated heights (bottom right).

There is a hypothesis behind the decision to design the “correlated” and the “non-correlated” models in this way. The reason is that the “correlated model” is expected to positively reinforce established schemata. It is usually the case in urban environments that higher buildings are situated on more integrated streets or on main streets. In general, these streets have higher densities of visitors and therefore are in need of bigger areas. Therefore development in height can provide the necessary space. The fourth model described, the inversely correlated, is opposed to such established schemata. When a high street, usually “integrated” street is perceived by someone as such, higher buildings are expected to be found on this street and then when turning back on some segregated alleys, low buildings are expected to be found. In this model this expectancy is inversed, by having the low buildings on the integrated, high-street type, road and high buildings on the segregated back alleys.

There is also one more difference between these two environments which has to do with the three-dimensional visibility in each environment. Three-dimensional visibility is the visibility that is offered due to building height differences such as the visibility of high buildings in a block which are behind other lower buildings. Three-dimensional visibility is referred here opposed to two-dimensional visibility which is the visibility depending on the boundary that the buildings on a first level of foreground create, while three dimensional visibility depends also on the buildings at the background. The three dimensional visibility is not therefore irrelevant of building heights as two dimensional visibility would be.

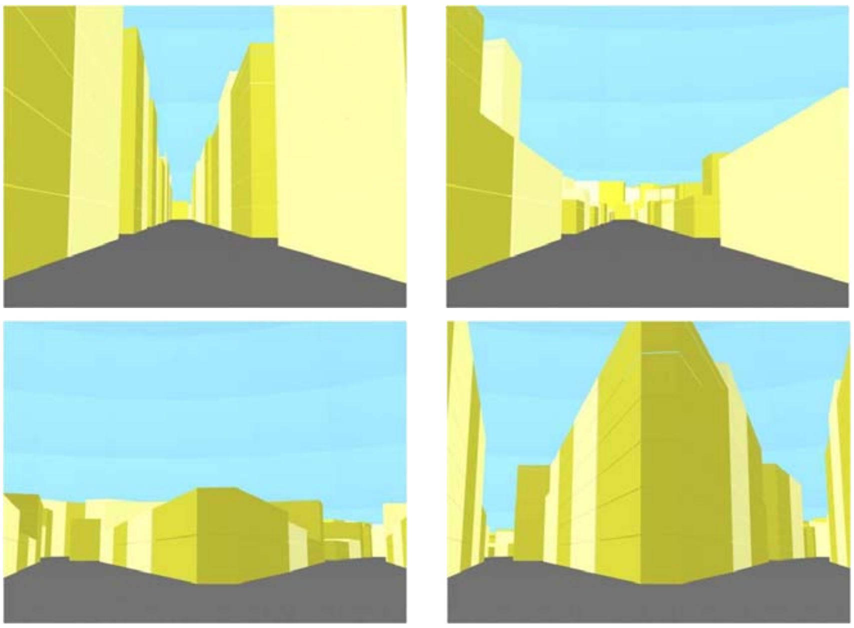

Figure 5.5 Aspects of the correlated (left) and inversely correlated model (right) from the same point on an integrated street (top row) and on a segregated street (bottom row).

In the experiment, the case is that when there are low buildings along a street, the higher buildings at the back are visible due to the variations of heights from one street to another (figure 5.5). This means that in the “correlated model” the three dimensional visibility is better on a segregated street. When someone is on a segregated street which has low buildings, one can see behind the low buildings of this street, the high buildings of the other sides of the blocks. On the integrated streets the buildings are high and are not offering view of the buildings behind them. The opposite is happening in the inversely correlated model; when someone is on an integrated street where buildings are low, one can see behind the low buildings of this street the high buildings at the back. So in the “correlated model”, the segregated streets with low buildings have better three dimensional visibility and in the inversely correlated model the integrated streets with low buildings have better three dimensional visibility.

Summing up, this means that in the “correlated model”, there is a buildings height configuration that, on one hand, reinforces established schemata and, on the other hand, it offers better three-dimensional visibility on the segregated streets. In the inversely correlated model, the building heights configuration is opposed to established schemata and it offers better visibility on the integrated streets than on the segregated ones (table 5.1). The question that arises from this situation is whether it is a) correlatedness or b) visibility that has the stronger impact on navigation and wayfinding, or whether it is c) integration per se, irrespective of building heights, as already defined by space syntax.

	Integrated streets	**Segregated streets**
Correlated model	Reinforce established schemata	Reinforce established schemata
	Worst 3d visibility	Better 3d visibility
Inversely correlated model	Opposed to established schemata	Opposed to established schemata
	Better 3d visibility	Worst 3d visibility

Table 5.1 Differences between established schemata and three dimensional visibility for each of the two virtual models.

The previous question along with the question resulting from the design of the first two virtual worlds, one with low buildings and one with high buildings, which is which one and in which way does it affect navigation and wayfinding performance, are going to be the main issues of the analysis in the next chapter.

In order to ensure the correct design of the experiment a pre-pilot study with two participants and a pilot study with ten participants were conducted before the actual experiment took place. The feedback from these two pilot studies informed the set-up of the experiment regarding any problems related to the design of the virtual worlds, of the task and of the apparatus. After the problems that had been raised were corrected, the actual experiment started. The problems that were fixed had mostly to do with the apparatus.

Participants

Most of the participants were students who replied to an e-mail announcement. The experiment took place at the VR Lab of the Center of Cognitive Science in the University of Freiburg in Germany. The participants were thirty two native German speakers. It is acknowledged that cultural differences among the participants of the first and the second experiments may arise however these were not taken into consideration. Sixteen of them were men and sixteen were women. They were 20-38 years old, with average age of 24. Most of the participants had a virtual environments experience at least once (n=17) and quite a few of them more often (n=11) and most of them (n=19) had video game experience at least once and many of them more often (n=12). Only four of them never had a virtual environments experience and only one never had video game experience. The virtual environment’s experience is not included as a variable at the current research as the fact that the majority of the participants had a virtual environments experience at least once is considered a satisfying.

Procedure

All participants had to navigate in all of the four models. The task was to learn the route in each one and to answer some navigation performance questions. In order to avoid learning the route between models there were four different routes but with equal attributes (figure 5.7). Each participant travelled a different route in each of the four models. The models and routes were counterbalanced across participants.

The attributes that were held constant across all routes were: total route distance, start to end survey distance, number of intersections per route, type of intersections (T type, cross (+) type, star (*) type intersection), number of turns, type of angular properties of the turns (right angle, obtuse and oblique turns), and the sequence of syntactic property changes (integrated-segregated street) along the routes (table 5.2). The starting point of each route was on a cross intersection.

		Route 1	Route 2	Route 3	Route 4
Route distance (m)		588	514	565	570
Survey distance (m)		292	215	257	263
Number of intersections	**T intersection (3 streets)**	5	5	3	3
	+ intersection (4 streets)	4	4	6	6
	*** intersection (5 streets)**	1	1	1	1
Number of turns	**Obtuse angle**	2	2	2	2
	Oblique angle	4	3	4	3
Number of syntactic changes		4	4	6	4

Table 5.2 The attributes of each route.

The virtual worlds were projected on a 2.6m length x 2.0m high screen. The participants, who were sitting in front of the screen in about 2.5m distance, could navigate with the use of the arrow keys of the keyboard (figure 5.6). They were using the arrow keys both for body and for head movement. The experiment consisted of a training phase, a learning of the route phase and the navigation tasks phase.

Figure 5.6 Photograph of the experiment's set up.

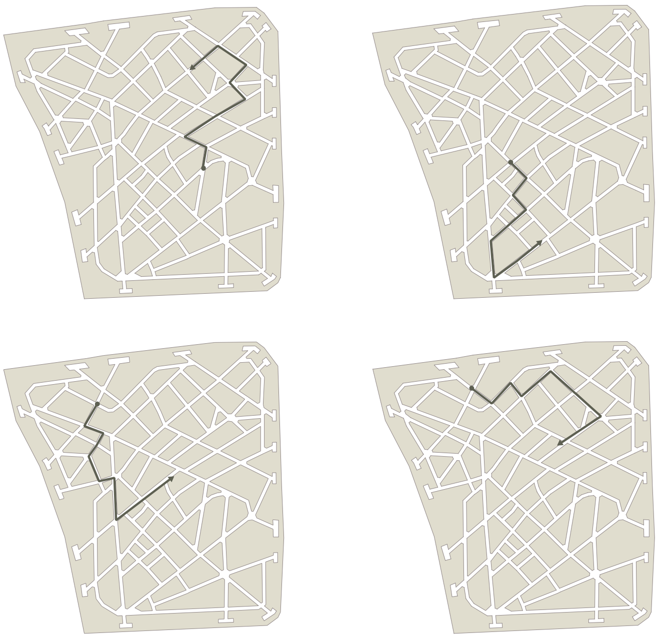

Figure 5.7 The four different routes R1(top left), R2 (top right), R3 (bottom left), R4 (bottom right).

During the training phase there were two training sessions lasting about 7-10 minutes. The first was a distance training and the second a task training. The aim of the distance training was to give the participants a sense of distance in the virtual world. For the distance training the participants were following a route with distance indication for every 25m. They were just walking on the world and a sign next to them was indicating the change from 0m to 25m, to 50m, to 75m and so on. The total length of the route was 300m.

The aim of the task training was to accustom the participants with the apparatus, the task procedure and with what would be asked from them. For the task training they had to perform the whole procedure of the experiment in a world which was different and much simpler from the virtual worlds of the actual experiment.

After these two training sessions the actual experiment started. The actual experiment consists of two phases: the route learning phase and the tasks phase. The route learning consisted of a passive and an active navigation episode. During the passive navigation the participants were watching a video of the route where the camera was stopping on each junction and was turning around to all streets of the junction. During the active navigation, the participants were walking along the same route following verbal direction instructions given by the experimenter. With this procedure the participants experienced the route twice before performance was measured.

The differentiation between active and passive navigation was introduced after the pilot study of the experiment. In the pilot study there was only the passive navigation with the participants watching the route in a video. However, it became clear that when the participants were not actively involved in the navigation the level of attention was low and therefore the questions harder to answer. Therefore it was decided to introduce both passive and active navigations.

Also, another element that was introduced after the pilot study was the peripheral view on each junction during the passive navigation. It was noticed that during the "go to the starting point" task the participants were stopping at each junction and looking around to get cues on which road to follow. Therefore it was decided to help them towards this direction by giving them the 360^{o} view of each junction. In any case this is something that happens in reality with much ease since when someone is walking on a road one always looks around.

When the participants reached the end point of the route in the active navigation, they were asked to complete the performance tasks. They were asked to give an estimation of the route distance, of the survey distance from start to end, this is the linear distance from one point to another, and to point to the starting point. Finally, they were asked to go back to the starting point following exactly the same route. The participants' wrong choice on a junction was corrected by invisible barriers that were obstructing movement and were put a few meters away of the junction. So the participants could not move forward if they had taken the wrong turn on a junction and they had to correct their choice. If the task was not completed after 5minutes they were asked to stop. After navigating all four routes, the participants were given a questionnaire to fill in (see Appendix B). The experiment's design is presented in the graph of figure 5.8.

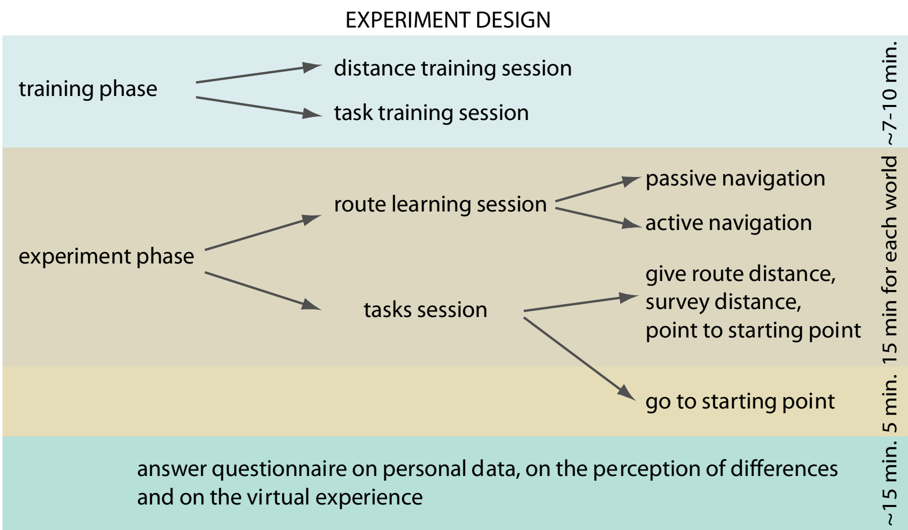

Figure 5.8 Graphic layout of the experiment's procedure.

Questionnaire

The questionnaire consists of two parts. Part I had some personal questions about participant's sex, age, occupation and previous experience on virtual environments. Part II was about the experience of the virtual environments. The questionnaire is found in Appendix B.

The first question of part II was asking from the participants to order the environments from the most arousing to the least, the most pleasing to the least, the most complex to the least and finally from the one they prefer most to the least. This question is based on environmental psychology's assessment of environments based on effective judgments like the model of Kaplan and Kaplan (1989) already presented in chapter 2.

They were then asked to specify what difficulty they found, to mention the differences among the four environments and finally were asked to say if they realized that the main streets had higher buildings than the secondary ones. The two last questions were on the level of difficulty on moving around (referring to the apparatus) and on their left or right handedness.

Dependent measures

The objective dependent measures, that will be used to test navigation performance and survey knowledge, are:

- The detour behavior. The number of wrong choices per route will be estimated. If people are better orientated in the low height environment then they are expected to perform less wrong choices.
- Total time to complete the task.
- Total distance until the task is completed.
- Speed (total distance divided by total time).
- Success to find starting point.

- The pointing error.

The subjective measures tested were based on the questionnaires that were given to the participants at the end of the navigation to reply.

Summing up

This chapter has presented the design of the experiment that has been set up in order to examine whether the change of building heights configuration affects the navigation and wayfinding performance of pedestrians in virtual urban environments.

The experiment has introduced four urban environments with the same layout and differences in building heights. One environment is with varying low buildings, one with varying high buildings, one with building heights correlated with the "integration" value of each street and one with building heights inversely correlated to the "integration" of each street. "Integration" is used as defined in the space syntax literature (Hillier and Hanson, 1984) and denotes how easily accessible or not accessible is a street from all other streets of the urban system. As it is usually the case that main high streets are integrated and back alleys are segregated an assumption has been made in this experiment. It is considered that the correlation of integration to building heights refers to a familiar image of cities where high streets usually have higher buildings. Therefore the correlated model reinforces established schemata and the no-correlated does not.

The participants after they watched a video of the route and then walked along it under the experimenter's route instructions, they were asked to evaluate the distance of the route, the survey distance from the end point to the starting point, to point to the starting point and finally to go back to the starting point. They were not asked to follow the same route exactly however their wrong route choices were corrected with invisible barriers that prohibit them to go to the wrong direction.

After five minutes of navigation and even if they hadn't found the starting point the navigation ended. Then the participants were asked to reply to a questionnaire with questions on their personal status, on the experience of each environment, on the ease of navigation and on the use of the apparatus.

The next chapter will present the data collected and the analysis of the data.

Chapter 6

Navigation, wayfinding and survey knowledge performance in virtual environments with different building heights configuration – Part 2

Abstract

This chapter presents the analysis of the data acquired from the experiment in virtual environments described in the previous chapter. The experiment was set up to test whether participants' performance in navigation, wayfinding and survey knowledge in four environments with exactly the same plan configuration but differences in building heights varies.

The findings point towards the direction that the building heights play a secondary role on the participants' navigation and wayfinding performance with spatial configuration having the primary role.

Introduction

The setup of the experiment in virtual environments has been presented in the previous chapter. What is tested in this experiment is the effect that building heights configuration may have on navigation, wayfinding and survey knowledge. There are three themes that the experiment is focusing in, as described in the previous chapter, and are repeated here:

- The cognition of route distances in different virtual urban environments when the building heights configuration is varying. The question asked is whether the estimation of a route distance is affected by the scale of the buildings along the route.
- The ease of navigation in relation to the building heights configuration. The question is whether navigation and wayfinding in virtual urban environments is affected by the scale of the buildings?
- The effect of the correlation of building heights to space syntax's measure "integration" (Hillier and Hanson, 1984) on navigation. The question is whether the navigation performance is affected by the buildings height when these are correlated to the syntactic "integration", according to the space syntax term, and when they are inversely correlated?

In what follows, the main findings of the experiment will be presented. The analysis is divided in four parts, in the first part a global analysis of all the worlds will take place where a comparison among the worlds will be done regarding main navigation and wayfinding measures, in the second part the analysis of the pointing task is presented, then in the third part a micro-analysis of participants' performance in the "correlated" and "inversely-correlated" models regarding the participants' performance on each junction is concluded. Finally, the fourth part is summarizing the participants' comments in the questions posed.

Before starting presenting the analysis a code name for each world/model will be given which will enable the presentation. Therefore M1 is the model with the low buildings, M2 the model with the high buildings, M3 the model with the heights correlated to the "integration" value and M4 the model with the heights inversely correlated to the "integration" value of the street. Relatively R1, R2, R3 and R4 are the four routes as described in chapter 5.

Global analysis

The navigation performance for the global analysis was measured with three dependent variables along each route: getting lost or not, time to complete the task for those not getting lost and number of detours for those not getting lost. Getting lost is defined as going to the wrong direction or admitting getting lost.

The research questions that the global analysis was designed to answer were:

- If there is a significant difference between models M1-M2 and M3-M4 regarding participants getting lost.
- If there is a difference between M1-M2 and M3-M4 regarding the numbers of junctions where the participants get lost.
- If there is a significant difference between M1-M2 and M3-M4 at the percentage above optimal (PAO).
- If there is a significant difference in time performance between M1-M2 and M3-M4.
- If there is significant difference between M1-M2 and M3-M4 at detours.

Let's start by looking into the first question, whether there is a difference between M1 and M2 in getting lost. Table 6.1 shows the percentages of people getting lost in each world. In absolute numbers, 27 participants were not lost and 5 were lost when navigating in M1. On the other hand, in M2 25 participants were not lost and 7 were lost (x^2 = 0.410, p=0.522). Thus, there is no significant difference between M1 and M2 in getting lost.

Regarding the difference between M3 and M4 in participants getting lost, 25 participants were not lost in M3 and 7 were lost while 21 were not lost in M4 and

11 were lost (x^2 = 1.237, p=0.266). Therefore there is no significant difference between M3 and M4 in getting lost.

	World M1	World M2	World M3	World M4
Lost	15.6%	21.9%	21.9%	34.4%
Not lost	84.4%	78.1%	78.1%	65.6%

Table 6.1 Percentage of participants getting lost in each world.

Regarding the performance of the participants who got lost in relation to the number of junctions where they got lost, there is still no significant difference between M1-M2 and M3-M4. In M1 the 5 participants who were lost, have been lost in 6.2 junctions and in M2 the 7 lost participants have been lost in 6 junctions. The observed deviation is indicated as not significant since t=0.161, p=0.875. On the other hand in M3 the 7 lost participants have been lost in 6.71 junctions and the 11 participants who were lost in M4 have been lost in 6.36 junctions. This deviation is also indicated as not significant as t=0.324,p=0.75.

	World M1	World M2	World M3	World M4
Number of junctions at which lost	6.20	6.00	6.71	6.36

Table 6.2 Number of junctions at which the lost participants lost their way.

It is apparent in table 6.2 that in all four models the participants were lost at 6 to 6.71 junctions. Thus it is consistent that the participants were lost at 6 junctions irrelevant of the model in which they were navigating.

The models show no significant difference regarding the percentage above optimal, (PAO). For the difference between models M1-M2, F=0.003,p=0.959, with a deviation of 0.209 and between models M3-M4, F=0.036,p=0.853 and the deviation at 0.983.

The participants of all four models have a mean value of PAO that varies between 15.39 and 18.07. Thus the participants have a statistically non-significant deviation of the variable PAO.

Proceeding with the analysis, looking into the next question, whether there is a significant difference of time performance between M1 and M2 for those participants who have not been lost the analysis shows that the difference is considered insignificant since the deviation is low at 4.123 (F=0.050,p=0.824). The same happens for models M3 and M4 as the deviation is 2.670 (F=0.018,p=0.894).

	World M1	World M2	World M3	World M4
Total time to complete task	228.59	232.56	244.48	241.81

Table 6.3 Mean values of total time in seconds to complete the task for those participants who didn't get lost.

Table 6.3 shows that the participants in all four models have a mean value of time performance which varies between 228.59 and 244.48 seconds. Thus, the participants have a non-significant deviation of the total time performance irrelevant of the model.

Finally, looking into the last question whether there is a significant difference regarding the detours between M1 and M2 for those participants who have not been lost, the finding is that again there is no significant difference (F=0.457,p=0.505). The deviation between the two models is low at 0.385.

The same occurs between models M3 and M4, where the difference at detours is still not significant (F=0.612, p=0.444) and the deviation is low at 0.515. Table 6.4 shows that the mean value of detours among all four models vary from 2.48 to 3.11, with no statistically significant differences between the models.

	World M1	World M2	World M3	World M4
Number of detours (for those not getting lost)	2.92	2.54	2.48	3.11

Table 6.4 Mean values of number of detours for those participants who didn't get lost.

Finally, regarding the route and survey distance estimation there were no significant differences between models but an underestimation in distances was notices. Specifically, in route 1, 78% of the participants underestimated the route distance by a mean of 31.5% and 59% of the participants underestimated the survey distance by 36%. In route 2, 68% of participants underestimated the route distance by a mean of 32.5% and 50% of the participants overestimated the survey distance by 60% while the other 50% underestimated the distance by 41%. In route 3, 75% of the participants underestimated the route distance by a mean of 31% and 60% of the participants underestimated the survey distance by a mean of 41%. In route 4, 68% of the participants underestimated the route distance by 35,4% and 50% of the participants underestimated the survey distance by a mean of 37% while the other 50% overestimated the survey distance by a mean of 50%. In general, route distances were underestimated by 30% and survey distances by 40%.

Direction estimates

The direction estimates are based on the data from the pointing task the participants had to complete during the experiment. The research question that is posed in this case is whether the survey knowledge, which is measured by the pointing task among others, is affected by the building heights configuration in each model.

The answer is that pointing does not differ among the four models (F(3,91)=1.075,p=0.362). In all four models the pointing performance was the same which means that it is independent of the building heights configuration. Although it has been observed that in models M2, M3 and M4 participants point off towards the clockwise direction while in M1 to the opposite direction (figure 6.1), the variance of pointing error is very similar between all models and that is why it is not significant.

Also, looking into the difference of the mean values between each two models, no significant difference occurs. In all cases p>0.05.

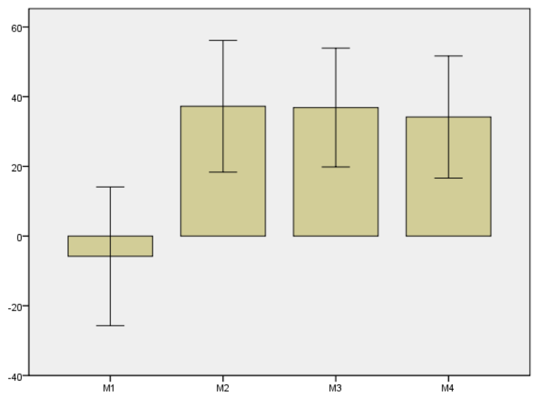

Figure 6.1 Graph indicating the pointing error in each world. People point towards the clockwise direction except for M1 (horizontal axis “Model”, vertical axis “mean degrees of pointing”).

Looking at the effect of model on pointing, another issue came to surface. This is the effect of the route that each participant was tested on, on pointing (F=28.125,p<0.001). As has been described in the previous chapter, in order to avoid learning the route from the participants when running the experiment in each one of the four different models, four different routes were designed. These routes were designed to be considered equal regarding navigation and environmental properties. In each of the four models the participants were following one of the four routes with the combination route-model never being the same among participants. It has now occurred that the pointing error is different in each route. In the graph of figure 6.2 it becomes obvious that route 2 has average pointing error counter clockwise, while route 1 and route 3 clockwise. Route 4 has the lowest pointing error and route 3 the highest.

However, the route effect remains (F= 17.972, p<0.001) even when looking into the absolute pointing error, treating a -X degrees off pointing the same as a +X degrees off pointing. With this analysis it is not examined whether the pointing is clockwise or counter-clockwise but just the degrees off the correct pointing. This provides a normalization of the pointing data. This analysis of absolute pointing error also shows no significant differences between the models.

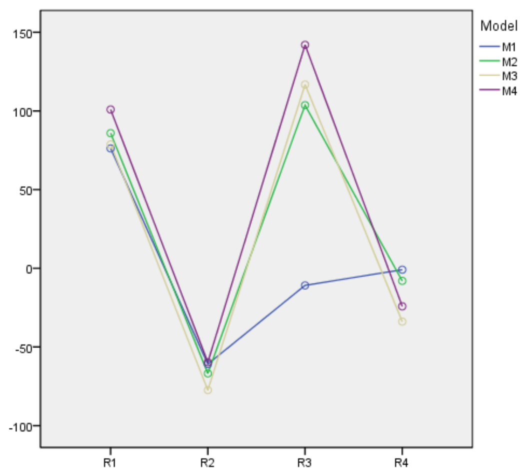

Figure 6.2 Graph illustrating the pointing error for each route in each model (Horizontal axis “Route” and vertical axis “Pointing error”).

An examination of the correlation between pointing and several other variables of the experiment such as the total time to complete the task, the total length covered, distance estimation difference, the survey distance estimation difference or other more qualitative variables as the appraisal of preference, of complexity, of pleasantness and of arousal or the percentage above of the optimal gave no significant correlation.

The graph in figure 6.3 validates that there is no main effect of model when taking into consideration the absolute pointing error, although M2 is numerically slightly worse than others but the variance is too large and too similar among models. However, a route effect appears again when looking into the absolute pointing error (F=17.972, p<0.001).

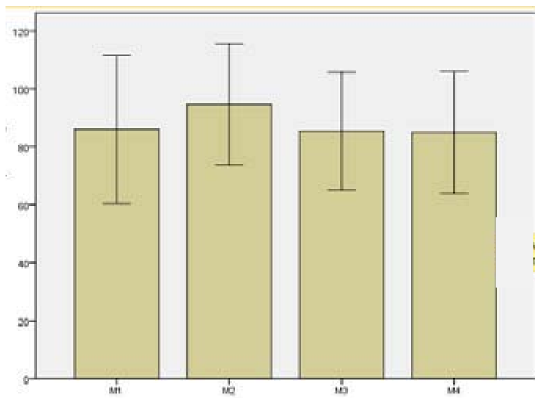

Figure 6.3 Graph indicating the absolute pointing error in all models (Horizontal axis "Model", vertical axis "Mean value of absolute pointing error").

Looking into the routes separately, it appears that R1 and R3 differ significantly (mixed model analysis of variance, planned contrasts, Sidak correction, p=0.001), R1 and R4 differ significantly (mixed model analysis of variance, planned contrasts, Sidak correction, p=0.015), R2 and R4 differ significantly (mixed model analysis of variance, planned contrasts, Sidak correction, p<0.001) and R3 and R4 differ significantly (mixed model analysis of variance, planned contrasts, Sidak correction, $p<0.001$).

An examination of the differences of the mean values of absolute pointing error for each route and of the standard error of the difference show that the pointing error is bigger in R3 and smaller in R4. So pointing is more difficult on one route than other.

Finally, looking into the correlations of absolute pointing error to several factors as described above, it appears that “getting lost” correlates significantly ($p<0.001$) with absolute pointing error. Then by examining participants who got lost and those who didn’t, it appears that there is a significant relation between getting lost and pointing error ($F(1,20.4)=11.920$, $p=0.002$). Participants who get lost have significantly higher pointing error than those who do not get lost (figure 6.4).

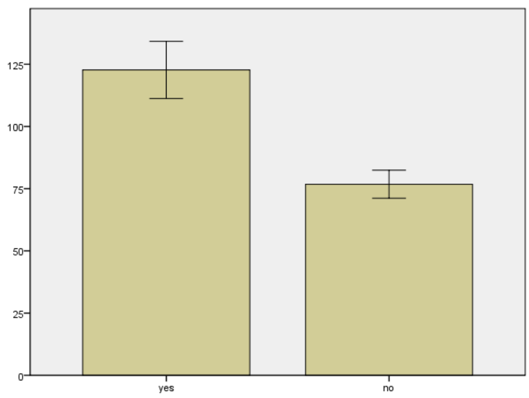

Figure 6.4 Graph illustrating the absolute pointing error for those participants who got lost and for those who didn’t (Horizontal axis “Participants getting lost”, vertical axis “Mean value of absolute pointing error”).

Micro-analysis of junction performance in "correlated" and "inversely-correlated" worlds

This section will investigate the question whether the navigation performance is affected by the buildings height when these are correlated to the syntactic integration, according to the space syntax term (Hillier and Hanson, 1984), and when they are inversely correlated. More specifically it will investigate a "micro-navigation performance" based on the analysis of the participants' choices on each junction in models M3 and M4. The global and pointing analysis presented above didn't rise up significant differences between the four models. Therefore, a micro-analysis is considered necessary for looking into participants' behavior and more specifically into path choice.

The question to be tested is what are the "hidden" strategies underlying a wrong choice? In other words, what are the path choices that participants make on each junction affected by? In this respect and more relevant to the theme of this question is the analysis of models M3 and M4. The reason that this analysis is done only for M3 and M4 is that the path choice regarding scale, has a meaning only in those two models as in M1 and M2 the path choices are equal regarding scale. In M1, for example, all the path choices in a junction have the same scale (which is low building heights) while in M3 or M4 each path of a junction has different scale (building heights) which is correlated or not to the "integration" value.

What is examined in this section is specifically what is called participants' performance on each junction and is based on the study of the path choice on each junction of each route in each model for each participant. All four routes have 10 junctions which are exactly the same in both models, the correlated and the inversely correlated, in plan view and the environmental properties which deal with the two dimensions. They differ however in the three-dimensional properties, in building heights. All the junction properties, both two-dimensional and three-dimensional, registered for the analysis were:

- Type of junction. There are three types, T- type junction with three path choices, (+) cross-type junction with four path choices and (*) star-type junction with five path choices (figure 6.5). The angles between path choices are not taken into account.

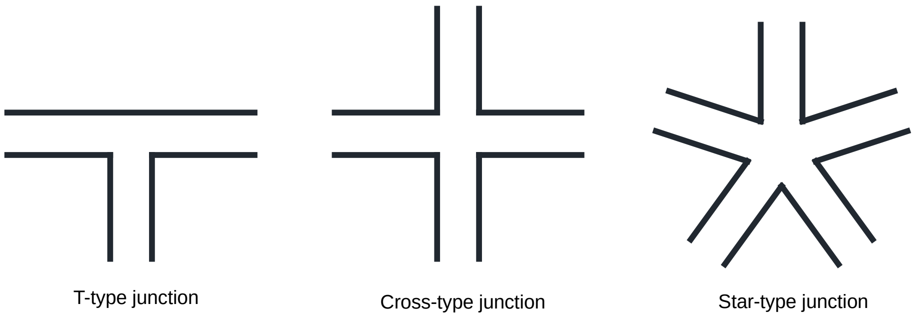

Figure 6.5 The three types of junctions.

- Mean integration of the junction. An integration value was assigned to each junction which was the mean integration value of all axial lines crossing the junction (figure 6.6).
- The integration value of each path choice of a junction, this is the integration value of each axial line representing a "path choice" (figure 6.6).

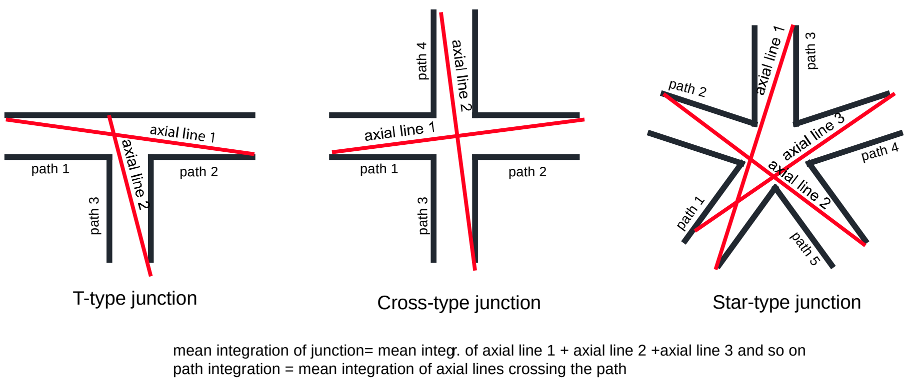

Figure 6.6 The three types of junctions and the calculation of the integration values.

- The height of the buildings of each path choice of a junction.
- The length of the isovist from the junction for each path choice of the junction (figure 6.7). The isovist is a representation of the visibility from a specific point taking into account all the surrounding elements as they appear in two dimensions. The term isovist was developed by Benedikt (Benedikt, 1979).

  Isovist as introduced by Benedikt is a planar polygon that represents the entire field of view, however not in a three dimensional manner but taking into account only the elements that this plane meets at eye level. An isovist can represent either the real human field of view which is roughly 180 degrees or a 360 degrees field of view representing a human who is looking around all possible choices on a route (Conroy, 2001). Figure 6.7 shows how the partial isovist was applied in the current case and how the length of the isovist was measured actually looking at the line connecting the observer to the furthest point of the isovist.

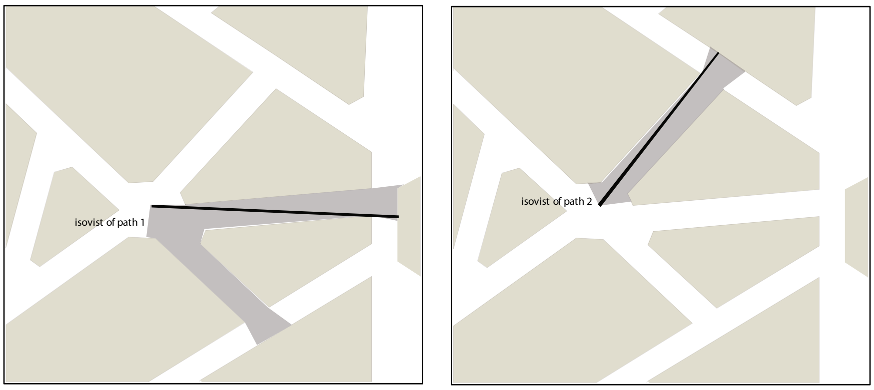

Figure 6.7 Two path choices on a junction with its isovist each and the line representing the length of each isovist.

In this type of experiment where the building's height is in question, a three dimensional isovist would be a useful concept to test the effect of building's heights on navigation. However, as the development of a three dimensional isovist software is not the focus of the current research, the two dimensional isovist is considered adequate. In any case the development of a three dimensional isovist opens up the way for future research (as it is presented in detail in chapter 8).

The navigation performance was measured with three dependent variables, separately for each individual junction along each route:

- Number of attempts to find the correct route; whether the participant chose the correct path on first attempt, second, third and so on.
- Whether the first choice was correct or incorrect. The reason that only the initial choice is tested separately from all the rest is because every other choice, after the first, is dependent on the new position of the participant due to the first choice. For example, there are three choices on a junction, left, ahead and right and the participant first chooses left which is wrong then the new path choices are again left, ahead and right but now ahead is what in the first choice was right. In this respect, every path choice after the first has to be tested both in regard to the initial position when entering a junction and to the new position the participant has after every choice. For subsequent path choices it is a matter of future research to establish a comparison to random (chance level) performance.
- Initial choice corrected: initial choice performance was corrected for the type of intersection, given that T-intersections are easier than star(*)-intersections (by 27.3 %). Also, cross(+)-intersections are easier than star(*)-intersections (by 8.9%), conceivably due to the number of possible choices. The differences of error probabilities for the different junctions were calculated and the performance of the initial choice was adjusted by the error probability due to the type of the junction (effectively “partialling out” the effect of junction type).

The research questions that are examined by analyzing the above mentioned dependent variables are:

- Whether there is a general performance difference between model 3 and 4.

- Whether there is a difference between model 3 and model 4 regarding the height of the buildings of the wrong options.
- Whether there is a difference between model 3 and 4 regarding the height of the buildings of the correct option.
- Whether there is a difference between model 3 and 4 if ahead is the correct option.

Finally, it is tested if there are any correlations between any of the dependent variables and any of the environmental properties for each of the two models.

A first hypothesis presents three factors that can affect path choice and will be examined. These factors are: three-dimensional visibility, correlatedness and integration. Also, the idea of "when don't know, just go ahead" will be tested. The help that three-dimensional visibility may offer for navigation is based on the extra information that can be gained from the fact that high buildings are visible behind low buildings. Correlatedness is an attribute of the model where the building heights are correlated to the syntactic integration. In this model the image of the 3d environment is reinforcing existing schemata of urban environments where usually high streets or main streets are having higher buildings while back streets or small alleys have lower buildings. Main streets are in general more integrated and back streets less integrated. Building heights then can give a hint about the street structure. Finally, integration is the main factor according to space syntax theory affecting route choice (Hillier, et al., 1993). The other case that will be tested, "when don't know, just go ahead" is observed by Conroy (Conroy Dalton, 2003) according to which people tend to follow a close to linear direction when they are not sure about the correct route.

Looking into the first question, whether there is a performance difference between M3 and M4, it appears that the global comparison of M3 and M4 across all junctions revealed no reliable difference between the correlated and inversely-correlated conditions regarding the number of attempts ($F(1,555.72)=.990$, $p=0.320$). The number of attempts on all junctions was the same in both models and therefore irrelevant to whether the model is correlated to "integration" or not.

Similarly, no global difference could be established within or between models for a comparison of junctions based on the mean integration values of each junction (t(533.78), p=0.632) meaning that the number of attempts on a junction was irrelevant to the mean integration of the junction.

Due to the fact that the global analysis does not reveal any difference between the models, it is hypothesized that there are substantial inter-individual differences in task performance and local route choice that may obscure some effects of the models. But more importantly, it is considered that participants' path choices are sensitive to local properties of the junctions, namely the relative building height and integration both for the correct choice at a junction as well as the spatial properties of the other path choice options that can (erroneously) attract movement decisions. Once these factors are taken into account in the fine-grained analysis presented below, differences between the models also become statistically visible.

Looking into the next research question, whether there is a difference between M3 and M4 considering the building height of the wrong options it appears that in model 3 there is a slight tendency to make more mistakes (number of tries) when the wrong streets involve more high buildings whereas in model 4 they make more mistakes when the wrong options involve more low buildings (statistical interaction of factors model * height: F(1,414.82)=2.138; p=0.144; table 6.5). More importantly, in model 3 there is a tendency to make more errors of the first choice (initial errors) when the wrong options involve more high buildings whereas in model 4 they make more initial errors when the wrong options involve more low buildings (again, interaction model * height: F(1,434.21)=4.144;p=0.042). This interaction effect is most prominent for the variable "initial errors corrected by the type of the junction" (F(1,433.10)=6.389;p=0.012).

Streets with high buildings in the correlated model 3, means that the streets are integrated and offer low 3d visibility while streets with low buildings in inverse correlated model 4 means that, again, the streets are integrated but now they offer high 3d visibility. In both cases though, when streets with these properties are available as erroneous choices the participants have a bad performance. Since visibility is not a constant factor in both cases, while integration is, it can be concluded that the wrong choices are based on the syntactic properties of the streets. This means that when the participants don't know which the correct route is, they follow the more integrated path option.

		No of attempts	Initial choice wrong	Initial choice wrong corrected
Model 3	More low-building options	1.25	0.79	0.67
	More high-building options	1.40	0.64	0.52
Model 4	More low-building options	1.38	0.68	0.55
	More high-building options	1.31	0.73	0.61

Table 6.5 Performance measures compared for building height of the wrong options (Note on "Initial choice" measures: 1= correct choice, 0= wrong choice, i.e. high values indicate good performance. On the opposite, on No. of attempts high values indicate bad performance).

The next question to be examined is whether there is a difference between the two models regarding the buildings height of the correct option. The finding of the previous research question is also supported by the fact that there is a statistical trend in model 3 for the participants to make more mistakes, when the correct street is with low buildings and in model 4 they make more mistakes when the correct street is with high buildings (interaction model *height: $F(1,522.36)=2.391; p=0.093$) (figure 6.8). Again, in the correlated model 3, the streets with low buildings are the segregated streets which also have high 3d visibility while in the inverse correlated model 4, streets with high buildings are also the segregated ones which though offer low 3d visibility. It seems again that visibility is not the crucial factor for the participants' choice while integration has an important effect on their performance. When the correct street is segregated their performance is hampered.

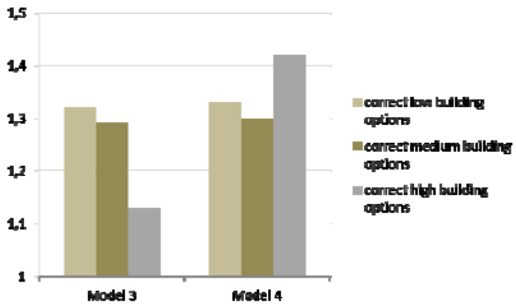

Figure 6.8 Number of attempts compared for buildings height of the correct option.

Taking into account the building height of the correct option also reveals a direct difference between models 3 and 4. For the “initial choice” and “initial choice corrected” measure we observe a significant effect of model (F(1,542.636)=2.944;p=0.087 and F(1,542.588)=2.638;p=0.105). In model 3 participants make fewer erroneous initial wrong choices (21,6 %) than in model 4 (28,3%).

	No. of attempts	Initial choice wrong	Initial choice wrong corrected
Ahead incorrect option	1.429	0.663	0.573
Ahead correct option	1.166	0.830	0.660

Table 6.6 Performance measures compared for direction of the correct option.

The final part is examining whether there is a difference between model 3 and model 4 if ahead is the correct option. Participants make significantly more mistakes if ahead is the incorrect choice (F(1,503.40)=22.848;p<.001) and they also make significantly more “initial errors” if ahead is incorrect

(F(1,525.20)=22.614;p<.001) and the same for "initial errors corrected by the type of the junction" (F(1,525.477)=8.135;p=.005) (Table 6.6). This indicates that one of the navigation strategies when people don't know the route is to go ahead and when this is not the correct option, performance suffers badly.

Statistically controlling for whether or not ahead is the correct option again helps to reveal some global difference between the models 3 and 4. In this analysis participants tend to have a better performance in model 3 than in model 4 regarding the number of attempts (F(1,506.51)=2.06;p=0.152) and regarding the "initial error" (F(1,542.125)=2.09;p=0.149) as well as the "initial error corrected by the type of the junction" (F(1,542.09)=2.08;p=.149). Although, these results are not strong enough, a tendency that model 3 is easier than model 4 is apparent.

The findings for the correlations of number of attempts, "initial errors" and "initial errors corrected by the type of the junction" with environmental properties are presented next (table 6.7).

		Low buildings at wrong choice	Medium buildings at wrong choice	High buildings at wrong choice
Model 3	number of attempts	-0.302 (*)	0.498 (**)	0.099
	initial errors	0.313(*)	-0.437(**)	-0.241
	initial errors corrected	0.261	-0.325(*)	-0.325(*)
Model 4	number of attempts	0.074	0.231	-0.069
	initial errors	-0.084	-0.344(*)	0.101
	initial errors corrected	-0.175	-0.253	0.089

Table 6.7 Correlations with environmental properties (*=p<.05; **=p<.01).

In model 3 there is a significant correlation of number of attempts (R=.498, p=.001) and the number of "initial errors" (R= -0.437, p=0.003) with the proportion of wrong streets being of medium height. This correlation remains in the same pattern even in the case of "initial errors corrected to type of junction" (R= -0.325, p= 0.031). This means that the more medium height streets are wrong, the more mistakes the participants make to find the correct way and the more initial mistakes they make.

Also, in model 3 there is a significant negative correlation of number of attempts to the proportion of wrong streets being of low height (R= -0.302, p=0.046) and of "initial errors" to the proportion of wrong streets being of low height (R= -0.313, p=0.039). The more low height streets are wrong, the fewer initial mistakes and the fewer subsequent mistakes the participants make. This is also supported by the correlation of "initial errors corrected according to the type of the junction" with the proportion of wrong streets having high buildings (R= -0 .325, p=0.032). The more high buildings streets are wrong, the more initial mistakes the participants make.

So participants show worse performance when the wrong streets are of medium or big height and better performance when the wrong streets are of low height. The low buildings streets are the segregated streets in model 3 and it seems that when the segregated streets are wrong the participants are enabled to find the correct route since their choice is towards the more integrated. This finding is also pinpointed by the trend that is noticed in model 3 for a negative correlation between number of attempts and integration of the correct option (R= -0.284, p=0.076). The higher the integration value of the correct way is, the less mistakes the participants make. It is concluded that when the participants don't know the route they pick the more integrated path choices.

In model 4 on the other hand, we generally observe much lower correlations between error patterns and building height than in model 3. In model 4 there is a correlation for «initial errors corrected by the type of the junction" to the wrong streets being of medium height (R= -0.253, p=0.098). The more medium height streets are wrong, the more initial errors the participants make. For model 3, the "initial errors corrected by the type of the junction" are correlated to the wrong streets having high buildings (R= -0.325, p=0.032, see above). The more high buildings streets are wrong, the more initial errors the participants make. It seems that in model 3 for initial choice the participants pick the high buildings streets, which are the most integrated, but in model 4 they pick the medium height streets which are of medium integration. If integration was the factor with the most impact on choice it would be expected that in model 4 participants would pick the low height streets, which are the most integrated. However, the fact that the integrated streets are opposed to existing schemata must be confusing them, leading them towards a more mediocre choice, the medium height and medium integration streets. Therefore it is not integration per se that has an effect but correlatedness also plays a role.

Taken together, model 3 appears to be overall easier than model 4 which is detailed up when considering the building height of the correct options and the case when ahead is correct. This is not directly apparent in the global analysis because of the noise of the different building heights but since it is taken into account then the difference becomes visible. Also, looking into the global performance of all models there were five participants lost in model 1, seven lost in model 2, seven lost in model 3 and eleven lost in model four. This also points to the direction that model 3 is easier than model 4.

Qualitative analysis of questionnaire

Looking into the participants' comments as replying to the questionnaires (the comments can be found in Appendix D) there are several comments that have been brought up many times and are summarised here.

Regarding the question about any difficulty that the participants may have come across it is important to mention that 19% of them were looking for landmarks in the environments and they consider it frustrating that they didn't find any. They found difficult that the buildings were similar, with no details and that there was nothing distinguishable in the environment. Although, the lack of any landmarks in the environments was done in purpose in order to test navigation in relation to the spatial configuration only, it may be the case that landmarks are cofounding variables. This could be clarified in further research.

A second point that 37.5% of the participants found difficult and confusing was the turn of the camera on each junction at the passive navigation of the training phase. Many of them mention that the turn of the camera made them loose orientation and the direction where they were heading.

Regarding the next question which was asking participants about the differences in the environments they were navigating in it was interesting that besides the building heights which 47% of them noticed as a difference, a small percentage of them (16%) also mentioned the width of streets and the change of the angles between streets (20%). This means that the change of the buildings height was creating an illusion about width of streets and angular changes of streets something that was also noticed in participants' comments in the first experiment. Other differences that were mentioned were the complexity of the environments (12%) and the size or shape of the blocks (12%).

Finally, regarding the question whether they had noticed in one of the environments that the main roads had higher buildings than the secondary roads a small percentage of them (16%) didn't notice, 59% of the participants mentioned that they noticed different building heights on a main street but they reported more than one environments where this happened and 19% of them mentioned the correct environment where this was happening. One participant commented that he/she didn't notice that in one environment the buildings on the main roads were higher but he/she did notice that in one environment the buildings on the main roads were lower.

Also, it is important to point out that most of the participants, 47%, found difficulty in moving around in the virtual environment, 28% found it nor easy nor difficult, 16% very difficult and the rest easy.

Summing up

In what follows the findings of the analysis that have been analytically presented above are summed up.

- There are no significant differences between M1 and M2 in getting lost (5 lost in M1 and 7 lost in M2).
- There is no significant difference between M3 and M4 in getting lost. (7 lost in M3 and 11 lost in M4).
- There is no significant difference among models regarding the number of junctions that the participants got lost in the model.
- There is no significant difference among models regarding the time performance.
- There is no significant difference among models regarding the percentage above optimal.
- There is no significant difference among models regarding the number of detours for those participants who didn’t get lost.
- There is no significant difference among models regarding the pointing error both directional and absolute.
- However, the routes are not equal regarding the pointing error both directional and absolute. R4 has the highest pointing error and R3 the lower.
- Participants who are lost have significantly higher pointing error than those who are not lost.
- M3 and M4 present no significant difference regarding the mistakes of participants in all junctions to find the correct path choice.
- The mean integration of all junctions in M3 and all of them in M4 and of all junctions within M3 and within M4 is irrelevant of the mistakes of participants to find the correct path choice.
- In M3 the participants make more mistakes, more initial mistakes when the wrong paths have high buildings and/or high integration. This means the participants tend to follow the high integration path when they don’t know which path is correct.

- In M4 the participants make more mistakes and more initial mistakes when the wrong paths have low buildings and/or high integration. This means that the participants tend to follow again the high integration path when they don't know which path is correct.
- In M3 the participants make more mistakes when the correct path is with low buildings and/or low integration. This means that when the correct path is segregated performance suffers badly since participants tend to follow the integrated choice when they do not know the correct.
- In M4 the participants make more mistakes when the correct path is with high buildings and/or low integration. This means again that when the correct path is segregated performance suffers badly since participants tend to follow the integrated choice when they do not know the correct.
- Participants make fewer initial mistakes in M3 than in M4.
- In both models participants make more mistakes, more initial mistakes and more initial mistakes corrected by the junction type if ahead is the wrong choice. This reveals, and reinforces the already existing idea (Conroy Dalton, 2003), that participants who don't know the route use the navigation strategy, "when don't know, go ahead".
- Participants have better performance in M3 than in M4 (when testing whether or not ahead is the correct option).
- In M3 the participants make more mistakes and more initial mistakes when the more medium height streets (medium integration) are wrong.
- In M4 the participants make more initial mistakes the more low height streets (high integration) are wrong.
- In M3 the participants make fewer mistakes the higher the integration of the correct path.
- In M4 the participants make more initial errors the more medium height streets are wrong.

- In participants’ perception the environments were difficult because there were no landmarks and nothing distinguishable.
- In participants’ perception the environments were different in building heights, in width of streets and in the angles between streets.
- The participants in general didn’t identify correctly the change in building heights with a differentiation of streets to main streets and side streets.

This study was designed to systematically test whether differences in building heights affect navigation, wayfinding performance and route distance estimation. The issue of the three-dimensional scale is also examined as a missing element in the space syntax theory. The experiment that was set up in virtual environments was an attempt to examine if building heights configuration plays any role, as a main source or in addition to integration, in navigation.

The analysis presented was focusing on four parts: on a global analysis of all four models, on the analysis of the pointing task, on the micro analysis of path choices in the “correlated” and “inversely correlated” models and finally to the qualitative analysis of the questionnaire.

From the analysis of the participants’ performance on each junction and the study of the path choices they made in relation to environmental factors, it is found that integration is indeed a crucial factor affecting the participants’ path choices irrelevant of building heights. The case is that when people are lost they follow either of two strategies a) “when don’t know where to go they to go to integrated places”, found in Peponis, Zimring and Choi (1990) or b) “when don’t know just go ahead”, found in Conroy Dalton (2003), and it is not affected by building heights.

What is furthermore added by this research to the above finding is that it is easier to perform wayfinding in the correlated world than in the inversely correlated. The fact that it only gets visible in the detailed micro-analysis and not on all variables is an indicator that correlatedness has a smaller impact than integration of a path choice.

The discussion of the findings of both this experiment and of the experiment described in chapter 4 is presented in the next chapter.

Chapter 7

Experimental data evaluation and discussion

Abstract

This chapter discusses the findings of the two experiments under the light of the theoretical preliminaries as they have been developed from Chapter 1 up to Chapter 3, in the first section. In the second section, it proceeds into a discussion of the use of virtual environments as a methodology in the current research.

Introduction

This chapter will discuss the findings of the two experiments presented in the previous chapters and the research questions that have been posed in each experiment and in the whole thesis. Before starting the discussion the research questions need to be reminded again.

The main thesis research question is whether the three-dimensional scale of the urban environment affects the intelligibility of the urban environment. It is reminded that as three-dimensional scale in this thesis is defined the cityscape scale which is described as the complex relation of what a human mind perceives when walking down a street which is a visual relation of urban form and the space that surrounds the urban form. In a scale relation both the urban form and the surrounding space are introduced with their metric properties however, as it has been discussed in chapter 2, regarding the human perception scale is mainly a visual relation and not a metric or mathematical one.

The research questions of the first experiment were:

- How are environments with different building heights configuration both in a small scale world and in a big scale world (double of the small) are perceived?
- Do differences in building heights configuration in a small scale world and in a big scale world (double the small) affect the perception of ease of navigation?
- How is the addition of elements of hierarchical scaling (windows, doors and pavements) in environments with different building heights configuration perceived?
- Is the perception of ease of navigation in environments with different building heights configuration affected by the addition of elements of hierarchical scaling?

The research questions of the second experiment were:

- Does the route distance estimation is affected by the three-dimensional scale of the buildings along a route?

- Does navigation and wayfinding is affected by the three-dimensional scale of the buildings?
- Does navigation and wayfinding is affected by the buildings height configuration being correlated or not to the street's syntactic integration?

Discussion of the experimental data

The first experiment presented in chapter 4 was designed to test how differences in three-dimensional scale in environments with the same layout would be perceived regarding environmental properties and ease of navigation by participants who would be navigating in the environments. The participants had to navigate in an intelligible layout with six three-dimensional scale variations and in a non-intelligible layout with the same three-dimensional scale variations. The intelligibility of the layouts was based on the space syntax term.

The second experiment presented in the previous chapter was designed to systematically test whether differences in building heights affect navigation, wayfinding performance and route distance estimation. The four virtual environments designed had exactly the same layout but different three-dimensional scale properties. One was with low buildings, one with high buildings, one with building heights correlated to the integration of the street (low integration – small height, high integration – big height) and one with building heights inversely correlated to the integration of the streets (low integration – big heights, high integration – small heights).

The first experiment resulted that the participants found navigation easier in the environments with the same and low building heights. One possible explanation given based on their comments was that the wider visual field of the skyline and of the sky seemed to help in navigation. The case is that the buildings with the same height were also low (6m) and this created more view of the sky and the buildings' skyline which is extra visual information. The environment with varying heights had buildings reaching quite high and not giving enough sky and skyline visibility and of course the double scale world was minimising even more the sky and skyline visibility.

Taking this into consideration part of the second experiment was based on the idea to test navigation performance and not participants' judgment in two environments, one with low buildings and one with high buildings. In this case it was clear that the difference between low varying heights or high varying heights didn't affect navigation. However, the only outcome that can be an indication without though being statistically significant is the number of people getting lost in each environment. In the low buildings height environment (M1) there were the least people lost, only 5, when in the high building heights environment (M2) there were 7.

There are two points to discuss in this case. The first is regarding the perception of ease of navigation that seems to be altered according to sky view or skyline view. In the case of sky view this brings to mind atavistic explanations on how navigation might have been enabled in the past times by sky view and therefore nowadays the sky view gives confidence for navigation. The view of the sky could provide information and orientation due to the sun. However, in the virtual environment there is no sun although there is a hidden light source which makes the sky to have a gradient colour as if there were sun. Therefore, what is considered to be helpful for navigation is the "amount" of sky visible from a specific position. This explained in Teller (2003) where the term "sky opening" is presented. What Teller is attempting to do is to measure the amount of sky visible on different open urban spaces through a spherical projection system. It is clear both in an empirical way and in Teller's way that the sky opening depends on the dimensions of the open space, on the building heights and on the observer's position.

On the other hand, in the case of the skyline view, it seems that it helps navigation by providing a clear boundary or a line that indicates the direction of the gaze and the horizon line. As mentioned in chapter 3, the horizon cue is one of the most important cues for size estimation. In cities where usually the horizon is not visible the coincidence of lines around the pedestrian are pointing to the focal point of the horizon and this may be helping the estimation of sizes. In real environments there are many such lines around a pedestrian like the pavement lines, the street centre lines, the windows' linear arrangement and many more. In the virtual environments which were stripped off of any such detail, the skyline and the buildings baseline were the only lines indicating where the focal point and the horizon were.

The second point to be discussed is regarding the apparatus used. In the first experiment, in the immersive virtual environment with head tracking, the participants could have more view of the sky with a slight head movement upwards which could be done non-consciously while navigating. However, in the second experiment the big screen projection was not offering to the participants the possibility to head slight upwards and have more sky view. The sky view they had was only at the far end of the street ahead. Therefore, the apparatus may have extinguished the navigational aid and this may have jeopardised the outcome. Consequently, it could be that the sky and skyline view were not significantly altered between environments and therefore navigation was not affected by the sky view.

In the second experiment, the pointing analysis didn't bring up any significant difference between the four environments. Even more, the pointing findings were not particularly good displaying poor survey knowledge and it is not totally clear if this is an effect of the environment or of the routes or of the three-dimensional scale. Therefore more research is needed towards this direction.

It has been mentioned, in the literature, that the texture plays a role in size perception as it gives a standard of measurement. On one hand, there is research (Gibson, 1979) that considers it important in environmental perception and on the other hand, there is research (Witmer and Kline, 1998) which shows that texture didn't have any effect on size perception. In the current experiments it was chosen to strip off the environments from any texture information in order to be easily supported by the provided apparatus. Therefore, the choice was to use objects of familiar size instead of texture. In the first experiment two of the environments had windows, doors and pavements which can be used as standards for the judgment of sizes. However, participants' comments were not clear whether this helped or not. In the second experiment there was only a lightly coloured line every 3m height on the building.

After the analysis of the second experiment it can be concluded that the cognition of route distances doesn't seem to be affected by the building heights configuration. In the first experiment it became implicit from participants' comments that the perception of the length of a road depends on the height of the buildings along this road. This led the research to test the hypothesis whether the cognition of route distances is also affected by the configuration of building heights. It can be concluded that although the perception of the length of a street may be affected by the building heights along this street this doesn't seem to affect the estimation of route distances.

A possible explanation for this outcome is that there is a difference between perceived distance and traversed distance. The judgment that is done by a static person of the length of a street is altered when movement is involved. The initial static estimation is updated by the proprioceptive information and a new judgment in distance is created. The first judgment is based on "visual perception" being static and momentous and the second on an "ecological perception" (Gibson, 1979) resulting from movement and from a holistic interaction with the environment. Therefore perceived and traversed distance varies. This was also apparent in some of the participants' comments in the first experiment when they mentioned that in the different heights environment they found the streets after traversing them longer than they expected.

Therefore the perception of the length of a street may be affected by the building heights but not the cognitive distance of the overall trip that depends on movement. On one hand, this means that the distance is not affected by building heights configuration but on the other hand, the perception of the length of a street may affect path choice. When a visitor who is walking in a city wants to find the shortest path to his destination and has to choose between two streets lying ahead, this choice may be affected by the building heights. Things may be different for a person who is familiar with the environment and who is walking this distance regularly. This person would make path choices based on the knowledge of traversed distance and not on perceived distance.

Furthermore, regarding route and survey distances it should be noted that route distances were underestimated in all cases by around 30% and the survey distances were underestimated by around 40%. This confirms previous findings that distances are underestimated in virtual environments (Willemsen, Gooch, Thompson and Creem-Regehr, 2008).

An unexpected finding in both experiments was the one regarding landmarks. There is wide literature on the help of landmarks on navigation (Lynch, 1960; Sholl, Acacio, Makar and Leon, 2000; Hegarty et al., 2002), however, it was not expected that in environments like the ones in these experiments which were stripped off any distinguishable characteristic the participants would still attempt to look for landmarks. This is a fact that reinforces the importance of landmarks in navigation. It was very clear by participants' comments in both experiments that they were looking for landmarks to aid their wayfinding. In the second experiment participants were even frustrated by the lack of landmarks or anything distinguishable in the environments. However, in the lack of any, the building heights configuration served as a landmark in the first experiment.

In the first experiment, in the case of a very low building among high ones, this configuration was recognized as a square and immediately was used as a landmark to help navigation. It was also commented by participants that environments with "squares" were easier to navigate due to the visibility they were offering behind the low building. There was a dual effect, the first was that these "squares" were working as landmarks and the second was that they were offering three-dimensional visibility. Three-dimensional visibility is the visibility of high buildings behind lower ones and was one of the tested variables in the second experiment in the correlated and inversely correlated models. Although, from participants comments in the first experiment it appears that the three-dimensional visibility plays a role in navigation, in the second experiment it didn't seem to affect participants' path choices.

One of the main findings was the effect of building heights configuration on the perception of environmental differences related to the geometry and topology of the environments. The case is that when discussing about the perception of environmental differences one would expect that the effect would be limited in the perception of building heights. What though appeared to be interesting is that the differences of the building heights configuration were altering the perception of geometrical and topological properties of space. The effect on one geometrical property of space, this of the length of streets, was presented above. Here below another the altered perception of another geometrical property will be presented.

In both experiments the layouts were the same and therefore the geometry and the topology were remaining invariant in all virtual worlds. However, according to the participants' comments in both experiments the worlds were not recognized as being the same. Differences that were mentioned in many cases were the different angles of incidence of the streets and the length and width of the streets. It is interesting that in the first experiment some of these differences were noticed only in the small scale worlds. A possible explanation is that since the skyline, which defines the building heights variations, in the big scale environments was mostly out of the field of view it was not affecting the perception of environmental properties.

Furthermore, in the first experiment the environments had the same spatial layout and were not recognized as such. The only few cases in which the environments were recognized as being the same was in the same heights environments with and without scaling hierarchy elements both in small scale and in big scale. In these cases the participants also learned the route and were following exactly the same route each time to complete the task. Therefore, it is concluded that the different height configuration alters the perception of the topological properties as well.

Another environmental difference that was mentioned by the participants was the order and structure of the environments. In the first experiment, they perceived the same height environments as more ordered than the different height ones. Also, in the second experiment they noticed that the environments were different at the level of complexity.

The third question of the second experiment was looking into a specific building heights configuration and whether this affects navigation. The idea was to construct an environment with a specific structure regarding building heights. The structure that was chosen to be used was that of building heights correlated or inversely correlated to the space syntax integration measure of a street. In a sense the structure that exists in the spatial layout and is measured by integration according to space syntax theory was reflected in the building heights. In this way there were two outcomes. The first is that there was an implicit but clear structure in the building heights configuration and the second is that this structure was corresponding to a real visual image of cities. This image corresponds to a common situation where in many cities the more integrated streets accommodate higher buildings. Therefore this image corresponds to established schemata in people's minds.

As previously mentioned the global analysis regarding the navigation performance of the participants in the second experiment revealed no actual difference between all four worlds. However, environments M3 and M4, the correlated and inversely correlated, were offering the possibility to conduct a more detailed micro analysis of path choices and investigate through this analysis any differences among the two, due to the different building heights configuration existing on each street. In models M3 and M4 each path on a junction has different building heights configuration (low, medium or high buildings according to the integration of the path) while in models M1 and M2 the paths had the same buildings height configuration (low buildings or high buildings).

This detailed micro analysis was based on the path choices that participants did on each junction. Variables that could affect the path choice were the buildings height, the integration or the three-dimensional visibility (meaning the view of high buildings behind lower front buildings).

The main finding was that the participants' choices were first dictated by the integration of the street. This means that any path choice was affected by the integration of the path and not by the three-dimensional visibility. The participants were most of the times choosing the most integrated street which in the case of

M3 had high buildings and was not offering three-dimensional visibility and in the case of M4 the street had low buildings and was offering high three-dimensional visibility.

The second outcome that was revealed from the analysis of the participants' performance on each junction and the study of the path choices in relation to environmental factors is that when people are lost they follow either of two strategies a) "when don't know where to go they to go to integrated places", found in Peponis, Zimring and Choi (1990) or b) "when don't know just go ahead", found in Conroy Dalton (2003). The current research therefore demonstrates that these two strategies are not affected by building heights.

Another finding of this research, which has not been strongly supported by all the analysis though and needs further examination, is that it was easier to perform wayfinding in the correlated world than in the inversely correlated. The fact that it only gets visible in the detailed micro-analysis and not on all variables is an indicator that correlatedness has a smaller impact than integration of a path choice. The explanation that is suggested for the effect of correlatedness is that the correlated model corresponds to established schemata of urban environments as the initial hypothesis was. These schemata usually follow the pattern that integrated streets (usually main streets) are having higher buildings and segregated streets (usually back alleys) are having lower buildings. This three dimensional structure could enable navigation either due to the recall of established schemata, which is a more psychological explanation, or due to the creation of a clear visual-spatial structure in the built environment.

It would be naïve to conclude simply that if the same structure that applies on the spatial configuration on the two dimensions could be reflected on the three dimensional configuration, navigation would become easier. However, it is an issue that opens up a discussion and is a fertile ground for future research. In the case used in this experiment it could be said that the three-dimensional image of the city supports the underneath two-dimensional structure and this brings to surface and makes more apparent what people seem to already perceive about two-dimensional spatial configuration.

Consequently, it seems that the spatial structure is more important for people navigating in an urban environment. Therefore it could be mentioned that syntactical intelligibility plays the major role. However, visual legibility seems to play also a role and particularly in people's perception of the environment. Looking into participants' comments it becomes apparent that the visual image is very important for them not only at the level that they are looking for distinguishable elements and landmarks to help their navigation but also at the level that other geometric attributes of the environments, like width of streets and angles between streets, are altered due to differences in building heights. This was apparent in both experiments conducted for this thesis.

The two experiments conducted for this research have pointed to the direction that the spatial layout remains indeed the main factor affecting navigation and wayfinding in urban environments. However, what has been added by this research is the contribution of the three-dimensional scale in the creation of a legible image of the environment.

The research question posed in the beginning, whether the intelligibility of an urban environment is affected by the three-dimensional scale can now be replied. The three-dimensional scale does not seem to be the main factor that affects navigation and wayfinding but a secondary factor and it seems to affect mainly people's "reading" of the urban environment, it seems to affect the visual legibility. The issue is that the visual legibility is not confined only in the legibility of the building heights which are the variable but it seems that the building heights affect the visual legibility of other properties of the environment as well. This is what three-dimensional scale is about. How the change of just one attribute affects the perception of others as well.

The study of scale shows that the perception of the built environment is not based on metric properties. The perception of distances, sizes and scale is a very complex procedure that involves many attributes of the environment which are visually related. In the literature presented, scale was defined as size perceived by the human eye, as the inherent claim to size, therefore scale, perception and cognition are closely related and should be closely studied.

Discussion on the methodology

As it has already been presented in chapter 3, factors that affect performance in virtual environments are the apparatus, the level of immersion, the level of detail of the environment and the sense of embodiment (Ruddle, Payne and Jones, 1999; Riener and Proffitt, 2002; Ruddle and Lessels, 2009; Sousa Santos, et al., 2009). The question is whether any of the findings of this research could be attributed as a side effect of the methodology used. Such a characteristic side-effect for example is the underestimation of distance estimations that are noticed in experiments in virtual environments (Henry and Furness, 1993; Lampton, McDonald, Singer and Bliss, 1995; Witmer and Kline, 1998).

Of course the more straight forward way to discover and discuss such side-effects would be the replication of an experiment both in real and virtual environments (Cromby, Standen, Newman and Tasker, 1996; Witmer, Bailey and Knerr, 1996; Van Veen, Distler, Braun and Buelthoff, 1998; Richardson, Montello and Hegarty, 1999; Colle and Raid, 2000; Conroy, 2001; Chabanne, Péruch and Thinus-Blanc, 2003; Waller, Loomis and Haun, 2004; Koenig, Crucian, Dalrymple-Alford and Duenser, 2011). However, since there is not such possibility to replicate the virtual environments designed for the current experiments in reality, the discussion has to be produced at the level of what appears to be a flaw in the way virtual environments were used in the experiments.

The apparatus and the level of immersion used in this thesis were different for each experiment. In the first experiment the apparatus was a head-mounted display with head tracking and a mouse for movement. Although it was a new experience for most of the participants, the apparatus was found amusing and interesting at least at the beginning. It was clear that participants were getting tired after long use and this is why many intervals were included in the experiment. Three participants quit the experiment after feeling dizzy. The participants' judgement of the apparatus, based on the answers of the questionnaire, was that it was difficult. The apparatus used for this experiment is considered to create an immersive virtual environment which may be expected to recreate the real world in the best possible way. However it seems that the apparatus doesn't offer very confortable conditions in order to increase presence by taking participants mind away of the real world and transfer it to the virtual.

On the other hand, it would be expected that due to the level of immersion being high in this environment that embodiment would be less of a problem. However, there are two facts that took place in this experiment that have raised important questions regarding the use of the virtual environments in a study of scale due to the lack of embodiment. The first is that the double scale in the first experiment was not recognised as such and the second, in the same environments again, that the difference between the small and the big scale environments was considered as slower speed of the apparatus.

There are two reasons why this may have happened. First, is the lack of contextual cues and the second is the lack of embodiment (Glennester, Hansard and Fitzgibbon, 2009; Mohler, Creem-Regehr, Thompson and Buelthoff, 2010). Contextual cues would be objects of known size such as, people, cars or trees that would help someone to relate their size to the building size. All these were missing from the environments as they were stripped off any such detail. A pedestrian's own body also works as a contextual cue, therefore, it would not be expected in a real environment that the pedestrians would miss the difference in scale between two environments. This problem brings to the front the issue of embodiment in virtual environments. Kinesthetics, the physical effort and the existence of the body of a pedestrian in a real world would help realising whether the walking speed is changing or whether the size of the buildings is different.

In the second experiment the sense of embodiment could not be judged with the same criteria as the conditions were different. There was no difference in the size between the environments like in the first experiment and therefore there is no input for such a condition. The apparatus in the second experiment is considered to be non-immersive as the projection was done on a big screen in front of the participant and the movement with the keyboard arrows. Participants were more accustomed to this type of apparatus since besides the size of the screen it is very similar to a desktop projection. Still, in this case they have also reported difficulty in the use of the apparatus.

The forementioned issue of embodiment that was strongly raised in the first experiment can be considered a drawback of the use of virtual environments; however, it is not strong enough in order to diminish the advantages. Both of the experiments could not take place in real environments therefore the virtual environments have offered a huge tool for research. The question is to study the effect of a variable, which is scale, on people’s behaviour in conditions that would be impossible to recreate in real environments. It seems that participants in virtual environments do not realise scale exactly as it is which wouldn’t be expected in a real environment (Glennester, Hansard and Fitzgibbon, 2009). It can be the case that in experiments where embodiment is more crucial the results may be jeopardised in virtual environments. This is the reason that although there was an important finding in the first experiment, the one on the perception of the double scale which was not perceived as such, this was not taken further in the second experiment. This finding should first be studied as an issue of the methodology (this is the virtual environments) than as an issue of scale. However, the main aim of this thesis is to study scale and not the use of virtual environments in such a research.

In any case comparing advantages offered and disadvantages faced it can be concluded that virtual environments are a successful methodology for the study of scale. Of course there are issues that could be improved and problems faced that will be presented in the next chapter.

Another question that is posed is whether a study involving scale and navigation has any validity to take place in virtual environments regarding the transferability of the results. As the scientific world is still using the virtual environments as a replica of the real world and is not interested, at least not yet and not the major part of the scientific world, in investigating how people would live, use space and behave in the virtual world the issue of transferability of results is crucial.

As it has been reported in chapter 3 there are two types of transferability of results, the transferability of the knowledge acquired by the participants in the virtual environments to the real environment (Cromby, Standen, Newman and

Tasker, 1996; Witmer, Bailey and Knerr, 1996; Richardson, Montello and Hegarty, 1999; Chabanne, Péruch and Thinus-Blanc, 2003; Wallet, et al., 2011) and the transferability of the knowledge, as findings this time, acquired by the researcher in the virtual environments to the real environment (Van Veen, Distler, Braun and Buelthoff, 1998; Conroy, 2001; Colle and Raid, 2000; Waller, Loomis and Haun, 2004; Koenig, Crucian, Dalrymple-Alford and Duenser, 2011). This second type is of interest in this research as the idea is to transfer the knowledge acquired on the effect of the three-dimensional scale on navigation and on the perception of environmental properties from the virtual environments to real environments.

According to the literature provided the transferability of results regarding navigation in virtual environments has validity. Therefore the transferability of the results regarding the navigation performance in the current experiments is considered valid. However, the question is about the transferability of results regarding perception of scale. A possible answer is that perception of scale is not about the perception of a single metric property but how the perception of one metric property affects the perception of another metric property. Therefore perception of scale is based on relativity which is considered to be the same in each type of environment. It may differ as a relation in a real environment than in a virtual environment but the rules that govern each world, keeping the analogies, seem to be the same. Of course, no need to say that the best way to investigate this would be with the replication of the same experiment or with another scale experiment in real environments.

Summary

This chapter has discussed the findings of the two experiments conducted for this thesis under the light of the theoretical preliminary presented in previous chapters and the methodology used which is testing participants' performance in a virtual replication of real world conditions.

The discussion has been focused on the following issues, on the effect of three-dimensional scale on navigation, on its effect on the sense of direction, on the importance of familiar size elements in the understanding of the environments, on the use of three-dimensional scale as landmarks in the aid of navigation, on the effect of building heights configuration on the perception of environmental properties and on the effect of a structured building heights configuration on navigation. Regarding the methodology used, the issue of embodiment in virtual environments and the issue of transferability of results from the current studies to reality have been discussed.

The next chapter will present the conclusions of this thesis and will attempt to sum up the argument.

Chapter 8

Conclusions and implications of the findings on design

Abstract

This chapter summarizes the findings of the current research, presents the implications of the findings on design, discusses what could have been improved or altered in a repetition of the same study and points towards possible future research.

Findings and implications on design

The research question of the current thesis was whether there is an effect of the three-dimensional scale on the intelligibility of the built environment. It has been clarified in the introduction that what is meant by intelligibility is the way that people "read" the urban environment consciously or non-consciously which is a combination of the syntactic intelligibility of space syntax (Hillier, 1996) and of the visual legibility of Lynch (1960). It is considered as the attribute of an environment to convey information to the pedestrians. This information is cognitive or perceptive, not affective, useful and applicable first of all for movement and then for use. However, intelligibility is at the same time based on the ability of the human mind to comprehend the environment, the information provided. In order for both these two conditions to take place the information needs to be "compatible" to the human mind.

The findings of this research can give a suggestion on the direction that architectural design could proceed regarding building heights, ease of navigation in cities and ways of increasing perceptual intelligibility in urban environments.

As seen in the previous chapter, the main finding is that the three-dimensional scale does affect the perception of geometrical and syntactical attributes of the built environment and at the same time it does affect navigation and wayfinding but less than the spatial configuration of the built environment. It has been discussed how the length and width of streets and the angles of incidence between streets have been perceived as different, when they are the same, due to varying building heights configuration along them. It has been discussed that in the same spatial layout participants performed better in an environment with a specific three-dimensional structure favorising established schemata than in another opposed to established schemata. However, in both cases there were two strategies prevailing which are both related to the spatial structure showing that spatial configuration plays the main role. These two strategies were "when don't know the route go ahead" (Conroy Dalton, 2003) or "go to the most integrated places" (Peponis, Zimring and Choi, 1990).

What is concluded from the above findings is that the three-dimensional scale does play a role in the intelligibility of the built environment. Of course three-dimensional scale cannot change the syntactical intelligibility of the environment but it can change the visual legibility and also alter how the environment is perceived and comprehended by people moving in it.

One of the theoretical contributions of the thesis is the overcome of the duality between space and form in the existing literature through scale. Scale is not seen as the scale of the space or the scale of the form but as a relation between the two. It could be easily concluded that such a relation would be a metric relation since it is metric properties that are compared however the metric relation of form and space which is called scale doesn’t seem to be metric. It is a relation very much based on perception and it has been clear from the literature that perception of such properties is not working metrically. Even more, what is presented in this research is that the perception of metric properties is affected by properties of the built environment both metric and not.

Therefore this thesis has introduced the term of cityscape scale which is defined as a relation between form and space as it is perceived by a pedestrian in an urban environment. This is not a relation of form and space as it appears in block structure maps or street section images but a three-dimensional image of a street which is constantly updated by movement in the urban environment.

The main aim of this research is to effectively use the obtained knowledge in order to inform the discourse on three-dimensional scale and building heights in architecture and urban design. The discussion on building heights in architectural and urban design is still focused on issues like population densities, view restrictions or aesthetic quality and more important lately on the environmental sustainability of high buildings. Such a discussion has never taken place at the level of the three-dimensional intelligibility of the city, at the level of navigation and wayfinding. This research is throwing light into the question whether scale could be important on navigation in the city or whether it should always derive, as until now, from policies, technology, aesthetic rules and other environmental factors.

There are a few issues that have been raised in the thesis that could inform the design process and will be discussed below.

One important finding was that building heights configuration affects geometrical and topological properties of the built environment. This means that some of the environmental properties which have been designed to serve a goal are not working as it was in purpose. The case is that they are not perceived by people in the way they were conceived by designers and therefore don’t really succeed in their goal. Perception and cognition studies should work tightly with design studies in order to find how the users will be served best and the designers will aim best their goals. Geometric properties of the environment cannot be perceived metrically and for that reason mathematical representations cannot help their study. Mathematical or metric representations can be useful for ergonomy or for construction. Design problems, like the three-dimensional scale, must be studied based on perception and cognition as well.

The second important finding that can inform design is the fact that although the spatial structure was indeed the most important factor affecting navigation, the visual structure also helps. What has been apparent from this study is that although visual structure is not the main factor, the people seem to be looking for it. The case may be that a clear and legible visual structure is giving confidence to pedestrians to navigate in a city. A strong imageable city could increase the comprehensibility that it offers to pedestrians. The aim would then be to design cities that offer syntactic intelligibility and visual legibility through buildings height structure. Spatial structure may indeed be the most important factor for navigation but it seems that visual legibility or structure helps as it gives confidence to the pedestrians that they comprehend the urban environment.

One issue that has occurred from the research is that navigation seems to be easier with more of sky view or buildings skyline view. It is not clear at the current stage of research which of the two is that helps most. The case is that in order to have more view of the sky or to be able to see the skyline this wouldn’t mean necessarily low buildings but such a relation between width of streets, length of streets and height of buildings that would allow for more sky and skyline view. More research is needed towards this direction in order to clarify how the sky or skyline view would help and which relation of width of street/height of buildings/length of street is offering best view.

Another issue is the implication that the difference between perceived and traversed distance can have on the walkability of cities. Since perception can be tricked and specific building heights configurations can make streets look shorter, this can be used to make routes more attractive for people to walk regarding their distance. This heuristic would definitely work well for visitors in a city or for first time users of a street. People familiar with a route would use the traversed distance feedback which would put things in the right place. However, thinking of someone living in an overall big scale environment where his distance perception may have been altered and distances are shrunk overall, it could be the case that the psychological limit of what is a walkable distance is increased.

Another implication of the findings on design is that the building heights configuration can be used by designers as a landmark in urban environments and help wayfinding. The height of buildings has been widely over history and present used as a landmark but it is mostly the case of a unique very tall building or a sum of buildings in a small area of a city like the “Defense” in Paris or the “Docklands” in London. It is here suggested that the building heights configuration can be used as a landmark throughout the city in a more holistic way by creating specific configurations or structures of building heights that will give a distinctive character and create visual legibility.

Feedback on the experiments’ design

There are a few issues that have occurred during this research regarding the experiments design that although they considered to be the right decision at the moment, after examining the findings and the participants’ comments it is apparent that they could be avoided or done differently. These issues will be presented here.

The environments were very simple without many details in order to strip them off any other element that could be used as a standard for understanding sizes, since the point in this stage was to investigate only the pure, main dimensions of buildings. Any other environmental element, either texture, objects or avatars that would be used as contextual cues would give a sense of scale. This was done only in the environments with doors, windows and pavements. In the second experiment also the buildings had lines on their façade roughly indicating the floor level (participants didn't know that this was the case although they could possibly understand). However, it seems that this type of environment was tiring and confusing for participants. Therefore, there could be at least a type of texture or grid on the facades that would increase the environments comprehensibility.

In the second experiment during passive navigation the camera was stopping at each junction and turning around 360^{o} in order to give the participants better view of all the streets. This element was added after the pilot study. During the pilot study when participants were actively navigating in each environment they were stopping at junctions and were looking around. Therefore it was considered to be helpful the same thing to happen in passive navigation as well. However, participants' comments at the questionnaire revealed that they found this rotation of the camera extremely confusing and disorientating.

In the first experiment a big issue occurred with a few participants not recognising the double scale environment as such and a few believing that the walking speed was slower and not the environment bigger. This was an unexpected finding since when designing the environments it was thought that participants would naturally recognise the double scale. The reason for this confusion was the lack of any contextual cues in the environments that would help participants to relate sizes. Therefore it would be interesting if there was also a set of double scale environments with doors, windows and pavements (as with the small scale ones) which would give a sense of familiar size. It is expected that in this case the participants wouldn't miss the difference in scale.

For both experiments, individual differences have not been taken into account as they were not the main question of the thesis to test them and they were not considered to alter much the outcome. However, there were differences among participants that could be tested for biased results. Such individual differences were the participation of architects in the first experiment and the cultural differences that may arise between the first experiment where participants were English speakers living in the UK and the second where they were native German speakers living in Germany. Furthermore, participants could be tested for their sense of direction with tests like the Santa Barbara Sense of Direction Scale (SBSOD) (Hegarty et al, 2002) and differences among verbalizers and visualizers and among visualizers those who focus on space and those who focus on form (Kozhevnikov, Hegarty and Mayer, 2002; Kozhevnikov, Kosslyn and Shepard, 2005).

Recapitulation of the story presented

The first chapter starts by introducing the research question of this thesis which is whether the three dimensional scale affects the intelligibility of the built environment. The thesis attempts to approach scale as an urban and cognitive problem and examine whether the three-dimensional scale design decisions should be based only on policies, environmental factors and population densities as up to now or they should also be taken into account the effect they have on pedestrian movement, on navigation and wayfinding.

The chapter sets the two main theoretical bases for its approach, the first being space syntax theory and the second the exploration of the term intelligibility in space syntax (Hillier, 1996) and in Lynch’s approach (Lynch, 1960). Space syntax will be used as a theory that already explores pedestrian movement, navigation and wayfinding problems in relation to the spatial layout but also as a theory that is missing the three-dimensional scale in its approach. Lynch’s idea of the importance of the visual legibility of the city will be one of the main starting issues of this thesis. The term intelligibility will be then used in a combination of what the two theories advocate, both in the syntactical approach and in the visual. These two will be then examined in relation to the perceived intelligibility which is the intelligibility as the pedestrians experience it.

The research question was then approached in chapter 2 by looking into the existing literature to discover how scale is defined. The research has led to the conclusion that scale is defined as relations. Scale is relations of something to the human body, to a standard or of things among each other. Chapter 2 documented three approaches of the concept of scale: the first, the formal approach, looks into scale as an attribute of form, the second, the experiential, looks into how scale is perceived and the third looks into configurational scale which introduces a more specific definition of scale of the built environments and is the approach that this research suggests.

Scale as an attribute of the built environment is usually found in three fields of research of the built environment. These fields are architecture, urban design and geography. Each of these fields is approaching the term scale in a different way. Architectural scale, urban scale and spatial scale are concepts of scale which create a duality between space and form or look at it in a more fragmented way.

The chapter concludes to an approach of scale that includes the relation of the built to the unbuilt, of form to space in all three dimensions, as these are deployed in front of the human eye of an observer walking in the environment. This means that the image of the environment is three dimensional, perspective and human-centric. This scale has been named cityscape scale and it intends to describe the complex relation of what a human mind perceives when walking down a street which is a combination of architectural forms and of the space among them.

The findings of the experiments have backed up such a definition of scale as they have brought to surface the relation between metric properties of form and metric properties of space illustrating how the one can affect the other.

Continuing in chapter 3 the methodology used in this research has been discussed. The methodology is the use of virtual environments for the conduct of experiments where three-dimensional scale differences are the variable. The reason that virtual environments are chosen is because they give the opportunity to test the variable in a systematic and controlled way that wouldn't be possible in real environments. Furthermore, the behavioural tracking and data gathering is easier and more precise in virtual environments.

Chapter 3 has been preoccupied with the advantages and disadvantages in the use of virtual environments for scientific research, the transferability of the knowledge obtained in virtual environments to real environments and finally the way virtual environments have been used as a methodology in the studies of spatial cognition and environmental perception by illustrating research in these fields.

The next chapter has described the first experiment conducted in virtual environments attempting to understand how three-dimensional scale properties are perceived by people navigating in an urban virtual environment. The experiment has concluded that three-dimensional scale affects the perception of distance and in general geometric and topological properties of space, the perception of order and structure in an environment and to the hypothesis that low height environments may be easier to navigate than big height ones.

The findings of chapter 4 have formed the base on which the design of the virtual experiment was presented in chapter 5. This experiment investigated in the navigation and wayfinding performance of pedestrians in virtual environments with the same layout and varying building heights configurations. The findings presented in chapter 6 have shown that building heights do not seem to affect distance estimation in navigation limiting the results of the previous experiment in the effect of scale on the difference between perceived and traversed distance. Building heights do not affect neither the sense of direction nor navigation. The main factor that affects navigation has been found to be the topology of space.

The discussion that has followed in chapter 7 has raised many issues regarding the effect of scale on the intelligibility of the built environment by people navigating in it. It has been clarified that the building heights configuration affects the visual legibility of the environment in such a way that it affects the way that the environment is comprehended and understood. It is clear that the spatial intelligibility is the factor that mainly and unconsciously affects navigation but the visual legibility is crucial for the way this spatial intelligibility becomes comprehended by people. Therefore the two should be studied closely.

Future research directions

This thesis has attempted to approach the issue of three-dimensional scale in the urban environment. What is certain from the research that has been completed is that many more issues and questions have been opened up. In what follows some remarks for future research related to the three-dimensional scale are presented. Future research can be directed towards three different fields of research:

- Studies of perception and cognition of three-dimensional scale differences and how they affect the perception of other environmental properties of space and spatial cognition.
- Transferability of the results of the research on three-dimensional scale from virtual to real environments.
- The issue of embodiment in virtual environments regarding the research on three-dimensional scale.

The experiments that have been done in the current research could be repeated with many variations. One variation would be a test of free navigation in the second experiment instead of having the task to go to the starting point following exactly the same route. In free navigation the navigation performance could be tested in relation to the syntactical properties of space. Also, in the second experiment, additionally to the correlated and inversely correlated worlds there could be a random assignment of building heights configuration to streets in order to test whether it was the “established schemata” idea that made the correlated environment easier for navigation or not.

From the findings of the experiments presented in this thesis many hypotheses have been created that can each be tested separately in future research. In what follows there are suggestions for studies looking into some of these hypotheses.

One hypothesis created was that the view of the sky or of the buildings’ skyline helps navigation in urban environments. One way in which this hypothesis can be tested is through an experiment of navigation in environments where the sky and skyline view is altered and eye tracking or head position data will be recorded in order to track if and in which cases participants' gaze is directed upwards. The environments can be one with low building heights, one with medium, one with high, all in two different conditions one with textures or detailed facades, mostly with linear elements, and one without. The reason that two conditions regarding the detail of the facades are used is to examine whether the pursuit for the skyline view is done by participants in order to contemplate for the lack of any elements lower of the skyline pointing to the vanishing point on the horizon.

In order to test the effect of three-dimensional scale on the perception of streets' angles of incidence, a regular grid pattern can be created for layout where the same street angles will be repeated. Then an analysis based on the path choice of each participant on each junction relating the buildings scale and the angle of the street can be done. This issue can be investigated additionally to the analysis done by Conroy (2001) for the navigation in the environment illustrated in figure 8.1. The experiment in Conroy (2001) took place in virtual environments and the data were analyzed by applying string matching technique based on the angles of incidence between streets to analyze the navigation patterns. The finding that was based on the angular choices of participants on each junction was that the participants are choosing routes which tend to approximate straight lines. The same experiment can be repeated with different building heights configurations in order to test if the angular choices will be affected.

The effect of three-dimensional scale on the perception of the length of streets and the difference between traversed and perceived distance can be tested with the following experiment. A layout can be used with a totally orthogonal grid with different building heights along each street designed in such a way as to have streets with the same length and different building heights. Participants will be asked to navigate choosing each time on a junction the shortest street. It can be investigated whether the participants choice will be affected by the height of the buildings along a street and furthermore if the feedback they will be getting from the traversed distance estimation will make them eventually correct their final perceptual choices in relation to the initial ones.

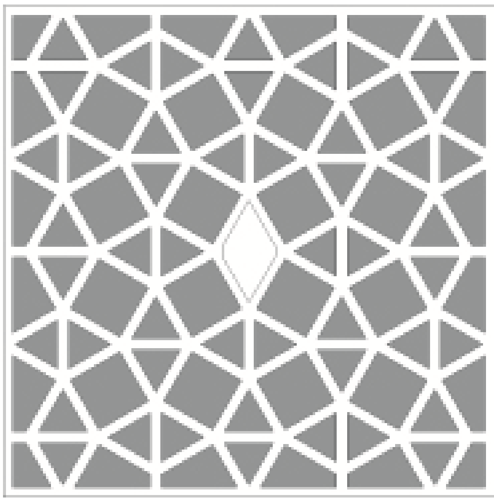

Figure 8.1 Layout found in Conroy (2001) which can be used in an experiment testing the effect of three-dimensional scale on the perception of angles of incidence between streets.

The investigation into the hypothesis that the three-dimensional scale affects the perception of topological properties of space can be done with the following experiment. In environments with the same layout and different building heights configurations like, low buildings, high buildings, same height buildings and varying height buildings participants will be asked to perform navigation, wayfinding and survey tasks. The effect can be tested by comparing navigation performance measures to space syntax measures.

The above experiment can also test the effect of several structured building heights configurations like:

- Building heights correlated and inversely correlated to the width of the street.
- Building heights correlated and inversely correlated to the length of the street.
- Varying building heights by area (alteration of low areas – high areas).
- Random variation of building heights per street.

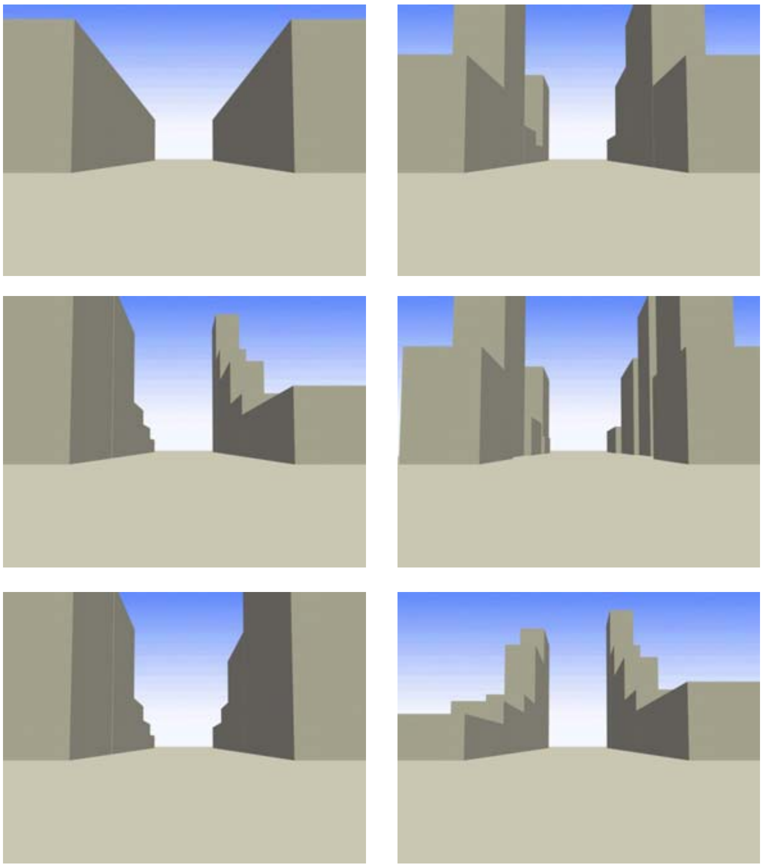

Figure 8.2 Different building heights configurations along a street with the same length and width are illustrated. One can notice how the perception of the length of the street is affected by the different building heights configuration along a street.

Next, the effect of the apparatus on the perception of three-dimensional scale in virtual environments and the possibility of perceiving different scales, small – big, in virtual environments can be tested with the same experiment which would be taking place with different apparatus, like desktop, screen projection, head-mounted display and in CAVE. The environments beyond scale differences can test also other conditions like, environments with and without familiar size elements, doors, windows, pavements, cars, trees and with or without human body representation or populated or not.

Last, a mapping methodology of the three-dimensional scale as a relation of form and space based on perception can be subject of further research. The mapping methodology can attempt to map the perception of length of a street as this is affected by the buildings' form along it as the findings of this thesis have pointed (figure 8.2). This can be approached with an analysis of the three-dimensional images of a street as these are perceived by a pedestrian.

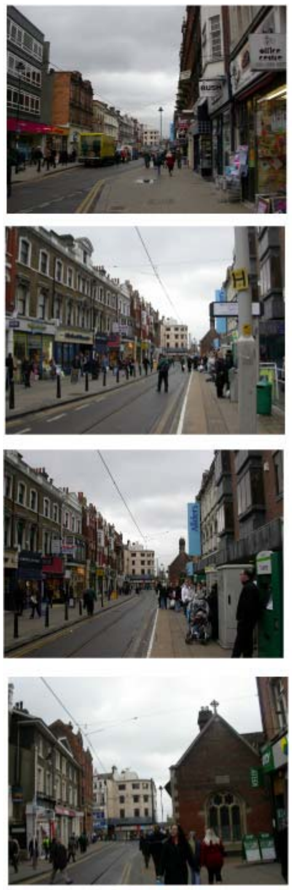

Figure 8.3 Serial vision images of a street.

The idea is based on a representation of what the human mind perceives along a street as a representation of serial images. Cullen (1961) in his book "The concise townscape" has introduced the idea of the "serial vision" as a series of all the images that the human eye perceives as someone is walking along a street (figure 8.3). The serial vision idea can be applied for many point positions of a street, as for example if there were a grid tessellation on the plan and the observer was standing on each little square of the grid and taking a picture of what is lying ahead.

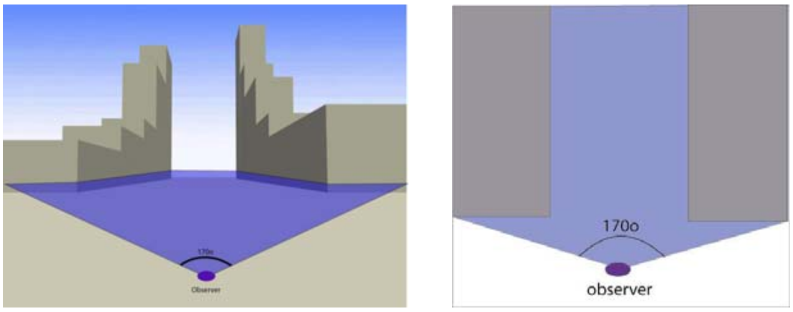

Figure 8.4 The perspective isovist on the left based on the classic two-dimensional isovist on the right.

The analysis of all these pictures can be based on the relation of the perspective isovist to the building form shape. Perspective isovist is the isovist as it is deployed in a three-dimensional image as shown in figure 8.4. and the building form shape is the shape created by the outlines of the buildings configuration on each side of the street as they appear at the image perceived by the human eye. Figure 8.5 illustrates how from the above serial vision picture of figure 8.3 the buildings shape can be outlined.

Figure 8.5 Serial vision pictures on the left and the outline shape of the buildings form on the right.

In the sequence a shape analysis can be applied for the shapes of each image taken from each single point of the street. What type of shape analysis can be used is subject to further research. However, a simple analysis can be based on the relation of the centroids of the shapes. Figure 8.6 illustrates the centroids of the three shapes of two different building height configurations along a street (the first and last from figure 8.2). A hypothesis created from this image is that the three-dimensional triangle created by the three centroids may have a relation with the perception of the length of the street as this is affected by the buildings form along it. This means that the triangle can give the relation between real distance and perceived distance. It is apparent from the two images that in the case of same building heights where the length of the street seems longer than in the case with the varying heights, the triangle has different geometric attributes. There may be a relation between perception and these attributes. In any case this type of representation seems to be introducing a relation among form and space.

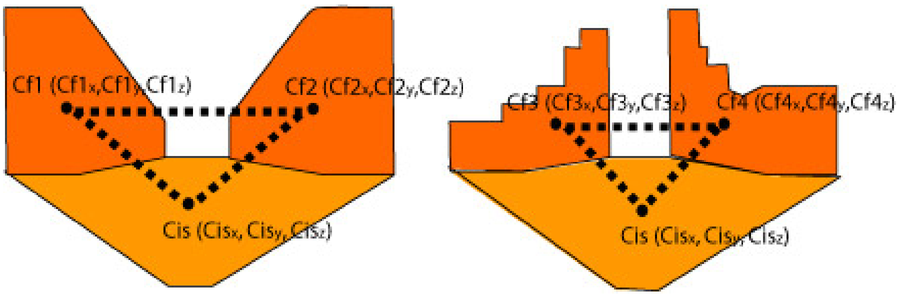

Figure 8.6 (Left) The two shapes of the buildings forms with their centroids Cf1 and Cf2 and the perspective isovist shape with its centroid Cis for a building heights configuration with same height buildings.(Right) The two shapes of the buildings forms with their centroids Cf3 and Cf4 and the perspective isovist shape with its centroid Cis for a building heights configuration with varying height buildings.

The analysis of the shapes occurring from the above representation of serial vision images is subject to a whole different field of investigation. In any case, any mapping representation that may occur from the shape analysis needs to be tested for its validity with real or virtual environment experiments.

One experiment could be testing any metric property that the study of the centroid triangles would give with people’s appraisals of the same images regarding the perception of the scale and proportions of the street or of the building heights, streets’ length and width. This would be a static appraisal not involving movement giving however a first idea of the relation between perception and the “scale values” as occurring from the centroids metric property.

A second experiment could test the idea in navigation and cognition. This experiment probably needs a sophisticated software to back up the process. This can be a software like the visibility graph analysis software Depthmap (Turner, 2001) where the streets of an urban plan are segmented by a grid tessellation and each small part of the grid is coloured according to a value which in the existing software is a syntactic value. In a different version, each part of the grid can be coloured with a “scale value” occurring from the centroid analysis for each of these points of the grid. Sequentially, participants can be asked to navigate in these environments with tasks related to the scale of the environment, like navigate by choosing the longer street each time or follow always the wider paths and so on. The correlation of the routes traces or of the single path choices in relation to the "scale values" could test the validity of the proposed mapping methodology.

It is believed that this thesis has managed to approach the issue of three-dimensional scale in a combinative way and has enriched the knowledge on scale in many fields. It is mainly hoped that it has managed to raise even more questions than it has answered which can be the starting point for future research.

Bibliography

Aglioti, S., Goodale, M.A. and De Souza, J.F.X., 1995. Size-contrast illusions deceive the eye but not the hand. *Current biology*, 5, pp.679-685.

Alder, K., 1995. A revolution to measure: The political economy of the metric system in France. In Wise, M.N., ed., pp.39-71, *The values of precision*. Princeton University Press.

Appleyard, D., 1969. Why Buildings are known: A Predictive Tool for Architects and Planners, *Environment and Behavior*, 1(2), p131.

Arnheim, R., 1955. A review of proportion. *The Journal of Aesthetics and Art Criticism,* 14(1), pp.44-57.

Arnheim, R., 1977. *The dynamics of architectural form*. Berkeley: University of California Press.

Belingard, L. and Péruch, P., 2000. Mental representations and the spatial structure of virtual environments. *Environment and Behavior*, 32(3), pp.427-442.

Benedikt, M.L., 1979. To take hold of space: isovist and isovist fields. *Environment and Planning B*, 6, pp.47-65.

Bertamini, M., Yang, T.L. and Proffitt D.R., 1998. Relative size perception at a distance is best at eye level. *Perception and Psychophysics*, 60(4), 673-682.

Birgham, G.P., 1993a. Perceiving the size of trees: Biological form and the horizon ratio. *Perception and Psychophysics*, 54, pp.485-495.

Birgham, G.P., 1993b. Perceiving the size of trees: Form as information about scale. *Journal of Experimental Psychology: Human Perception and Performance*, 19, pp.1139-1161.

Blumenfeld, H., 1953. Scale in civic design. *The town planning review*, 24(1), pp.35-46.

Brösamle, M., Mavridou, M. and Hölscher, C., 2009. What constitutes a main staircase? Evidence from Wayfinding Behaviour, Architectural Expertise and Space

Syntax Methods. In Koch, D., Marcus, L. and Steen, J. (eds) *Proceedings of the 7th Space Syntax Symposium. Stockholm, June 8-11 2009*.

Communities and Local Government Publication, 2000. By Design: Urban Design in the Planning System – Towards Better Practice [online] available at:< http://www.communities.gov.uk/publications/planningandbuilding/bydesignurban > . [Accessed 9 December 2011].

Conroy Dalton, R., 2005. Space syntax and spatial cognition. *World Architecture: Space Syntax Monograph,* 11(185), pp.41-45.

Conroy Dalton, R., 2003. The secret is to follow your nose: route path selection and angularity. *Environment and Behavior*, 35(1), pp.107-131.

Conroy, R., 2001. *Spatial navigation in immersive virtual environments*, PhD thesis, University College London.

Chabanne, V., Peruch, P. and Thinus-Blanc, C., 2003. Virtual to Real Transfer of Spatial Learning in a Complex Environment: The Role of Path Network and Additional Features. *Spatial Cognition & Computation*, 3(1), pp.43-59.

Cheng, I. and Boulanger, P., 2004. Perception of scale with distance in 3D visualisation. In Ronen Barzel (ed) *Proceedings of ACM SIGGRAPH 2004 Posters, ACM, New York, NY.*

Ching, F.D.K., 1996. *Architecture: Form, Space and Order.* New York: Van Nostrand Reinhold.

Coeterier, J.F., 1994. Cues for the perception of the size of space in landscapes. *Journal of Environmental Management*, 42, pp.333-347.

Colle, H.A. and Reid, G.B., 2000. The room effect: exploring paths and rooms in a desktop virtual environment with objects grouped categorically and spatially. *Ecological Psychology*, 12(3), pp.207-229.

Cromby, J.J., Standen, P.J., Newman, J. and Tasker, H., 1996. Successful transfer to the real world of skills practiced in a virtual environment by students with severe learning difficulties. *Proceedings of 1st European Conference on Disability, Virtual Reality & Associated Technologies*, Maidenhead, UK, July 8-10 1996.

Crozier, J.B., 1980. The new experimental aesthetics-The beginning or the end?. *Motivation and emotion*, 4(2).

Cubukcu, E. and Nasar, J.L., 2005. Influence of physical characteristics of routes on distance cognition in virtual environments. *Environment and Planning B: Planning and design*, 32, pp. 777-785.

Cullen, G., 1961. *The Concise Townscape.* London: Architectural Press.

De Lucia, P.R. and Hochberg, J., 1991. Geometrical illusions in solid objects under ordinary viewing conditions. *Perception & Psychophysics*, 50, pp.547-554.

Dixon, M.W., Wraga, M., Proffitt D.R. and Williams, G.C., 2000. Eye-height scaling of absolute size in immersive and non-immersive displays. *Journal of Experimental Psychology: Human Perception and Performance*, 26(2), pp.582-593.

Eysenck, M.W. and Keane, M.T., 2003. *Cognitive Psychology, A student's handbook.* Hove and New York: Psychology Press.

Fontaine, G., 1992. The experience of a sense of presence in intercultural and international encounters. *Presence: Teleoperators and Virtual Environments*, 1(4), pp.482-490.

Forty, A., 2000. *Words and Buildings, A Vocabulary of Modern Architecture*. London: Thames and Hudson.

Gibson, J. J., 1979. *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin Company.

Glennester, A., Hansard, M.E. and Fitzgibbon, A.W., 2009. View-based approaches to spatial representation in human vision. In D. Cremers, et al. (eds), *Visual motion analysis*, *LNCS*, 5604, pp.193-208.

Gregory, R.L., 1970. *The intelligent eye*. New York: McGraw-Hill.

Gregory, R.L., 1980. Perceptions as hypotheses. *Philosophical Transactions of the Royal Society of London*, Series B, 290, pp.181-197.

Groat, L., 1983. A study of the perception of contextual fit in architecture. Environmental Design Research Association Annual Conference, Lincoln, NE.

Haken, H. and Portugali, J., 2003. The face of the city is its information. *Journal of Environmental Psychology*, 23, pp. 385-408.

Haq, S. and Zimring, C., 2003. Just down the road a piece: The development of topological knowledge of building layouts. *Environment and Behavior*, 35(1), pp.132-160.

Hegarty, M., Richardson, A.E., Montello, D.R., Lovelace, K. and Subbiah, I., 2002. Development of a self-report measure of environmental spatial ability, Itelligence, 30, pp.425-447.

Henry, D. and Furness, T., 1993. Spatial perception in virtual environments: Evaluating an architectural application. *IEEE Virtual Reality Annual International Symposium,* pp.33-40, September 18-22, Seattle, WA, USA.

Hillier, B. and Hanson, J., 1984. *The social logic of space.* 5th edn. Cambridge: Cambridge University Press.

Hillier, B., Penn, A., Hanson, J., Grajewski, T. and Xu, J., 1993. Natural movement: or configuration and attraction in urban pedestrian movement. *Environment & Planning B: Planning & Design*, 20, pp.29-66.

Hillier, B., 1996. *Space is the machine.* Cambridge: Cambridge University Press.

Hillier, B. and Iida, S., 2005. Network and Psychological effects in urban movement. In Cohn, A.G. and Mark, D.M., (eds), *COSIT 2005, LNCS 3693*, pp.475-490.

Hoelscher, C. and Broesamle, M., 2007. Capturing Indoor Wayfinding Strategies and Differences in Spatial Knowledge with Space Syntax. *Proceedings of 6th International Space Syntax Symposium,* June 12-15 2007, Istanbul.

Holtier, S., Steadman, J.P. and Smith, M.G., 2000. Three-dimensional representation of urban built form in a GIS. *Environment and Planning B: Planning and Design*, 27, pp. 51-72.

Ijsselsteijn, W., 2002. Elements of a multi-level theory of presence: Phenomenology, mental processing and neural correlates. In *Proceedings of Presence 2002*, pp.245-529, Universidade Fernando Pessoa, October 9-11 2001, Porto, Portugal.

Ittelson, W.H., 1970. Perception of the large-scale environment. Transactions New York Academy of Sciences, 32, pp.807-815.

Jacobs, A.B., 1993. *Great Streets.* Massachusetts Institute of Technology: MIT Press.

Juan, M.C. and Perez D., 2009. Comparison of the levels of presence and anxiety in an acrophobic environment viewed via HMD or CAVE. *Presence: Teleoperators and Virtual Environments*, 18(3),pp. 232-248.

Kaplan, R., and Kaplan, S., 1989. *The experience of nature: A psychological perspective*. Cambridge: Cambridge University Press.

Kilpatrick, F.P. and ittelson, W.H., 1953. The size-distance invariance hypothesis. *Psychological review*, 60, pp.223-231.

Karimi, K., Amir, A., Shafiei, K., Raford, N., Abdul, E., Zhang, J. and Mavridou, M., 2007. Evidence-based spatial intervention for regeneration of informal settlements: the case of Jeddah central unplanned areas. *Proceedings of 6th International Space Syntax Symposium,* June 12-15 2007, Istanbul.

Karimi, K., Mavridou, M. and Armstrong, M., 2005. Understanding cities through the analysis of their prime activity axes: The capital routes. *Proceedings 5th International Space Syntax Symposium*, June 13-17 2005, Delft.

Kim, Y.O., 2001. The role of spatial configuration in spatial cognition. *Proceedings of 3rd International Space Syntax Symposium*, May 7-11 2001, Atlanta, USA.

Koenig, S., Crucian, G., Dalrymple-Alford, J. and Duenser, A., 2011. Assessing navigation in real and virtual environments: a validation study. *International journal on disability and human development,* 10(4), pp. 325-330.

Konkle, T. and Oliva, A., 2011. Canonical visual size for real-world objects, *Journal of Experimental Psychology: Human Perception and Performance*, 37(1), pp.23-37.

Kozhevnikov, M., Hegarty M. and Mayer, R.E., 2002. Revising the visualizer-verbalizer dimension: Evidence for two types of visualizers, *Cognition and Instruction*, 20(1), pp.47-77.

Kozhevnikov, M., Kosslyn, S. and Shepard, J., 2005. Spatial versus object visualizers: A new characterization of visual cognitive style, *Memory and Cognition*, 33(4), pp.710-726.

Krampen, M., 1979, *Meaning in the urban environment.* London: Pion Limited.

Lampton, D.R., McDonald, D.P., Singer, M. and Bliss, J.P., 1995. Distance estimation in virtual environments. *Proceedings of the human factors and ergonomics society*, 39th annual meeting, pp. 1268-1272.

Lányi, C.S. (ed.), 2012. *Applications of Virtual Reality*, Croatia, InTech.

Le Corbusier, 1948. *The Modulor*. Translation in English in 1954 by De Francia, P. and Bostock, A. London: Faber and Faber Limited.

Le Corbusier, 1958. *The Modulor 2, Let the User speak next*. London: Faber and Faber Limited.

Levin, C.A. and Haber, R.N., 1993. Visual angle as a determinant of perceived interobject distance. *Perception and psychophysics*, 54(2), pp. 209-259.

Levy, A., 2005. New orientations in urban morphology. *Urban Morphology*, 9, p.50.

Licklider, H., 1965. *Architectural Scale.* London: The Architectural Press.

Lombard, M. and Ditton, T., 1997. At the heart of it all: The concept of Presence. *Journal of computer mediated communication*, 3(2).

Loomis, J.M., 1992. Distal attribution and presence. Presence: Teleoperators and Virtual Environments, 1, pp.113-119.

Lynch, K., 1960. *The image of the city.* Cambridge, MA: MIT Press.

Maertens, H., 1884. *Der optische Masstab in den bildenden Kuensten.* 2nd ed. Berlin: Wasmuth.

Mansfield, B., 2005. Beyond rescaling: reintegrating the "national" as a dimension of scalar relations. *Progress in Human Geography*, 29(4), pp. 458-473.

March, L. 1998, *Architectonics of Humanism* Academy Editions, London.

McManus, I.C., 1980. The aesthetics of simple figures. *British Journal of Psychology*, 71, pp. 505-524.

McManus, I.C., 1997. The golden section and the aesthetics of form and composition: a cognitive model. *Empirical studies of the arts*, 15(2), pp.209-232.

McManus, I.C., Cook, R. and Hunt, A., 2010. Beyond the golden section and normative aesthetics: Why do individuals differ so much in their aesthetic preferences for rectangle? *Psychology of Aesthetics, Creativity and the Arts*, 4(2), pp.113-126.

Meiss, P.V., 1990. *Elements of architecture: from form to place.* London: Van Nostrand Reinhold.

Mikiten, T. M., Salingaros, A. N., and Hing-Sing, Y., 2000. Pavements as Embodiments of Meaning for a Fractal Mind. *Nexus Network Journal*, 2, pp. 61-72.

Mohler, B.J., Creem-Regehr S.H., Thompson W.B. and Buelthoff H.H., The effect of viewing a self avatar on distance judgments in an HMD-based virtual environment. *Presence: Teleoperators and Virtual Environments*, 19(3), pp. 30-242.

Moles, A., 1966. *Information theory and esthetic perception.* Chicago, London: University of Illinois Press Urbana.

Molnar, F., 1974. Experimental aesthetics or the science of art. *Leonardo*, 7, pp.23-26.

Montello, D.R., 1993. Scale and Multiple Psychologies of Space. In Frank, A.U. and Campari I., eds., *Spatial Information Theory: A theoretical basis for GIS*, Berlin: Springer Verlag.

Moore, C. and Allen, G., 1976. *Dimensions: Space, shape and scale in Architecture.* New York: Architectural Record.

Murray, C.D., Bowers, M.B., West, A.J., Pettifer S. and Gibsob S., 2000. Navigation, Wayfinding and place experience within a virtual city. *Presence: Teleoperators and Virtual Environments*, 9(5), pp. 435-447.

Naceri, A., Chellali, R. and Hoinville, T., 2011. Depth perception within peripersonal space using head mounted display. *Presence:Teleoperators and Virtual Environments*, 20(3), pp.254-272.

Nasar, J.L., 1998. *The evaluative image of the city*. California: Thousand Oaks, Sage Publications.

Nasar, J.L., 1988. *Environmental Aesthetics: Theory Research and Application.* New York: Cambridge University Press.

Navarre, D., Palanque, P., Schyn, A., Winckler, M., Nedel, L. and Freitas, C.M.D.S., 2005. A formal description of multimodal interaction techniques for immersive virtual reality applications. *Proceedings of Interact*, pp.170-183, Springer Verlag.

Norman, J., 2002. Two visual systems and two theories of perception: An attempt to reconcile the constructivist and ecological approaches. *Behavioral and brain sciences*, 25, pp. 73-144.

Ohno, R., 2000. A hypothetical model of environmental perception. In Wapner, S., Demick, J., Yamamoto, T. and Minami, B.H., eds, *Theoretical perspectives in environment-behavior research*, pp.149-156, New York: Kluwer Academic/Plenum.

Orr, F., 1985. *Scale in Architecture.* New York:Van Nastrand Reinhold Company Inc.

Osmann, P.J. and Berendt, B., 2002. Investigating distance knowledge using virtual environments. *Environment and Behavior*, 34, pp. 178-193.

Paasi, A., 2004. Place and region: looking through the prism of scale, *Progress in Human Geography*, 28, (4), pp. 536-546.

Padovan, R., 1999. *Proportion: Science, Philosophy, Architecture*. New York: Routledge.

Penn, A. and Turner, A., 2001. Space syntax based agent models. In Schreckenberg, M. and Sharma, S., eds., *Pedestrian and evacuation dynamics*, pp. 99-114, Heidelberg, Germany: Springer-Verlag.

Penn, A., 2003, Space Syntax and spatial cognition: Or why the axial line? *Environment and Behavior*, 35(1), pp. 30-65.

Peponis, J., Zimring, C. and Choi,Y. K., 1990. Finding the building in wayfinding. *Environment and Behavior,* 22, pp.555-590.

Plato, *Timaeus*. Translated by Zeyl, D.J., 2000. Indianapolis: Hackett Pub.

Richardson, A.E., Montello, D.R. and Hegarty, M., 1999. Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory and Cognition*, 27(4), pp.741-750.

Riener, C. and Profitt, D., 2002. Quantifying spatial presence. *Fifth Annual International Workshop, PRESENCE 2002*. Universidade Fernando Pessoa, October 9-11 2002, Porto, Portugal

Rizzo, A. and Kim, J.G., 2005. A SWOT analysis of the field of virtual reality rehabilitation and therapy. *Presence: Teleoperators and Virtual Environments*, 14(2), pp.119-146.

Ruddle, R.A., Payne, S.J. and Jones D.M., 1997 Navigating buildings in desktop virtual environments: experimental investigations using extended navigational experience. *Journal of Experimental Psychology: Applied*, 3(2), pp. 143-159.

Ruddle, R.A., Payne, S.J. and Jones, D.M., 1999. Navigating large-scale virtual environments: What differences occur between helmet mounted and desktop displays. *Presence: Teleoperators and Virtual Environments*, 8, (2), pp. 157-168.

Ruddle, R. A. and Lessels, S., 2009. The benefits of using a walking interface to navigate virtual environments. *ACM Transactions on computer-human interaction*, 16(1).

Sadalla, E.K. and Magel, S.G., 1980. The perception of traversed distance. *Environment and Behavior*, 12, pp.65-79.

Sayre, N.F., 2005. Ecological and geographical scale: parallels and potential for integration. *Progress in Human Geography*, 29(3), pp. 276-290.

Schiffman, H.R., 1967. Size estimations of familiar objects under informative and reduced conditions of viewing. *American Journal of Psychology*, 80, pp.229-235.

Sholl, M.J., 1992. Landmarks, places, environments: Multiple mind-brain systems for orientation, Geoforum, 23(2), pp.151-164.

Sholl, M.J., Acacio, J.C., Makar, R.O. and Leon, C., 2000. The relation of sex and sense of direction to spatial orientation in an unfamiliar environment, Journal of Environmental Psychology, 20(1), pp.17-28.

Slater, M. and Wilbur, S., 1997, A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and Virtual Environments*, 6, pp.603-616.

Sousa Santos, B., Dias, P., Pimentel, A., Baggerman, J.W., Ferreira, C., Silva, S. and Madeira, J., 2009. Head mounted display versus desktop for 3D navigation in virtual reality: a user study. *Multimedia tools and applications*, 41(1),pp.161-181.

Steuer, J., 1995. Defining virtual reality: Dimensions determining telepresence. In Biocca, F. and Levy, M.R., eds., *Communication in the age of virtual reality*, pp.33-56, Hillsdale, NJ: Lawrence Erlbaum Associates.

Stylianou, S., Fyrillas, M.M. and Chrysanthou, Y., 2004. Scalable pedestrian simulation for virtual cities. *ACM Symposium on Virtual Reality Software and Technology*, November 10-12, 2004, Hong Kong.

Teller, J., 2003. A spherical metric for the field-oriented analysis of complex urban open spaces. *Environment and Planning B: Planning and design*, 30, pp. 339-356.

Terrance, G., 2004. The concept of proportionality and principles of "good fit" in architectural theory. In Weber, R. and Amann, M.A., eds., *Proceedings of the Dresden International Symposium of Architecture : Aesthetics and Architectural Composition*, Lehrstuhl Raumgestaltung, TU Dresden.

Thiel, P., 1997. *People, Paths and Purposes.* Seattle, London: University of Washington Press.

Thomson, D., 1917. *On growth and form.* Cambridge: Cambridge University Press.

Turner, A., 2001. Depthmap: a program to perform visibility graph analysis. In *Proceedings of 3rd International Symposium of Space Syntax*, pp.31.1-31.9, May 7-11, Atlanta, USA.

Turner, A., Doxa, M., O'Sullivan, D., and Penn, A., 2001. From isovists to visibility graphs: a methodology for the analysis of architectural space. *Environment and Planning B: Planning and design*, 28, pp. 103-121.

Turner, A. and Penn A., 2002. Encoding natural movement as an agent-based system: an investigation to human pedestrian behaviour in the built environment. *Environment and Planning B: Planning and Design*, 29(4). pp.473-490.

Van der Laan, D., 1983. *Architectonic Space.* Leiden: E. J. Brill.

Van Veen, H.A.H.C., Distler, H.K., Braun S.J. and Buelthoff, H.H., 1998. Navigating through a virtual city: Using virtual reality technology to study human action and perception. *Future Generation Computer Systems*, 14, pp.231-242.

Viciane-Abad, R. and Poyade, A.R.L.M., 2010. The Influence of Passive Haptic Feedback and Difference Interaction Metaphors on Presence and Task Performance. *Presence: Teleoperators and Virtual Environments*, 19(3), pp.197-212.

Vitruvius, P. M., *The Ten Books on Architecture.* Transalation by Rowland, I.D., 1999 Cambridge: Cambridge University Press.

Waller, D., Loomis, J.M. and Haun, D.B., 2004. Body based senses enhance knowledge of directions in large scale environments. *Psychonomic Bulletin and Review*, 11(1), pp.157-163.

Wallet, G., Sauzeon, H., Arvind Pala, P., Laruue, F., Zheng, X. and N'Kaoua, B., 2011. Virtual/Real transfer of spatial knowledge: Benefit from visual fidelity provided in a virtual environment and impact of active navigation. *Cyberpsychology, Behavior and Social Networking*. 14(7-8),pp. 417-423.

Wallet, G., Sauzeon, H., Rodrigues, J. and N'Kaoua, B., 2009. Transfer of spatial knowledge from a virtual environment to reality: Impact of route complexity and subject's strategy on the exploration mode. *Journal of virtual reality and broadcasting*, 6(4).

Willemsen, P., Gooch, A.A., Thompson, W.B. and Creem-Regehr, S H., 2008. Effects of Stereo Viewing Conditions on Distance Perception in Virtual Environments. *Presence: Teleoperators and Vortial Environments*, 17(1), pp, 91-101.

Witmer, B.G. and Kline, P.B., 1998. Judging perceived and traversed distance in virtual environments. *Presence: Teleoperators and Virtual Environments*, 7(2), pp. 144-167.

Witmer, B.G. and Singer, M.J., 1998. Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoperators and Virtual Environments*, 7(3), pp.225-240.

Weber, R., 1995. *On the aesthetics of Architecture, A psychological approach to the structure and order of perceived architectural space*. Aldershot, UK: Avebury.

Weber, R. and Amann, M.A., (eds), 2004. *Proceedings of the Dresden International Symposium of Architecture : Aesthetics and Architectural Composition.* Lehrstuhl Raumgestaltung, TU Dresden, pro Literatur Verlag.

Whitehand, J.W.R., 1992. *Urban Landscapes: International Perspectives.* London and New York: Routledge.

Wiest, W.M. and Bell, B., 1985. Steven's exponent for psychophysical scaling of perceived, remembered and inferred distance. *Psychological Bulletin*, 98(3), pp. 457-470.

Witmer, B.G., Bailey, J.H. and Knerr, B.W., 1996, Virtual spaces and real world places: transfer of route knowledge. *International Journal of human-computer studies*, 45(4), pp. 413-428.

Wittkower, R., 1949. *Architectural Principles in the Age of Humanism*. London: Alec Tiranti Ltd.

Woodworth, R. S., 1938. *Experimental psychology*. 1955 edn, London: Methuen.

Appendix A:

1st Experiment's Questionnaire

QUESTIONNAIRE

Code No: _P______

PART I: This part contains some personal questions. Could you please tick the appropriate box and answer the questions:

A. Sex: Male ☐ Female ☐

B. Age: 20-25 ☐ 25-30 ☐ 30-35 ☐ 35-40 ☐ 40-50 ☐ 50-60 ☐ 60-70 ☐

C. Occupation: (if student, please specify)

____

D. Did you have a previous experience of an immersive virtual environment?

Never ☐ Once to a few times ☐ Many times ☐

E. Did you have an experience of a non-immersive virtual environment like computer games before?

Never ☐ Once to a few times ☐ Many times ☐

PART II: This part contains some questions which will be asked during the experiment and some after it will finish. Could you please tick the boxes or answer the questions.

Answer the next question after walk B1.

A. Do you think the last two environments were exactly the same? Have you noticed anything different between the last two environments?

☐ No, they were exactly the same.
☐ Yes, there was something different but I cannot tell / I cannot remember.
☐ Yes, there was something different and it was...: (describe in your own words being as more precise as you can)

____
____
____
____
____

☐ Other: (if nothing of the above covers your answer, please comment here)

____
____
____
____
____

Answer the next question after the fourth walk.

B. Do you think there was something different among the four environments?

☐ No, they were exactly the same.
☐ Yes, there was something different but I cannot tell / I cannot remember.
☐ Yes, there was something different and it was: (describe in your own words being as more precise as you can)

☐ Other: (if nothing of the above covers your answer, please comment here)

Answer the next question after the last walk.

C. Did you find any of the six environments easier to navigate? Could you explain why?

Answer the next question after you finish.

D. Moving around in the virtual environments was:

Very easy ☐ Easy ☐ Nor easy nor difficult ☐ Difficult ☐ Very difficult ☐

If you found a difficulty could you please specify why?

Appendix B:

2nd Experiment's Questionnaire

(Translated in English)

QUESTIONNAIRE

Code No: _P_______

PART I: This part contains some personal questions. Could you please tick the appropriate box and answer the questions:

A. Sex: Male ☐ Female ☐

B. Age: ☐

C. Occupation: (if student, please specify)

____

D. Did you have a previous experience of a virtual environment?

Never ☐ Once to a few times ☐ Many times ☐

E. Did you have an experience of a virtual environment like computer games before?

Never ☐ Once to a few times ☐ Many times ☐

PART II: This part contains some questions related to your experience of the virtual environments and of the experiment.

A. Can you order the four environments you navigated in based on:
(use the order they were presented to you i.e. first, second, third and fourth)

- **from the most arousing to the least (making you have a particular feeling or attitude)**

- **from the most pleasing to the least**

- **from the most complex to the least**

- **from the one you prefer most to the one you prefer least**

____

B. If you found a difficulty could you please specify what it was?

____
____
____
____

C. Could you explain what the differences between the different environments you navigated in were?

____
____
____
____

D. Did you realise in one of the environments you navigated, that the main roads had higher buildings than the secondary roads?

____
____
____
____

E. Moving around in the virtual environments was:

Very easy ☐ Easy ☐ Nor easy nor difficult ☐ Difficult ☐ Very difficult ☐

F. Are you:

Left-handed ☐ **Right-handed** ☐ **Both** ☐

Appendix C:

Participants' comments on the 1st Experiment's questions A, B, C and D

Comments of participants who participated in the intelligible environments. Question A.

A. Do you think the last two environments were exactly the same? Have you noticed anything different between the last two environments? *

Yes. Building heights+shapes were different. The layout was also very different, more narrow paths - more confusing the second one.

Yes.Different heights of buildings, (a few at least two) strange objects within the built environment, different shapes of buildings (not sure).

Yes. Heights of walls / blocks were different. Shapre of street network structure semed different, 1st more regular grid, 2nd non regular

Yes. A distinctive broad alley, so I took this path.

Yes there was something different but I cannot tell/remember what it was.

Yes there was something different but I cannot tell/remember what it was.

Yes. The second one seemed to have more small buildings where pathways met. These were different shapes and on the second experiment they were reference points for me.

Yes. The height of the buildings was different. (mostly similar height in the last one). There were more deadends streets in the last one.

Yes, there was something different but I cannot tell/remember. It seem the last one is more easierthan the previous to navigate the world, the street quite wider and also the angle are quite different from previous.

Yes. The last one had none height differentiations and seemed more varied / loose 9irregular) compared to the one before

Yes, there was something different but I cannot tell/remember.Not sure if exactly the same.

* tha last two environments were A1 and B1 not necessarily in this order

Comments of participants who participated in the non-intelligible environments. Question A.

A. Do you think the last two environments were exactly the same? Have you noticed anything different between the last two environments? *

the building heights are different in latter one; and more long narrow spaces in the latter one.

yes. The fact that the second one, the walls were unequally high even sized. I think that in the first one all the green walls were equally high/tall

Yes. the first had varying building/wall heights,with very small/ low ones.

No, they were exactly the same.

Yes, there was something different but I cannot tell /remember.

Yes. The height of the walls was constant (4th).
Yes there was something different but I cannot tell/remember.

No, they were exacty the same.

Yes. The 3rd environment had the same height volumes through out where at the 4th the volumes had different heights. In fact I thought that the 1st and the 3rd were the same as well as the 2nd and 4th.

yes. The second to last had low buildings and tall buildings. The last was all tall.

Yes, there was something different but I cannot tell /remember.

* tha last two environments were A2 and B2 not necessarily in this order

Comments of participants who participated in the intelligible environments. Question B.

B. Do you think there was something different among the four environments?*

there was something different between the first 3 but I think the fourth was the same as the first. Differences: building size, length of streets, width of streets.

Yes. The third one had a big central square although only the first one was distinctively different. Maybe buildings were bigger in the fourth one.

The 1st and 3rd ones seemed very similar. The 4th had much higher walls / blocks. Some streets seem much harded to navigate / walk than others. Wall colours seemed higher tone variation (dark to light green) in the 4th environment. Higher walls in the 5th env. Maybe is more difficult to navigate because I couldn't see always the sky.

first and thirs environemtns maybe the same environment but no clear visual cues (such as broad alley) to comparebetter the two. I think they are the same. Second and fourth are the same environments.

Yes. The buildings in the first two were higher or they were bigger chunks, something about size.

Yes. First one had almost same height of blocks whereas other had variations and some larger open spaces in between.

Yes. Shape of buildings. The shapes became more complex in my view. More shading, variation in height (and shape?)

Yes, there was something different but I cannot tell/remember. The buildings were less high in the last two. The streets seem longer in the last two.

Yes. 1.street wide 2. street length 3. angles (to turn) 4.block size (4th or 5th one side more orthogonal and the other more organic) 5. shadow 6. not all had deadends 7. hight was varying sometimes and in different location 8. the arrangement of th eblock (symmetry)in one side of street anf other side assymetry. It was hard to me to knkow my destination as i go pass through the space, it might be becasue there are no sample or sight as if i pass the building before or not, the wall all same and green, sometimes the shadow or hight or maybe angle givelittle confidence where moving to world.
I can't remember exactly but some elements were repeated in some of the walls. Such as low buildings in a square at the beginning, so they might have been the same with varies starting points,, last one had lots of irregular spaces. I cannot tell 100% if they were the same.

There were similarities. Open space at starting point at the first environment. There were many similarities in the structuring of the environmetns, dead ends, periphery.

* the four environments are A1, B1, C1 and D1 not necessarily in this order

Comments of participants who participated in the non-intelligible environments. Question B.

B. Do you think there was something different among the four environments?*

Yes. The first one and the third one might be same. The second one and the fourth one might be same at theheight of the building; however the form layouts are similar

Yes. That in the third walk the green walls were equally high, equally sized, the corridors between they were quite broad and there were dead-ends. In the fourth one on the contrary there was no dead-end, the corridors between the walls were unequally large or small and the walls themselves were unequally high.

the first and third had lower blocks. The third and fourth were appart from that (lower blocks) identical. The first two could also be identical, but it wsa too hard to tell.

Yes. Environment 3 had more variation in building heights.

Yes. In some, some walls were taller or shorter. The layout also seemed different. first one, evrything had same height. On 2nd one I saw the shorter long wall at the beginning for the first time.

Yes, there was something different but I cannot tell / remember.

Yes. I think the environments were different in terms of building heights and the variation of block shapes.

yes. I think that in the third environment there was a difference in the 3rd dimension, that is a differentiation in height of buildings. There could be a differentiation in the urban grid, smaller blocks etc.

Yes. The 1st and 3rd were the same (or similar). The 2th and 4th were the same (or similar).

Yes, some had black walls - the last three. The second to last (or maybe third to last) had some low buildings.

Yes, there was something different but I cannot tell / remember.

* the four environments are A2, B2, C2 and D2 not necessarily in this order

Comments of participants who participated in the intelligible environments. Question C.

C. Did you find any of the six environments easier to navigate? Could you explain why?

Yes, the last 2 were easier the the first four due to windows, doors, so I could reference certain streets.

I do not know why but I have got the feeling that the buildings in two built environments were bigger. The last one had too much details.

not really, maybe the 5th because of pavements that helped walk in straight distance but 6th was too clutterred with windows, etc. and took more time to navigate.
the 4th and 6th were easier to navigate because they were familiar from the 2nd environment. The 4th easie, the 6th easiest. The 1st, 3rd anf 5th were more or less undistinguishing in terms of visual qualities. The windows and doors did not make any difference.
The last two environments were easier with tehir windows and doors. When I turn backwards myself, I could recognise the places I've just been.

Maybe the last one because I started with tallest block next to me but I'm not sure since I have a feeling that I was going round and round.

4 and 6. Increased confidence and ability to "walk". Low buildings in junctions were very useful reference points. For exp. 6, I recognised the layout from exp. 4 and guessed the door would be in the same place.

The first two. The color of the buildings help to remember where you have been.

I think the last two environments was quite easier to navigate maybe because 1. I got familiar with the space and the system 2. I try to find a different method to navigate, I was more careful where to go 3. the angle and wider street make it some times easy to make your decision where to goalso the height of building

I found spatial difference easier to navigate than colour but strange façade or window design also acted as "landmark"

The ones without windows. No need to look around for the door/ would have been too obvious to miss.

Comments of participants who participated in the non-intelligible environments. Question C.

C. Did you find any of the six environments easier to navigate? Could you explain why?

I think the last one is easier to navigate because It can give more information about where I stay in that environment, such as the height of building. The colours of doors and windows and the characteristics of space. Another reason is that I Hve familiar with the environment through the previous five naivgations because I think six environments are as bit similar.

the fifth one was the easier one. All the walls were full of colourful spots, they were quite low, not so high, there was no other obstacle when one's viewing the sky. The corridors were quite vast.

I thought the 5th was easier: pavements, doors and windows with colours and varying building height. I could recognise where I was and look in the distance (above lower blocks) to think where to go and where I had been. However, I couldn't find the door...it was the same space as 1 and 2. the last had the previou sadvanteges minus varying height but i did recognise the space and went straight to the door. navigation from memory not trying to find the way.

the 6th seemed easiest althoughthere was little building height variation, the street were more angular. The 5th was easier than 4,3,2 and 1 as there was a lot of building height variation, it was less boring and made things easier to remember (i.e. left past the tall building, rather than just left, right, left, left....)

the 2 last ones (with doors and windows and sidewalks) They seem to give more info about the form of space.

the last two probably easier because there were pseudo-real building elements rendered in the scene, although I think the very last was easier, despite the wall height was constant, not only because I managed to find the door and returned to thestarting point but because there seemed to be more (longer) visibility available on the way, which somehow made me easier to navigate and remember the path.

The ones with windows and doors were a bit easier.

Certainly, the differentiation in the height of buildings was helpful in navigation. However, all six environments were difficult ot navigate because of the absense of any (other) clues in space. Asithough the first two environments had more elaborated facades which made navigation more playful I can't say that this didn;t make the task easier.

In my opinion the 4th and the 2nd was the eaiest one. AlthoughI had more visual information (windows, doors, pavement…) at the last 2, I found it quite hard to cope with because of the playful colour scheme.

The one with the low buildings because you felt you could see around better.

environments with buildings of different size and streets of different widths were easier because I could tell the difference between them - easier to orient myself. Environments with doors didn't really help.

Comments of participants who participated in the intelligible environments. Question D.

D. If you found a difficulty moving around could you please specify why?

It was hard to work out where I was, where I had been and where I needed to go! Areas looked very similar, so at times it felt like I was going round incircles!

It was incredible boring.

very slow in some streets. Difficult to navigate in straight line (tended to deviate to the left).

easy to navigate

Hard to differentiate between blocks/ streets. No hierarchy evident in streets.

in terms of system, I was personally not comfortable with mouse. In terms of design, first four environments were too monotonous and I lost desire to explore very quickly, was just moving around without purpose.

I found that I would travel in slightly different directions than I intended. Without peripheral vision, I walked into corners often. In experiments 1 and 2 I was often backing away from walls.

I couldn't see around as I do in reality so I had to turn around to see the streets in my sides.

nor easy nor difficult.

everything looks so similar, no details when you turn all around, difficult to remember where you came from

Speed, rendering misleading sometimes.

Comments of participants who participated in the non-intelligible environments. Question D.

D. If you found a difficulty moving around could you please specify why?

Because I feel I cannot estimate my walking speed in it. In other words, I expected I can go to one place in a minute but I spent three minute to arrive there.

very easy

not so easy to look 360degrees to identify a space. Very slow, specially the models with windows and doors.

it was slow hense frustrating. 5 and 6 were less difficult. The variation in views seemed to make things more intelligible, less like being lost in an nendless maze of despair!

bumping with walls. Understanding the surroundings with blank walls (whether some place was a dead end or not etc.)

Although it was presented in 3d, it was difficult to guess the depth of sight: I had difficulties in determining if my way ahead is a dead end. Also the sight was monotonic - difference in colour of building height seemed to matter little.

sometimes the walking speed dropped which caused incosistency in memorizing the directions

Navigatinf in an undifferentiated or monochrome environment is difficult. The absense of any movement or attraction made the task more difficult. There were also other technical difficulties like wearinf a heavy handset or using a standard mouse and coordinating my hand movement with my position in the virtual world.

The view angle did not seem to be that realistic. The volumes were very similar to each other in every environment. My navigation get better If I use a map. The sense of scale was not apparent and the "walking speed" seem to be slow.

Not moving as quickly as I would like and sometimes I felt it was goingsideways. It is also difficult to not see on the sides so felt like I had blinders on.

very easy to use the controls, but difficult secondary to diziness triggered by rapid turning that made the image look unsmooth.

Appendix D:

Participants’ comments on the 2nd Experiment’s questions B, C and D

Comments of participants on question B.

B. If you found a difficulty could you please specify what it was?

everything looks the same

loss of orientation

often difficulties to remember the path in the middle, sometimes also the beginning

the first run with views in all aisles often led to confusion; of course the same shape and composition didn't make it easy; the distance estimation was often questionable --> huge difficulties

lost orientation due to long-lasting rotary motion

In the last environment there was sun and shadow which I used to orientate myself, they weren't there anymore in the test environment

partly very confusing colors

in the training programm I didn't find the way back and it was irritating that the computer looked into every corridor

The pan shots [the pivoting of the camera at the junctions, CK] were confusing sometimes.

no point of reference, grafic errors confused me too much, other background colors in the video (blue and green walls), ugly green

control = very bad; speed with respect to distance = questionable

the uniform appearance of the buildings

Where is the starting point?

it's hard to find the endpoint; looking into the corridors is confusing

one couldn't orientate oneself at fixpoints

There were turnoffs with angles other than 90°; no sun/shades

not specified

everything looked pretty much the same - had the feeling of losing orientation every time and of losing the feeling for the covered distance

in the video the glances to the left and the right irritated more than they helped

1. in the video the starting direction was lost due to the pan shots, 2. I changed strategies (different priorities, observation of the characteristics of the environment)

due to the fact that the objects (walls, streets) have similar colors I lost track quickly

videos were confusing at the beginning because of the views into the streets one doesn't walk along

Because the implementation of movements was viscid (esp. when "turning the head") a distorted picture was generated, so that one wasn't able to orientate oneself by a constant flow of movement

Locating a clear reference point and thereunto orientated fix point in the environment

no distinct differences between the buildings, the video caused even more confusion due to the different perspectives/lines of vision

no details in the environments (--> everything is the same), no possibility to look back

The pan shots were too quick; there was no feedback; it is hard to remember the exact path because other paths would be shorter but one isn't allowed to use them; the way back had no barriers so that one accidently walks to the

Everything looked the same to me, the pan shots in the video are irritating

The virtual environment was to homogeneous, i.e. the purely green colour with a spot of blue contrast from the "sky" hardly allowed for any cues.

It was hard to follow the head turns to the left and right without losing the sense of orientation.

After turning it was hard for me to orientate myself. Towards the ending of the sequences it was hard for me to remember the individual branch-offs

It is not possible to steer in two directions simultaneously. I didn't know how to relate the shown way (video) with the walked way (I couldn't find the starting point anymore); no reference points in the environment; movement too slow; corners of houses partly too pointy

Comments of participants on question C.

C. Could you explain what the differences between the different environments you navigated in were?

height of the "buildings" as well as width of the streets vary

angles and heights of walls

environment 1 and 2 had little conspicuousness on the walls. 2 was a little more complex than 1. Environment 3 and 4 had conspicuous buildings and seldom also helpful labels. I found 3 more complex than 4.

sometimes it was easier to follow the course of the road because they ran in right angles or parallel to toher streets; the intersections in which more than two roads concurred and were in different angles to each other caused problems

different measure of leads due to changes in light, distinct blocks, variation in breadth of streets

in the first ones the buildings had the same height, different heights increased by and by; in the first ones there were mostly right angles, later on there were different angles

color, shape and size of blocks; position of blocks; number of branch-offs at crossroads

there were not really many differences, at the utmost different heights of blocks

They differ with respect to the height and the size of the buildings, the width of the streets, the amount of junctions and the colouring of the houses.

4. with bigger buildings, brighter, colors not too ugly as in 3 and 2; 2. very high buildings, partly with gables, deprimating grey

all looked the same, except the height of the buildings (question c)

different height of buildings, complexity of the routes

light-dark

building size, street width, course of curves

the buildings were presented in a different way

Variation in heights of buildings/ colors

in the environments 1 and 4 rather small blocks, main and side roads; in 2 and 3 big, massive blocks

partly the colors of the blocks differed more from each other, besides I concentrated more on the route than on the environment

difference in number of turns, partly (e.g. in 2) the buildings were more different from each other --> easier

partly more complex architecture, different colors, reference points

in 1 and 4 the buildings had similar heights and were lower than in 2 and 4, therefore environments 1 and 4 were clearer for me

different colors and heights of buildings

different heughts of cubes, different shapes of turns/junctions (partly split in two), highly branched vs.

In some of the environments the horizontal lines offered a distinctive structure orientated to each other and thus built a clear reference frame

to me the environments weren't discriminable from each other, always the same colors, the same buildings, no distinct points one could remember

height of buildings, one time clear blue sky, to a greater or lesser extent differences between the buildings

building height and -colour, building pattern/texture, luminosity of the environment, colour of sky, size of streets

there were none for me

1 & 2 were totally homogeneous with respect to colouring and their paths were rather rectangular (orthogonal). 3 & 4 were optically more pleasurable because the "houses" were distinguishable. And the paths and junctions were better differentiated.

there were hardly any differences

4 was circle-shaped, 3 was strongly zigzag

number of colors, type of color (yellow, green, black, grey), height of the buildings, richness in detail of the builings

Comments of participants on question D.

D. Did you realise that in one of the environments you navigated, that the main roads had higher buildings than the secondary roads?

no, I noticed that the buildings on the main roads were lower
2-3-4
environment 3
I didn't notice it
yes, especially in the 3rd environment. in the 4th there was the least variation in heights
4,3,2
2 and 3
3 and 4
In the first and the second environment
yes, in 4 and 2
yes, I noticed it in 3
2-3-4
no
3
no. I didn't notice it
yes, above all no.3
1 and 4
yes, in environment 3 and 4 it seemed so but I attributed it to the different colors
2,3
no. only that there were buildings with different heights --> I didn't attribute them to main roads, no. 4 and 2 ?
2 and 3, the buildings were higher, the streets were wider (main roads) than the side roads
I did notice the differences in buildings heights in all environments but didn't associate them with main and side roads
yes, in 4 and in 3 (?)
3,4
there were different building heights, but I didn't notice there were main and side roads
2,4
yes, in one of the first two environments
yes, in 2 and 4
I think in the third
yes, in 3 and 4
4
probably in the fourth, but I didn't make the discrimination between main roads and side roads