Are Pedestrian Path Choices During Exploration Contingent on Measures of Shape Complexity and Visual Content of the Environment?

Donny Seto

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ABSTRACT

Are Pedestrian Path Choices During Exploration Contingent on Measures of Shape Complexity and Visual Content of the Environment?

Donny Seto

This thesis investigates pedestrians' path choices when confronted with a decision point in a novel environment. The two main research foci were how different testing setups of virtual environment (VE) affect pedestrian path choice behaviour, and how the visual characteristics of Shape Complexity (SC) and Visual Content (VC) affect pedestrian path choice behaviour.

Two VE testing setups were tested: the type of VE environment and the sampling method. Both were found to have a medium effect on pedestrian path choices. Photorealistic Print VE and Quick Time Virtual Reality (QTVR) VE had an effect on the choices participants made. Testing in a group setting was also found to produce different results than in individual testing.

SC and VC have a significant role on pedestrian path selection. Overall, we compared behaviours in a VC-rich environment to those in a VC-poor environment, which made evident that VC is an important in formulating our path choice behaviour. Bi-variate correlation and multiple regression analysis showed that a number of SC and VC factors affect path choice behaviour. The significant SC factors were occluded edges, legibility, and links; while significant VC factors were colour, cobblestones and signage, people. Increasing our sensitivity to these factors in the guidelines governing the development and the design of urban pedestrian spaces will increase the success of future pedestrian-oriented spaces.

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Chapter 1

Introduction

1.1 Research Foci

This investigation addresses two fundamental research foci: 1- the utility of different Virtual Environment (VE) setups for testing pedestrian path choice behaviour, 2- the relationship between both Shape Complexity (SC) and Visual Content (VC) factors on pedestrian path choices made in a novel environment. These two investigations seek to provide validation for the methodological framework for future studies using this type of VE to test pedestrian path choice behaviour.

1.2 Pedestrian Path Choice Behaviour and Virtual Environment (VE) Testing Setups

VE test setups are the first element studied in this thesis. Specifically two variables are considered: group versus individual response settings and type of VE representation. Their effects on path choice behaviour are measured. The validity of the use of VE is not questioned here, rather the differences of VE testing setups. VEs have already been employed for more than a decade, to test for visual preference and spatial representation (O'Neill, 1992, Stamps, 1999, 1997; Bishop, Ye, Karadaglis, 2001; Ruddle, Lessels, 2006); over the years, VEs' validity in testing both visual preferences and cognitive ability has been demonstrated. Replication studies and task-oriented performance-testing studies have confirmed VE as a good surrogate for the real environment in preference testing and cognitive studies (Ruddle Lessels, 2006; and Oman et al, 2004). The type of VE testing setups, however, have not been subjected to the same battery of tests, hence group versus individual response methods and the type of VE representation are studied to further our understanding of VE representations and their application in testing pedestrian path choice behaviour. Note that it has become usual to use group response data for this kind of test but there are reasons to think the responses might be different in a group setting. Understanding their effects will add to the knowledge of the relationship between the environment and behaviour and inform environment and behaviour researchers whether or not they need to verify their experimental setups' effect on the data collected.

Group versus Individual Response setting

During my research assistantship with Dr. Zacharias studying exploratory behaviour in the real and virtual environment and pedestrian dynamics in a virtual shopping mall, we noted an interesting finding. Within the same experiment, data collected from participants in a group response setting were different from those collected from participants tested individually. This anomalous outcome prompts the study of testing situations and to verify, in particular, whether the response setting–group versus individual response setting–has an effect on pedestrian path choice behaviour. This categorical variable, however, is secondary in this study and the statistical power of this test was not pushed to a significant level– the number of participants and number of different testing environments needed for significant power would have been infeasible for this initial stage of testing. The group and individual data samples are compared to identify whether it is likely or not that it has an effect on path choice behaviour. If the study suggests that there may be an effect of group and individual response setting then further studies would be needed to verify this. This preliminary study tests the potential effect size of response setting on path choice behaviour and how worthwhile it is to pursue this line of study further.

Type of Virtual Environment (VE) Representation

The utility of two VE testing environments, QuickTime Virtual Reality (QTVR) VE and Photorealistic prints VE were compared in this study (Figure 1). Both types of VE have been employed for visual preference testing; however, whether they are equal in utility for testing pedestrian path choice behaviour is the question here. A review and cost benefit analysis of VE deemed that QTVR VE and photorealistic prints are appropriate tools for studying pedestrian path choice behaviour during an exploration task (Appendix 1). My undergraduate Honours thesis showed that QTVR VE was a good surrogate for the real environment for testing path behaviour (Seto, 2003). By comparing two different testing setups, the QTVR VE and the photorealistic prints testing environment, the effect of type of VE on path choice behaviour is tested. If the path preferences are significantly different, we may confidently state that the type of VE affects the path choice behaviour. Otherwise, both VE types are valid to study pedestrian path choice behaviour. If the path choice behaviour in the two environments are different, then the following question needs to be answered "Why do such discrepancies exist?"

1.3 Urban Environment and Pedestrian Locomotion

In this experiment, the main independent variables studied are SC and VC. The query is whether the SC and VC measures affect pedestrian path choice behaviour in a novel environment. SC is defined as the configuration characteristics of the environment's street layout. Configuration characteristics are defined as the Euclidean measurement that exits in space; examples include isovist (Benedikt, 1979), enclosure, and occluded edges. VC is defined as the non-configurational visual characteristics and transient visual characteristics of the environment. Non-configurational visual characteristics are defined as non-structural elements within a path choice; examples include colours of the façades, the amount of greenery or plant foliage, the material of the street (cobblestones or pavement). Transient visual characteristics are defined as elements that are not fixed in space, and the amount of which changes from one period of time to another; for example, the number of people, cars or bikes present in a path choice. Understanding how SC and VC factors affect pedestrian movement helps planners create pedestrian spaces that are vibrant, attractive and functional. The different SC and VC attributes of urban environment are the independent variables, and the pedestrian path choices is the dependent variable of this study.

The relationship of these two factors on pedestrian path choices can be illustrated as an interaction of form and function–the form being the SC and VC measures of the surrounding environment, while the specific function is the path choice behaviour expressed during the exploration of a novel environment. A better understanding of the relationship between this particular form and function should lead to better-equipped urban designers, planners, architects able to create and program space. As moving around is a daily activity, understanding the effect spatial elements have on the pedestrian in an urban environment gives us the tools to create a predictive model. Modeling this movement is still in preliminary stages; hence, the importance of this type of study, which identifies possible influences on pedestrian movement and tests them.

Two reasons reinforce the need for research on pedestrian preferences during exploratory locomotion: 1- the growing popularity of 'healthy' cities; 2- the development or redevelopment of pedestrian public spaces that the public deems as usable, interesting and functional.

Healthy Cities

First, the growing popularity of healthy cities has increased the importance and awareness and understanding of pedestrian motivation. Healthy cities reject the form of the modern city, which are scaled to the mobility of the automobile. Promotion of city forms scaled to the mobility of our feet and public transit and other alternative modes of transport from single occupancy vehicles are the main motivations in creating healthy cities. These focused types of development or redevelopment, give much importance to pedestrians and their preferences. Many cities exemplify this mindset such as Paris, Amsterdam, Copenhagen, and Freiburg. These cities were mostly developed before the introduction of the car into the city and were later retrofitted to accommodate them. However, can the opposite be done? Can we retrofit streets that were created for the car to better accommodate pedestrians? What are the elements that make some streets pedestrian-active and others pedestrian-inactive? How can we identify these elements? These are a few issues brought up by some recent articles focused on healthy cities (Handy et al., 2005; Handy 1999). This study analyses the importance and role of visual characteristics on pedestrian path choices. Understanding these visual influences on pedestrian locomotion through the environment seeks to promote the creation of healthy cities and to convert cities labeled auto-dependent to ecological and activity-oriented ones.

Public Opinion

Second, the development or redevelopment of pedestrian public spaces must take the public needs into consideration. Expert opinions of how these developments should take place often are not tested for their conformity to those of the general public (Stamps, 2000). Testing these expert opinions for their conformity with those of the local public is a crucial step. Planners must understand the needs and woes of the surrounding communities and address them. Part of this problem is addressed by ensuring that development and redevelopment of pedestrian public spaces are sensitive to the public's interaction between VC and SC on pedestrian path choices. It is the public who deems the success of public spaces. If the public finds that the space is usable, interesting and functional it is a recipe for success, and if they do not, such public spaces often fall into disuse and become dilapidated, with the purpose of planning defeated. Understanding how these visual characteristics affect the public's perception and interactions of future pedestrian environment are keys that can be employed to creating spaces that address the needs of the public. Ensuring that guidelines for the development public space are matched to the preferences of the local public would ensure that future pedestrian spaces are well received. With these tools, political leaders can provide more appropriate the guidelines on development and redevelopment of pedestrian-oriented spaces.

Chapter 2

Literature Review

This literature review focuses on the fundamental theories on pedestrian path choice behaviour. They describe the links between the physical space, human understanding of space, and pedestrian spatial behaviour. These are key ideas that explain the assumption and premises while embarking on this line of study.

2.1 Spatial Representation

Spatial representation is a process, which is difficult to explain, for we process spatial information mostly unconsciously, such that much time and effort are needed to accurately and consciously constitute and describe it. Therefore, this topic is divided into three sub-sections: an introduction to our image of the environment; a summation of the knowledge collected on this topic; an explanation of how spatial representation applies to path choice behaviour. The collective knowledge on the existing theoretical models explains how humans encode and understand the physical environment. These topics are ordered to match the process that pedestrian take while encoding surrounding spaces and translating that understanding into behaviour within those same spaces. The first premise is that pedestrian's path choices as any environmental behaviour is directly linked to how one understands and encodes the spatial environment.

2.2 Image of the Environment

The root connecting all environment and behaviour studies is the image of the environment that people have stored; hence, it is the first topic of the literature review. Golledge (1999) uses the term "Spatial representation" to sum up the finding from two specific research foci within studies on our images of the environment. These two constructs are 1-cognitive mapping and 2-internal spatial representation. They are used in the academic field of spatial cognition to describe two areas of thought on spatial representation.

Cognitive mapping is the first area of development on spatial representation. Cognitive scientists formulated objective definitions of this concept, by mapping the steps involved in acquiring spatial information about the environment. Also, different parts of the brain have been identified for different functions of cognitive mapping. Vision, movement, encoding, and information retrieval are all linked to certain identified sections of the brain. Cognitive mapping depicts how humans encode space by creating a mental map of the environment, suggesting that people with the most Euclidean maps are those that can move and understand space most effectively. Portugali (2004) labels this same idea "Classical cognitivism". He defines this concept as the information-processing approach, where information about individual spaces is created and stored as one discovers or explores an environment. Such cognitive maps are then stored in long-term memory. Visual cues are encoded within these environments and then act as triggers that particular information encoded in one's stored cognitive maps. Pedestrian behaviours within an environment are directly influenced by the storage and the retrieval of the information on that environment.

Internal spatial representation, a more recent term, is used instead to argue that human encoding and memory of the environment are not necessarily accurate one-to-one representations of the real environment. Internal spatial representation conveys the sense that encoding of the environment happens at a schematic, conceptual, and categorical level (Tversky, 1999). This model identifies two main reasons for the distortions present in human spatial representations of environments (Chown, 1999; Nadel, 1999). The first reason for distorsion is the storage capacity limitations of our brains, so that the storage capacity for the information about the environment can be reduced to a manageable size. The second reason for distorsion is to increase the accessibility and flexibility of the knowledge that is encoded. Since we cannot encode all information that a city contains, our brains employ methods that help us to organize and retain as much information as needed for our task, without overburdening ourselves. In either case, information is stored in a schematic, conceptual and/or categorical fashion, which is then drawn together to form our internal representation of space. Internal spatial representation research has shown that spatial ability is not only linked to the accuracy of one's cognitive map, but it is also liked to other elements within the space. This finding from internal spatial representation has changed the approach of the cognitive scientist interested in spatial representation. Hence, the dividing barrier between the two terms has become less and less visible, since internal spatial representation has been gaining much acceptance and, yet, the finding derived from cognitive mapping studies holds fast; namely, with regard to visual hierarchy, route and survey knowledge, and orientation. As a result, at present, both of these terms are used within this field of research almost interchangeably, because the underlying research question for both is the same–i.e. *"how is space understood and* *stored in the human mind?"* For these reasons, Golledge (1999) employs the single term of 'spatial representation' to eliminate any confusion when discussing the general ideas about the human mental construct. Since this study focuses mainly on the amalgamation of this research topic, we will also be employing this term–spatial representation–for the remainder of this thesis. A brief summary of the collected knowledge on spatial representation is the next section to be presented.

2.3 Summary of Spatial Representation Knowledge

Spatial Representation is divided into two bodies of research, internal representational network (IRN) (Portugali, 1996; Haken and Portugali, 1996) and decision field theory (DFT) (Stern, 1998; Buesmeyer and Townsend, 1993). The IRN research focuses on the inner working of how humans encode and cognize the environment (all), while DFT focuses on how we interact with the environment (Stern and Portugali, 1999). Each research field is described separately, followed by deriving the accepted knowledge from IRN and DFT studies which focus on spatial representation and spatial locomotion preferences. The rapidly growing interest in spatial representation provides essential but only initial findings across a wide variety of academic fields. This is the reason why there is so much development in this field of study and why it is important to amalgamate findings across different research disciplines.

IRN describes how the human mind is responsible for the comprehension of spatiality (Belingared and Peruch, 2000; Nadel, 1999; Berthöz and al., 1999, Chown, 1999); Peruch and al., 1995). Neuro-scientists seek to divide-up the brain into different parts according to the roles each part plays. Meanwhile, the cognitive psychologist focuses on the influences these parts have on our environmental perception and how it may influence human preference.

Meanwhile, DFT researchers focus on the conditions of the environment and how they directly affect pedestrian behaivour. In the context of this study, DFT researchers suggest that visual characteristics are linked to human action and preferences within urban environments (Baskaya & al., 2004; Belingared and Péruch, 2000; Bittener and Stell, 2002; Haq and Zimring, 2003; Hillier and Penn, 2004; Jansen-Osmann and Wiedenbauer, 2004; Portugali, 2004; Sadalla and Montello, 1989; Stamps, 1999; Wilson, 1999; Yao and Thill, 2006x; Zacharias, 2001a). Planners use the links discovered between the built space and human action to develop and hypothesize on the mental construct responsible for choices made at decision points, and to identify path choice behaviour. Urban designers strive to use these mental constructs to design space so that it may be used to its full potential. Planners, urban designers, and many other behavioural scientists have much interest in DFTs. Most DFTs findings are then used to draw links back to IRN research. Therefore, an analysis of the knowledge found by both IRN studies and DFT studies are necessary to more fully understanding human spatial representations and its application in human spatial movement.

2.4 Internal Representation Network (IRN) and Decision Field Theory (DFT) Findings

Four areas of spatial representation are revealed in the findings on IRN pedestrian movement research within an urban context. They are listed below, ordered from the most quantitative to the most qualitative: 1-Neurocognition, 2- Distance and orientation knowledge, 3- Survey knowledge and route knowledge, 4- Schema-like knowledge. Each section will end with a short discussion on the DFT findings and the implication they have on our two main research questions, 1- the utility of different VE testing setups for testing pedestrian path choice behaviour, 2- the relationship between both Shape Complexity (SC) and Visual Content (VC) factors on pedestrian path choices made in a novel environment.

2.5 Neurocognition

Neurocognition research areas are further divided into three sections: the centre of cognition, hierarchy of encoding, and errors within spatial representations. Each of these areas adds vital knowledge on the formation of spatial representation, and gives us clues about its employment in path choice behaviour.

Neurocognitive research has identified the Hippocampus as the core component of the brain that is responsible for the encoding and the recalling of human spatial representation. Two study areas confirm this: 1- studies on hippocampus lesion and its effects on spatial abilities, 2- neurophysiological recording studies, or also known as brain activity measurement (Golledge, 1999). Human patients with brain lesions on the hippocampus show impaired ability in learning, remembering, and navigating though environments (Nadel, 1999; Maguire & al., 1998). This implies that not only is the hippocampus responsible for the encoding of space, but also linked to the process of summoning and operating of spatial representation information. The second body of literature measures the activity in the brain during the performance of certain tasks (Berthoz & al's, 1999). They have found that while performing any spatial task the hippocampus always shows great signs of activity, suggests that neurons in this region of the brain stores and retrieves spatial data. Both of these findings strongly suggest that the role of the hippocampus is greatly responsible for our understanding of space. It is often referred as the navigation centre. Knowing where spatial representations are produced and stored, the next sections looks at how are they made, and how they affect our understanding and behaviour within space.

Hierarchical encoding is the main theory on how spatial information is created and encoded. Nadel (1999) demonstrates the hierarchical way in which we encode information and that it is visually biased. The hierarchy of encoded spatial information starts at the retinal frame due to the direct visual field; followed by the head frame, due to the visual field with head movement; then to the trunk frame, due to our trunk rotation; to the body frame, due to the space directly around us; and finally to the world frame, which includes the space outside our direct field of vision, but which has been previously viewed. Stern and Portugali (1999) suggest this type of hierarchy not in the encoding of space but in the employment and retrieval of spatial information. As familiarity increases, one moves from using direct information from the space, to a more global understanding of the space. Pedestrians pull visual information from the immediate spaces during an exploration of an unfamiliar environment in path choices, then as familiarity increase the information collected on the site, as a whole, the information is used to frame their decisions.

This last section deals with the errors within our spatial representation. Chown (1999) states that our spatial representation of space are flawed and filled with errors, but there are reasons for them being so. Spatial representations are not Euclidean; they are qualitative, hence, they are manageable and easily adjusted. Even computational robotics has moved from a quantitative structure to a more qualitative one, for the sacrifice in accuracy greatly increases practicality and efficiency (Chown, 1999). The information required to represent urban environments would be immense if our spatial representations were Euclidean, especially because environments are complex and are becoming increasingly more complex. If our spatial representations were purely Euclidean, updating them would be very difficult and time consuming. Since, our environments are forever changing and we are constantly moving from one place to another, a purely Euclidean map is inefficient. Researchers from a variety of different fields that have come to the same conclusion, human perception of spatial representation employ largely qualitative encoding approaches (Chown, 1999; Murakoshi and Kawai, 2000; Soeda and Ohno, 2002; Yao and Thill, 2006; Bittener, Stell, 2002; Knauff, Jola, Stube, 2001). They have made strong suggestions to increase the academic focus on the qualitative elements of our spatial representations and decreasing the attention of research that are driven solely on quantitative elements. Clark's (1989) theme in his information processing theory helps to illustrate this point "only information that is useful is stored". Memory reduction measures (Chown, 1999) provide more support for the error-prone spatial representation concept. It suggests that humans encode space by employing encoding methods that clumps similar elements together. The amount of information needed to be encoded is reduced by employing the following three methods: *numerical clumping*, which reduces the number of object remembered by grouping objects into one according to proximity, schematic similarities, or emotional attachments; *landmark clumping*, which reduces the number of objects remembered by grouping objects surrounding a landmark or a number of landmarks into one object to remember; *structure clumping*, which reduces the number of objects remembered by grouping objects with similar geometrical features. Memory reduction measures show two main advantages against a Euclidean representation of the environment: ease in storage and ease of retrieval. This idea of error in our spatial representation is the foundation of Schema-like Knowledge, the last IRN research topic to be discussed.

Expansion on Neurocognition

Loomis (1996) describes how different methods of spatial information retrieval cause different behaviours, but would it be valid to suggest that the differences in ways of information storage would have the same effect? Would the visual hierarchical method of information gathering and storage explain certain behaviours that are prevalent in the urban environment? One widely accepted DFT is forward path preferences (Bailenson, Shuman and Uttal, 1998; Conroy Dalton, 2003). The rule is to follow your nose, where the most preferred path is usually directly in front of the point of entry. Could this finding be resulting from of the hierarchical encoding of our field of vision? Since, we encode more information from the forward path, do we prefer the forward path more? This line of questioning may also infer on other spatial behavioural preference, for the underlying motivations behind such behaviours are often unknown. Pursuing the research so as to identify such the underlying motivations behind these behaviours would be a highly worthwhile venture. Would a more in-depth understanding of the inner working of our spatial representations be the key to answering the motivation of certain behaviours and how they take place? Answering this question would require more studies focused upon the links between these two concepts of spatial behaviour and spatial representation. Once the link between human spatial behaviours and spatial representations is more fully understood, a number of environmental cognitive researchers suggest that such inferences will be the next step in this field of research (Allen, 1999; Amorim, 1999; Riesier, 1999; and Nadel,1999).

2.6 Distance and Orientation Knowledge

Distance and orientation knowledge is thought to be important in the process of creating spatial representations, especially when our representations are believed to be Euclidean. Distance here is defined as the measurement of path length (McNamara & Diwadkar, 1997), while orientation knowledge is defined as the ability to keep a good directional bearing during navigation or locomotion within an environment (Sadalla & Montello, 1989).

Distance Knowledge

The recent findings on distance knowledge add to the theory that human spatial representations are non-Euclidean. Mental measurements of path lengths are often not accurate, and are more often subjectively derived though other qualitative measurements. Distance in spatial representations is not encoded in terms of metric distances but in a schematic measure, such as cognitive storage space, cognitive time or cognitive effort

(Jansen-Osmann & Wiedenbauer, 2004; McNamra & Diwadkar, 1997). A proof is provide in Jansen-Osmann & Berendt (2002) and Sadalla & Montello (1989), where overestimation of path lengths occurs as paths hold more changes in direction and the underestimation of path lengths occur as paths hold few or no changes in direction. The more complex a path, the more it is over-estimated; whereas, the simpler the path the more it is under-estimated–does this have to do with the amount of effort necessary to cognize the path? This provides support for the theory that our spatial representation of the environment is schematically encoded.

Orientation Knowledge

Orientation knowledge can be divided into four theories: vision-based orientation, angular perception, object orientation, and body orientation. These models explain orientation and its role in human spatial representation.

Vision-Based Orientation

Berthöz and al. (1999) revealed that the orientation system in our brain functions in tune with our visual functions such as in the case hierarchical encoding of information, vision-based orientation. The orientation system is partially controlled by our gaze and the head rotation. Our gaze guides the way we learn about space. The differences between orientation-specific and orientation-free spatial knowledge illustrate the validity of vision-based orientation theory. When using a map to create a spatial representation, the information collected is deemed orientation-specific; where the ability to link the spatial knowledge collected from the map to the physical environment is connected to the orientation in which the information was acquired, if one is not facing the original orientation then it is often quite difficult to attach information acquire from the map to the physical space.

Angular Perception

Angular perception of our spatial representations tends to be rounded to the nearest orthogonal angles at intervals of 90 degrees (Sadalla, Montello, 1989). For instance, if looking at a hallway at an angle of 80 degrees, we round it to the nearest 90 degrees interval, 90 degrees, if it were at 170 degrees, then it would be thought of as 180 degrees. This finding follows the one that the more orthogonal a path the greater the facility in recalling and storing the path (Baskaya, Wilson and Özcan, 2004). The greater the path angles differ from orthogonal angles the greater the amount of error in the construction of the spatial representation of the environment and the more difficultly in recalling such spaces.

Object Orientation

Object orientation, also known as landmark-based orientation, states that objects are used as a point of reference where spatial representation information is encoded in relation to them. These points of references are often physical landmarks. In this theory, landmarks are used to direct one towards and away from the landmark in order to keep proper orientation. Golledge (1999) also suggests that humans employ what he calls *piloting*, the act of navigating from one landmark to another landmark, or from one visible landmark to a direction relative to another landmark. These theories imply that orientation is only effectively achieved when landmarks are present in the environment. Parush and Berman (2004), however, suggest gender differences in this orientation task. Men do not rely on landmarks as much as women do. Men can complete a wayfinding task better without visible landmarks, while the presence of landmarks confuses and actually reduces performance. On the other hand, women improve their wayfinding task with the presence of landmarks, and are at a loss without them. This raises the question about the general role of landmarks and gender differences in orientation.

Body-Object Orientation

The final theory is body-object orientation, similar to object orientation, and defined as constantly updating one's orientation in reference to one's body and surrounding objects; however, the centre point of the spatial representation always remains oneself. Landmarks are used in body-object orientation within space using three tools. These tools are right-angle offset, triangulation resection, trilateration (Loomis, 1999). This theory suggests that spatial representation should always be orientation-free, which as we have already seen at the beginning of this section is not always the case.

Expansion on Distance and Orientation Knowledge

Overall, an element within both distance and orientation knowledge shows the important link between our spatial representation and our field of vision. The greater amount of visual information to be processed within the environment, the greater the flexibility of spatial representation and the greater the ease in recalling of such information. In the section of discussing distance, it was stated the more complex a path, the greater the effort is need to create a spatial representation of that path? If so, could we suggest that the distance measurement of a path is not as important as the complexity or amount of visual elements along the path? Looking at these ideas, we may argue that visual complexity is what causes interest. Complexity is thought to allow increase spatial legibility to a greater number of individuals that differ in spatial aptitude (Haq and Zimring, 2003). Do visual elements allow us to form more comprehensible and useful spatial representation? We sought to measure the effects of each SC and VC measures on pedestrian path choices behaviour.

2.7 Route Knowledge and Survey Knowledge

Navigation, as defined by Stern and Portugali (1999), is a sequence of path decisions made and executed within an urban space. Survey knowledge and route knowledge are the two types of spatial representation knowledge that are formulated during navigation. Both of these forms of knowledge grow as one becomes more familiar with the urban environment. The classical three-step model of spatial representation involves first encoding landmarks of the environment, followed by acquisition of knowledge of surrounding routes that one takes, followed by the creation of a spatial representation of a system of routes.

Route Knowledge

Route knowledge refers to one's ability to navigate a formerly learned path within an environment effectively (Bliss et al, 1997, Ruddle et al, 1997). Route knowledge is composed of two main components: 1-landmarks, which are linked to orientation knowledge; and 2-path intersections, which are points of reference (Richter, & al., 2004). These elements are the components that one must retain to provide an intelligible spatial representation of a path. It is, however, suggested that the interconnection of path intersections is more important than the landmarks. Without an in-depth knowledge of the path intersections of the environment, the landmarks themselves are said to be useless (Hafner, 2000). This idea will be readdressed later in the discussion concerning the different ways to create survey knowledge.

Survey Knowledge

Survey knowledge is often defined as an integrated understanding of an environment and how spaces are related to each other, which includes knowledge of spatial element interrelationships (Rossano and al, 1999; Thorndyke and Heyes-Roth, 1982; McDonald and Pellegrino, 1993). This type of knowledge is usually referred to as mental maps, similar to a bird's eye view. Survey knowledge holds landmarks, districts, nodes, edges, and paths as main components. There are two methods that are suggested in the formation of survey knowledge: one, maps; two, path integration.

Map knowledge

The first method of obtaining survey knowledge is encoding such knowledge from a map. Information is derived from a map where the urban environment is represented in a Euclidean bird's eye view or plan view. The most typical example is a road map. The limitation that arises in creating survey knowledge in this fashion is that information acquired is often orientation specific, where mapped knowledge is only accurately used in the acquired orientation. For example, if the map were learned in north orientation, then the survey knowledge derived would be most effective when facing north. The reason for this is that mental rotations of such survey knowledge have been shown to be quite difficult and have led to many errors in wayfinding task (Wilson and Tlauka, 1996). However, as familiarity of the environment increases, the level of errors of mental rotation decreases. The advantage that this has over the other method of formulating survey knowledge, path integration, is that it often provides for a more complete survey knowledge of the area (Thorndyke and Heyes-Roth, 1982).

Path Integration

Path integration is a term coined by Loomis (1999), which he defines as the connecting and overlaying of route knowledge from many paths to create mental representation of a system of paths, or survey knowledge. Loomis states that two elements are necessary for successful integration of paths and properly overlapping of landmarks upon the learned routes: one, landmarks must be present and visible; two, a high level of familiarity is required. Research has indicated that this type of knowledge builds upon landmark information, believed to be the first element collected in spatial cognition (Richter & al. 2004; Haq and Zimring, 2003; Schelender & al, 2000; Rossano & al, 1999; Rossano & Moak, 1998; Allen, 1999; Bliss & al, 1997; Ruddle & al, 1997). Subsequently, additional environmental information is transposed and adjusted in relation to the identified landmarks. In the works of Allen (1999), he suggests that landmarks must be strategically positioned to create an environment that is conducive to aid people in creating a good mental map of an area. However, Hafner (2000) states that landmarks are not necessary. She suggests that landmark knowledge is only formed after a high level of path knowledge is formed. When landmark knowledge is eventually formed it is only used as an aide or visual cue, for use for orientation, but is not a fundamental component of the cognitive map. Haq and Zimring' (2003) study on path integration of route knowledge supports this finding. Path integration of pre-learned overlapping route knowledge seemed successful without landmarks, as long as participants were allowed to freely explore the space. This seems to show that survey knowledge requires a level of familiarity of the space before it can be formed completely or used accurately (Haq and Zimring, 2003, Rossano & al, 1999).

Expansion Survey and Route knowledge

This brings up an interesting finding, where free exploration was seen to allow for the process of path integration without landmarks. What added spatial information is available in exploration that is not present in directed route studies of individually overlapping paths? Is spatial knowledge collected more efficiently or is different knowledge collected during free exploration? Studies striving to facilitate the creation of route and survey knowledge, suggested that increases in both path linearity, lining up of paths and connectivity, the number of visible path connections within each of the paths choices, are all thought to aid the creations of both types of knowledge (Hillier, 1993; Haq and Zimmering, 2003). One theory may provide more insight on this matter.

Research has suggested that this type of knowledge is more closely linked to complexity and spatial differentiation (Baskaya, Wilson and Özcan, 2004; Murakoshi and Kawai, 2000: Belingared & Péruch, 2000; McNamra & Diwadkar, 1997). They suggest that environments should contain aides that promote the creation of heuristic knowledge and non-spatial knowledge. Montello would disagree with this argument, suggesting that these heuristic elements are just another metric knowledge in disguise, that they are qualitative metric elements (1998). The "new framework" for understanding the acquisition of spatial knowledge, in large-scale environments, describes primarily a metric encoding of the environment, where quantitative information is stored. As familiarity increases more such information is encoded into our spatial knowledge. At a choice point in a small-scale environment, where one needs to decide which path to take, is encoding occuring in the same way? What elements aid in the creation of such spatial knowledge at these choice points? This question is explored later on.

2.8 Instrumental versus Diversive Behaviour

The qualities of instrumental and diversive behaviour during pedestrian locomotion may explain this difference of information collected from exploration compared to wayfinding or directed movement. Heath defines these two types of behaviour in Nasar's book on environmental aesthetics (1988).

Instrumental objectives are explained as motivations linked to completion of a particular task, such as wayfinding, finding a grocery store, or finding a metro station. Elements that aide in the completion of the task set forth, such as convenience, comfort, absence of distraction, will be the focus of movement.

Diversive objectives are linked to exploration; the behaviour of the tourist, vacationer, window-shopper and stroller. The main goal of this type of behaviour is to simply experience the space or the activity pursued. Attention to the environment is very different to that of an instrumental mindset, since such diverted individuals are paying more attention to the space as a whole.

Information acquired in an exploratory state is different from a task-oriented state. It allows more attention, slower movement, and more time, all of which allows for the collection of more information about the environment (Zacharias, 2001b). The encoding of the environment is more holistic during diversive behaviour than during instrumental behaviour. Instrumental behaviour refines encoding of spatial elements to only those that aid in the task at hand, while diversive behaviour encodes a wide range of elements present in the space. During a wayfinding task of reconstituting a path, one may focus on a large landmark and build information around it, whereas during an exploration of a space one may focus on a schematic element in space, such as the colour of the walls or the number of people in the space.

Expansion on Instrumental versus Diversive Behaviour

In the context of this study, diversive behaviour would provide equal opportunity of all the visual characteristics to be encoded, which would avoid the possibility of identifying task-specific visual elements. During a diversive activity, the preferences expressed for particular measures of visual characteristics are likely to be more vital elements in our path choice behaviour and spatial representation.

2.9 Schema-like Knowledge

We now look at schema-like knowledge often referred to as the employment of heuristics. Schema is defined as “rationality without rules” (Johnson, 1987). If we attribute spatial factors as the rules in the above quote, the definition of the schema-like knowledge becomes the knowledge of non-spatial elements within the environment. Lawton's study (1996) shows how participants might have employed this knowledge; participants lacking skill in configuration (those who could not draw an intelligible sketch map of the learned environment) used other generic skills to complete their wayfinding task. These individuals performed as well or better than those with highly intelligible sketch maps in the wayfinding task. This shows that other information besides the elements attributed to sketch maps are encoded in their spatial representations of the environment, that is non-spatial elements. Studies on schema-like knowledge have becoming increasingly important; spatial representations are shown to be less Euclidean and more qualitative (Chown, 1999; Murakoshi and Kawai, 2000; Soeda and Ohno, 2002; Yao and Thill, 2006; Bittener, Stell, 2002; Knauff, Jola, Stube, 2001). These findings suggest that the qualitative elements contained in urban environments and the information that is linked to them have a great influence in the formation, recalling and use of spatial representation.

Expansion on Schema-like knowledge

Many researchers describe this schema-like knowledge as the complex structures of underlying human preferences not easily tested for, such as previous knowledge and preconceptions of spaces, which may be linked to VC factors in the environment. VC are composed of the non-spatial elements that are employ to understand and recall information on the complexity of space, such as colour, design features, people presence and movement, stores, lighting, and material. If these constructs effects the general understand of space then their effects on path choices should be identified. The items listed above, which is only a small portion of a much longer exhaustive list, help to frame the problems researchers face in isolating the effect of each of these elements, for the weight of these elements in cognizing the environment seem to vary across individuals. Researchers have tried to quantify these items across a general population with little avail. Others have implied that VC information, or non-spatial information is not important to the cognitive understanding of space (Hiller & Penn, 2004; Haq & Zimmering, 2003; Knauff, Jola and Stube, 2001). Previous discussion sections have stressed the importance of VC in the initial development of spatial representations. The influence that VC exerts on pedestrian dynamics is the central issue in this study. Reviewing the theory behind spatial representation has presented the potential effect VC has on path choice behaviour. This effect must be studied to truly understand the complexity of the relationship between spatial representation and spatial behaviours.

2.10 The Controversial Issue

Are VC measures not important in spatial representation and spatial preference? Many studies have suggested that it is not important, for the strength of the effect of SC factor renders schematic knowledge and the VC factors of space relatively insignificant (Hillier, 1993; Hiller & Penn, 2004; Haq & Zimmering, 2003; Knauff, Jola and Stube, 2001). Non-spatial information in the context of pedestrian path decisions during an instrumental task may be unimportant, but that behaviour alone does not describe the whole picture of pedestrian path choice behaviour. Diversive exploration, the other facet of pedestrian movement, is missing to complete this image; hence, describing the role of visual characteristics associated with this mindset is imperative (Zacharias, 2000; Zacharias, 1993). Even if we assume that SC does account for seventy per cent of variance in path choices (Hillier, 1993), there remains at the least thirty per cent that is unaccounted for. If it could be shown that VC does accounts for this remaining amount, then is VC still unimportant? Other findings have suggested that VC may account for much more of behaviour then the above result. Kaplan's study (1987) suggests that VC has a large effect on preference ratings of an environment while SC factors had no effect on the preference rating. Stamps (1993) has shown that VC can explain up to ~70% of visual preference for environments. This relationship between spatial preference and path choice behaviour still needs to be more extensively examined, in particular to clarify the roles of SC and VC factors on human mental reconstruction of space, and pedestrian path choice behaviour. Thus, we move on to the next section, which focuses on the effect of VC and SC on pedestrian path choice behaviour.

Chapter 3

Effect of Shape Complexity (SC) and Visual Content (VC) on Pedestrian Path Choice Behaviour

The topics of this chapter precede in the following order: definition of SC and VC, the path choice behaviour model, visual factors, SC measures, and VC measures.

3.1 Definition of SC and VC

SC is defined as the visible configuration characteristics of the environment's street layout, where configuration characteristics are defined as the Euclidean measurement that exists in space. Examples of such SC characteristics in space include links, enclosure, and occluded edges.

VC is defined as the non-configurational visual characteristics and transient visual characteristics of the environment, where non-configurational visual characteristics are defined as the non-structural element within a path choice. Examples of such non-configurational characteristics in space include colours of the façades, amount of green plants, material of the street (cobblestones or pavement). Transient visual characteristics are defined as elements that are not fixed in space, which changes in amount from one period of time to another. Examples of transient visual characteristics are people, cars or bikes visibly present in a path choice.

3.2 Conceptual Path Choice Behaviour Model

A quote from Norberg-Schulz summarizes the parameters necessary in examining the relationship between the cognition of the visual characteristics of the physical environment and its effect on pedestrian behaviour:

> *"On the planet **man choose** and **creates paths** which gives his **existential space a more particular structure**. Man's taking possession of the environment always means a departure from the place where he dwells, and **journeys along a path which leads him in a direction** determined by his **purpose** and his **image of the environment**."* (Emphasis added)

The relationship between the purpose within the environment and the image of the environment is necessary to predict behaviour. In this case, we are talking about pedestrian path choices. Figure 1 shows a decision model explaining the process for selecting our paths when confronted with a decision point. In this study, we simplify this model by eliminating the process of "*accumulated knowledge*", by creating a testing condition that promotes a diversive mindset. Pedestrian participants, therefore, are more

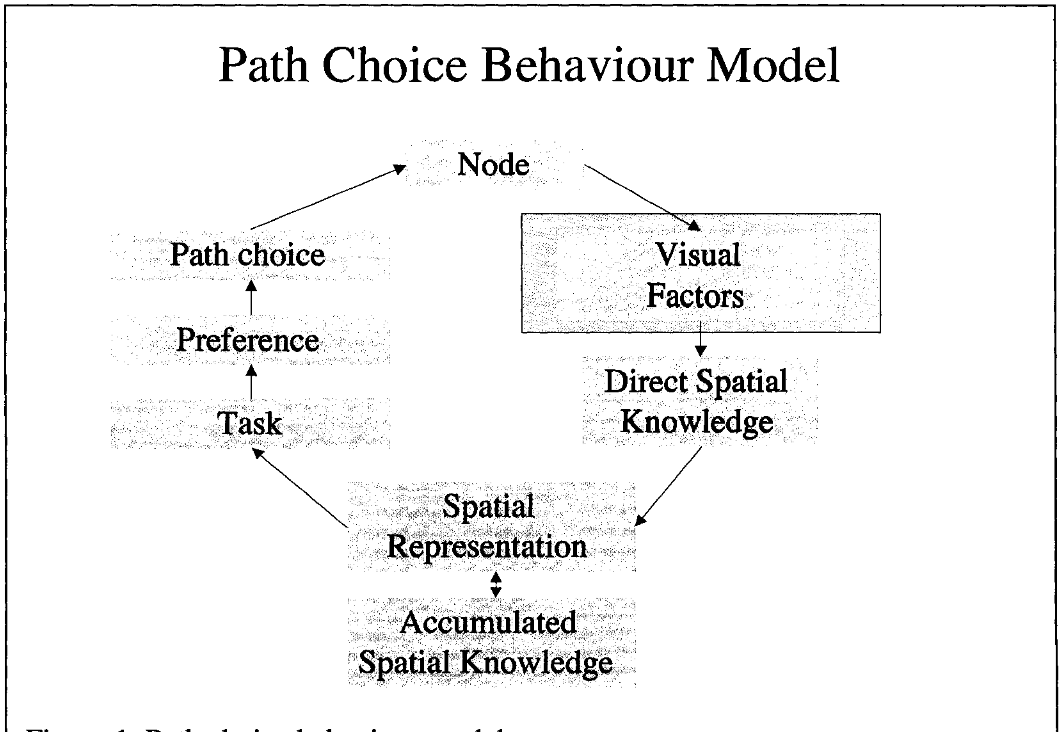

Figure 1. Path choice behaviour model

likely to focus on the elements within the space. By reducing accumulated knowledge effect in the equation, the effects of the visual characteristics of the environment can be more effectively tested.

3.3 Visual Factors

Visual factors of this study were divided into two groups: 1-SC, 2-VC. Figure 2 shows the visual characteristics of the environment, which is an expansion of the "Visual Factors" box present in Figure 1. This diagram illustrates the factors that are measured in the visual scene of the environment for this study. First, the theoretical models, which explain the role of SC and VC, are presented. Second, each of the SC and VC measures analyzed for this study are described along with their expected effect on path choice behaviour.

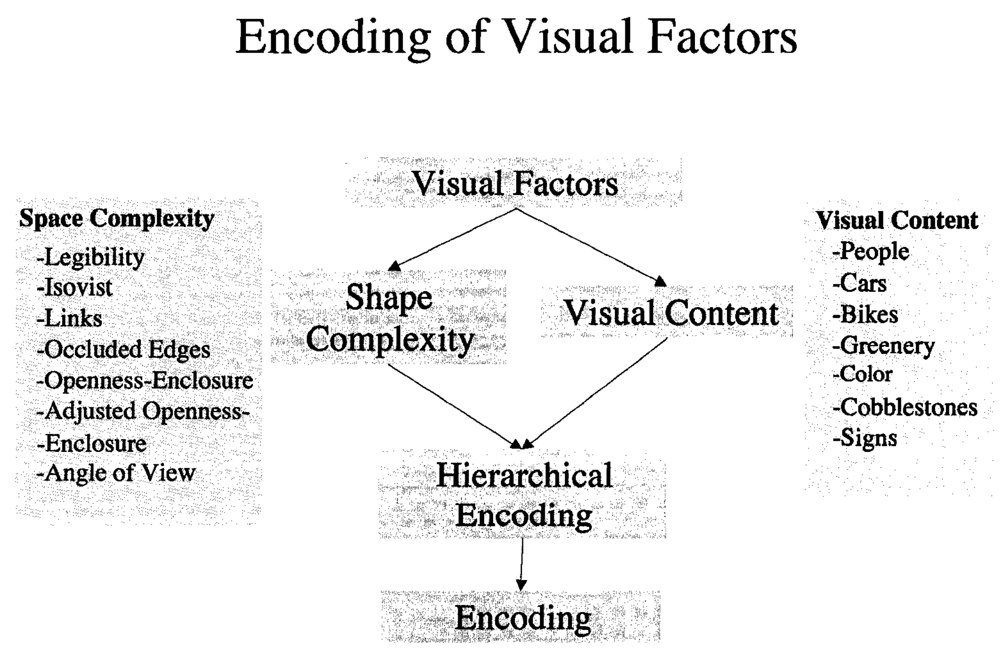

Figure 2. Encoding of Visual Factors

3.4 SC Measures

The configuration of the urban space is influential on path choice behaviours. The idea is that the environment can be stripped down to certain configuration qualities and structural properties of the physical environment, which predict the path decision of an explorer in a novel environment. Seven SC measures have been derived for examination. They were the following: angle of view, partial isovist, occluded edges, openness-enclosure, adjusted openness-enclosure, links, and legibility.

1-Angle of View

The angle of view is a two-dimensional measure, the angle covered by each of the paths present in a node. Each node totals a 360-degree Angle of View; hence this measure is expressed as a proportion of total. A greater angle of view contains a great amount of information. The greater the amount of information present the greater the likelihood that the path would be selected over the other paths available; therefore, the larger the angle of view the greater the overall preference for a path.

2- Partial Isovist

This partial measure of Isovist is related to angle of view, but it differs by accounting for the depth of the path. Isovist is a complex spatial measure that defines structural characteristics of urban layout (Benedikt, 1979). This study only employs one of the many isovist measures, area–identified as the key isovist measure related to spatial preferences (Stamps, 2005). This partial isovist was revised further for the purposes of this study, scaled down to represent the individual paths of each node. The partial isovist measure was defined and calculated as the viewshed area of each path limited to a field of view of 120-degrees–the human eye has an average field of vision of 120-degrees–centred on the midpoint of each path from the axis of the corresponding node. For the remainder of the study, partial isovist will be used in the context of this study, referring specifically to this isovist area measure. Stamps (2005) showed isovist area to be correlated to the amount of information present in each path, which is shown to be positively related to visual preference, and Wiener and al. (in press) show that while the isovist area was positively correlated to ratings of pleasingness, beauty, clarity and spaciousness, it was negatively correlated to interestingness and complexity. Overall, the hypothesis is this partial isovist measure should be positively correlated to path choice preferences.

3- Openness/Enclosure

Stamps (2005) defines enclosure as the proportion of views covered with physical features which block vision and motion. In this study, we have redefined this term as a measure that not only looks at how enclosed a space is but also the level of openness, adapted to path choice behaviour; hence, "openness/enclosure". It is defined as the amount of visible sky present in each path choice, not accounting for greenery coverage as a element that block the view. The increased amount of visible sky should be positively related to path preference.

4- Adjusted Openness/Enclosure

This factor is the same as the above with one exception; it takes into consideration the additional enclosure that greenery may cause. It is been stated that greenery also creates a sense of enclosure (Appleton, 1996; Kaplan, 1987). Therefore, any greenery that covers any portion of the visible sky is also removed from the calculated value for openness/enclosure. The adjusted openness/enclosure factor may be positively related to path choices.

5-Links

This measure counts the number of visible connecting paths that are present in each of the paths of an environment. It is thought that the greater the number of links the more preferred a path would be, for it affords opportunities to discover and see more of the surrounding environments. Two other elements that defined the global space linked to this factor are boundary relations or connectivity (Hillier, 1993; Haq and Zimmering, 2003).

6- Occluded edges

This SC measure is linked to mystery (Herzog and Miller, 1998; Kent, 1989) and prospect-refuge theory (Appleton, 1988). Occluded edges are defined as edges that hide part of the space within the scene (Yeap and Jefferies, 1999). As the amount of area hidden in the environment increases, the more information inferred onto the environment, also creating a certain level of uncertainty and mystery. Configurational mystery is positively related to preference (Herzog and Miller, 1998; Kent, 1989). If this should hold, then occluded edges should be positively correlated with path choice behaviour.

7- Legibility

The Legibility measure separates the path into three categories: curved or bent path, T-intersection path, straight-ahead paths. This is an interval variable since it has three specific changes in level of legibility. The first, curved or bent paths, provides the least amount of legibility, as the end of the path is not visible and no visible confirmation of potential path choices is available. The second, T-intersection paths, have slightly more legibility, as you can visually confirm two potential path choice options, even if no clues as to what lies within both choices are visible. The third, straight-ahead paths, provides for the greatest amount of legibility for all potential paths options are visible and at least one of those potential path choices is in direct line of sight. Legibility is suggested to be positively correlated with visual preferences (Kaplan, 1987), which suggests it should also be positively correlated to path choice behaviour. However, it has also been suggested that low legibility would result in a high level of mystery (Kent, 1989), which suggests that legibility should be negatively correlated with the level of path preference, if personal safety within the space is not an issue. Given the context of this study, which involves exploratory motion in a diversive mindset, the effect of mystery should overcome the effects of visual preference; hence, path choice behaviour should be negatively related to legibility.

3.4 VC Measures

VC has been linked with the level of visual preference for urban environments in a number of studies. Kaplan's study (1987) showed that SC had no significant effect on the preference ratings that participants gave to an environment, but that VC had a large effect. Stamps' (1993) states VC can explain ~70% of visual preference of environments, at the higher statistical range. Zacharias' (2001b) showed that the transitory factors are more important than architectural factors when selecting paths during novel exploration. Baskaya, Wilson and Özcan (2004) stated that in order to form clear spatial representation of an environment, one needs not only a clear communication of layout, but also some type of visual differentiation, which are often created by VC measures available within the environment. These studies show that VC measures may be highly influential to our preferences for environments. Assuming that visual preference is related to path choice behaviour, then VC also should be highly related to path choice behaviours. To test the above assumption, we have identified seven important VC measures to test their effect on path choice behaviour. They are the following: people, cars, bikes, greenery, colour, cobblestones, and signage.

1- People

Visual preference and also path choice behaviour are thought to be linked to the amount of people present in space. Pedestrians are attracted to the presence of other people during novel exploration in a diversive environment, following the crowd as an indicator of interesting sights (Zacharias, 2001a).

2-3 Car and Bicycle

As mentioned above, transitory factors seem to be an important factor in selecting a path, so this study also included cars and bikes to test for their influences in a pedestrian dominant environment. The hypothesis is that they are positively correlated.

4- Greenery

Greenery as a VC measure has been linked to visual preferences in articles by both Opperwal and Timmermans (1999) and Kaplan (1989). This factor is thought to have restorative properties that increases ones affinity for paths containing more greenery; therefore, positively related to path preference. Trees can be argued to be spatial structures in space that act as columns, which help to act as reference points in space, or a reference scale (Wiener et al., 2007). As it is not clear how the remaining spatial structures affect path choice behaviour, the effects of trees was not considered in tying down the effects of identified SC factors.

5- Colour

The number of colours a path contains has been positively correlated to the amount of activity on a path (Kaplan, 1987). Colour has also been suggested to help differentiate paths from one another, which helps one gain orientation information during exploration and navigation (Baskaya, Wilson, Özcan, 2004). Both of these relationships suggest that colour should have a positive relationship with the pedestrian's path preferences.

6- Cobblestones

Cobblestones differentiate available paths, unless all available paths share the same pavement treatment. Complexity of material, differentiation, and framing space are the underlying reasons for testing this particular element. Increased complexity of materials showed a positive correlation to visual preferences (Kaplan, 1987). Differentiation was shown to promote schema-like knowledge, the more different the space, the more distinguished it was from the remaining spaces, and the more schematic knowledge attached to such a space (Baskaya, Wilson, Özcan, 2004). Framing space was shown to promote the idea of segregation of different uses. Cobblestones physically frame a space as pedestrian oriented–the more visible the cobblestones the more intense the illustration of pedestrianisation. In this study, we looked at three levels of such segregation, where the increase of segregation should be positively related to path choice behaviour.

7- Signage

The amount of signage can be thought of as a factor representing commercial activity. Zacharias (2000b) has shown that pedestrian path choices were positively linked to commercial activity; so pedestrian path preference should be positively related to the presence of signage, as opposed to none.

Chapter 4.

Methodology I – Virtual Environment (VE) Creation Process

The methodology is divided into three sections: VE creation process, the three levels of VC testing environment, and the experimental setup. This section presents the VE creation process, which is composed of three sections: VE site selection criteria, study site, VE creation.

4.1 Virtual Environment (VE) Site selection Criteria

The site used for this study was carefully selected using the criteria described below.

1- Must be an unfamiliar site to participants
2- Must include different levels of SC and VC in the surrounding paths
3- Must contain many intersections, where ten nodes can be selected
4- Must be a pedestrian-oriented environment.

1- Unfamiliarity

The reason why the site must be unfamiliar is that it increases the pedestrian's attention to the spatial visual characteristics. Since the main examination is on the pedestrian's perception of SC and VC, both spatial visual characteristics, unfamiliarity of the environment is a key factor that must be included in the site selection criteria.

2- Different Levels of Shape Complexity (SC) and Visual Content (VC)

Researchers have identified the -SC and VC effects on visual preferences, but their effects on path choice behaviours have not yet been established. To establish the effects of SC and VC on pedestrian path choice behaviours, a range of SC and VC factors increase the power of the study to detect such relationships. Without a normal distribution of independent variables, higher numbers of participants will be necessary to obtain significant results. A pedestrian environment resulting from organic streetscape would hold such a wide range of both SC and VC levels. Therefore, pedestrian environments and older pedestrian city cores should be highly considered as possible sites.

3- Many Intersections

A study site holding many closely spaced intersections is necessary as it eases the VE creation process. A site with many intersections, a continuity of architectural styles and low variations of streetscape scale, reduces the potential effect of architectural styles and scales that may influence pedestrian path choice behaviours. Given the process of VE creation, a study site that contains many intersections significantly reduces data collection time. Many intersections allow the VE documentation process to be continuous, which reduces the strain of an already lengthy task. It allows the photographer to move from one intersection to another easily, without having to drag the necessary equipment through long and disconnected streets.

4- Pedestrian-Oriented Space

The last and most important selection criterion is that the space must be pedestrian-oriented. The whole motivation behind this study is to understand how pedestrian behaviours are informed by space or vice versa. To assess the quality of pedestrian areas and to better plan or redevelop other pedestrian areas, it is necessary to understand these pedestrian environments and the structures that "make or break" them.

4.2 Study Site: Old Freiburg, Germany

Figure 3: Views of Rathaus-platz, Freiburg, Germany

Site Selection

During the summer of 2006, a research trip and discussion with a fellow researcher, finalized the study site in Freiburg, Germany, which fulfills all the criteria set forth above. The research trip, which involved me working as a research assistant, placed me in Europe for the month of September, 2006. This trip also sparked a discussion between John Zacharias, my supervisor, and Christoph Hölscher, a researcher from SFB Spatial Cognition group, Freiburg University, both of whom expressed interested in working on a joint study. These two events made Freiburg, Germany an excellent candidate for a study site. A short visit confirmed that it was a perfect location, meeting all the site selection requirements. Unfamiliarity is addressed, since most North Americans have never visited Freiburg. The organic layout of this city addresses the issue concerning the range of SC and VC level. As a pedestrian city that was developed for pedestrians by pedestrians, Freiburg contains paths with rich amounts of VC and different levels of SC. The pedestrian area of the city is also made up of a total of 64 nodes, where no two are alike, but retain a similar architectural style and scale. All these elements combined make Freiburg the perfect study site.

Site Description

Freiburg is an old medieval town located in the southwest corner of Germany as is indicated in Figure 2. This town was exposed to a multitude of wars since medieval times. As a result, it was flattened, redeveloped and destroyed many times over. This title of "Old/New medieval town" is attributed to the city's determination to maintain the historical character of the city. An example of this stance occurred after the Second World War, where bombs destroyed large portions of many cities. Others cities, for example Rotterdam, chose to modernize and forgo the pre-existing structure of the city. Freiburg, however, chose to preserve its urban fabric, instead of modernizing. They rebuilt reproducing what was destroyed; hence, the term Old/New medieval town. The only exception to this rule was widening of certain streets to allow for a tramway to enter into the old city;

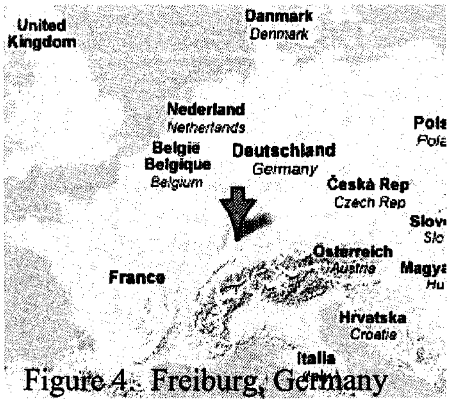

Figure 4: Freiburg, Germany

otherwise, the historical center of the city remained as if untouched by the bombing of the Second World War.

4.3 Virtual Environment (VE) creation

The two types of VE utilized in this experiment were panorama-based representations of the real environment. Ten intersections of the city of Freiburg were recreated in a VE panoramic environment. These intersections will be referred to as nodes for the remainder of the article, to facilitate the idea of how these intersections are represented

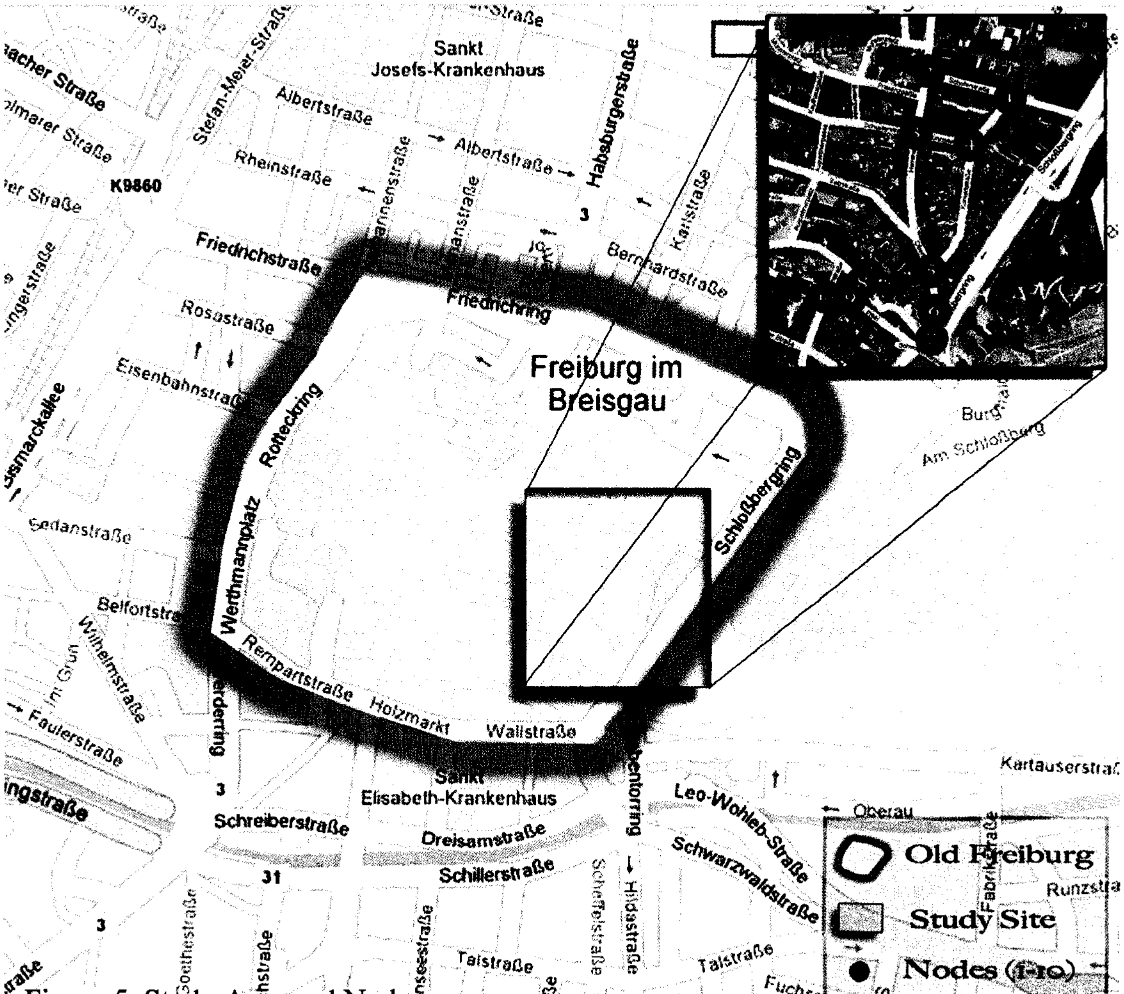

Figure 5. Study Area and Nodes

by these panoramic nodes. These ten nodes are illustrated in figure 5. The most efficient way to create this environment was to collect and prepare the environment in four stages.

1- Photo Session
2- Panoramic Images Stitching
3- Path Choices Labeling
4- Self-Panning Panoramic Nodes Creation.

The Photorealistic panoramic print environment required only the first three steps, while the creation of the panoramic QTVR environment required all four stages. Each step is explained in detail below, providing a framework for other investigators interested in using such an environment.

Stage 1 - Photo Session

The photo session followed the following structure; locating each node for the VE environment, identifying the point of axis for each intersection, taking each photo set of each node in a systematic fashion.

We located a total of ten nodes, chosen from the 64 nodes present in the Old/New pedestrian area of Freiburg. This selection of nodes is shown in figure 5. The ten nodes are composed of paths containing a wide range of visual and structural elements. The nodes also contain three, four or five path choices.

Within each node the axis of rotation for the VE representation of each node must be decided. Bi-section was employed to identify the axis for each node. Each path was bisected, and the centerlines of the paths were extended into the node. The conversion point(s)[1] of the centerlines was used to find the axis point for each node. If the node had more than one point of intersection, then the midpoint between them, by bi-section or tri-section, would be used; otherwise, that conversion point was used. The axis of rotation is very important, since this point influences how each path choice is viewed within the VE. It is necessary to control the view, so that all paths are equally visible, where possible, from that vantage point.

The last part of the photo session consists of documenting each set of pictures for each node. Following a protocol, which ensured not only ease in stitching them together, but also limiting the necessity of touching up the panoramic images once created. The ideal weather conditions were overcast, since it diffuses light across the area to be documented. Otherwise, if in sunny conditions, where the light is uneven, there would bright and dark spots in the panoramic images. This would need to be corrected by photo manipulation, which is often time consuming and if not corrected could add an unwanted independent factor, bright/dark spaces. During this ideal weather condition, here is the remaining element of the protocol for the photo session, which facilitates a productive stitching process:

1- Each node consisted of a minimum of 12 pictures (more were necessary if people were present at the edge of photo, or there was ghosting of elements that were moving fast in space),

2- Pictures were taken with a 51 mm lens digital camera, fitted with a tripod and panoramic head.

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[1] Sometimes the nodes had more than one point of centerline conversion

3- Photographs were taken 30 degrees apart, facilitated by the panoramic head.

4- The aperture and exposure settings on the camera were kept constant for all pictures, so that pictures would be easily stitched together without manipulation of images for exposure or colour settings.

Stage 2- Panoramic Image Stitching

This section describes the panoramic images stitching process. The product was a set of ten seamless 360-degree panoramic images, each 9238 pixel wide by 1978 pixels high. First, the photos for each node were organized in sets. The digital pictures were separated into sets representing each node. The sets were placed in their own folders to facilitate loading each picture set into the stitching program. Second, sets were then stitched together into panoramic images using VR Works 2.6. Depending on the number of transient elements in the space, each image was then verified and corrected for what is called 'ghosting'. Ghosting occurs when elements in space, such a people or bicycles, are present in one of the twelve frames, but have shifted locations in the next frame. This ghosting on the panoramas, if present, can be eliminated by two methods: by manually using Photoshop to replace the ghosted image with a sharper element, or by removing one of the twelve images before stitching the panoramic image together. The former is more time consuming then the latter, but it works consistently; while the later is quick, but often does not produce a clean panoramic image. Figure 6 shows a stitched

Figure 6. Panorama of Node 8

panorama ready to go to the next process. **Stage 3- Labeling Path Choices**

The labeling of the path choices within the panorama was created with Photoshop, so that each path choice would be easily identified. Within each of the nodes, there is a range in the number of path choices available; six contain three path choices, three have four path choices, and one consists of five path choices. All path choices within each panoramic image were labeled A to E, depending on the number present in each node. If there were 3 path choices, they were labeled A, B, and C; if there were 4 path choices, they were labeled, A, B, C, and D; and so on. This is the final preparation step for the Print VE, but for the other two VE setups, there is one last step required, where the stitched images are converted into 360-degree panning QTVR.

Stage 4- Self-Panning QTVR

This is the last stage for creating self-panning panoramic QTVR VE; used in the last two VE setups. A total of ten QTVR self-panning panoramic nodes were created. The panoramas created in the previous stages were wrapped into QTVR movies using VR Work 2.6. A self-rotating 'sprite' was then added to each QTVR using Vrhotwires 2.5. This sprite automates each QTVR movie to rotate 360 degrees from the right to the left. It was set to start rotating from the mid-point in between the first and last path choice in the node (random assignment of first path choice). This mid-point view was employed as the starting point of rotation, as a precaution, to eliminate the possibility of unequal exposure time given to the first initial path choice compared to the remaining available path choice. The next section illustrates the creation of testing environments with decreasing level of VC.

Chapter 5

Methodology II: Testing Environments with Diminishing Levels of VC

5.1 Background

Two other sets of the ten QTVR environments were created. They represent two lower levels of VC, for a total of three sets of VE, each differing in levels of VC. They are Photorealistic (R level), Architectural (A level), and Outline (O level) QTVR environments. These levels are an adaptation of the surface complexity levels used in Stamps' study on visual preference (1999). We created these additional environments to test the overall strength of SC on pedestrian path choice behaviour, by verifying if path choice behaviour changes as the number of visual elements within the scene is reduced. We will define the terms used; provide a in-depth explanation of the logic behind these three sets of VE, and explain the process in creating the two additional sets of VE, A level and O level.

5.2 Definitions of the Levels of VC

The terms and definitions of the three level of VC employed are the following:

1 - **R level** - Shows the actual QTVR environment, and all VC stimuli that are present at that place and time.

2- **A level** - Shows the geometric layout of the built space, the fenestration of the buildings, and the ground plane.

3- **O level** – Only shows the geometric layout of the built space, and the ground plane.

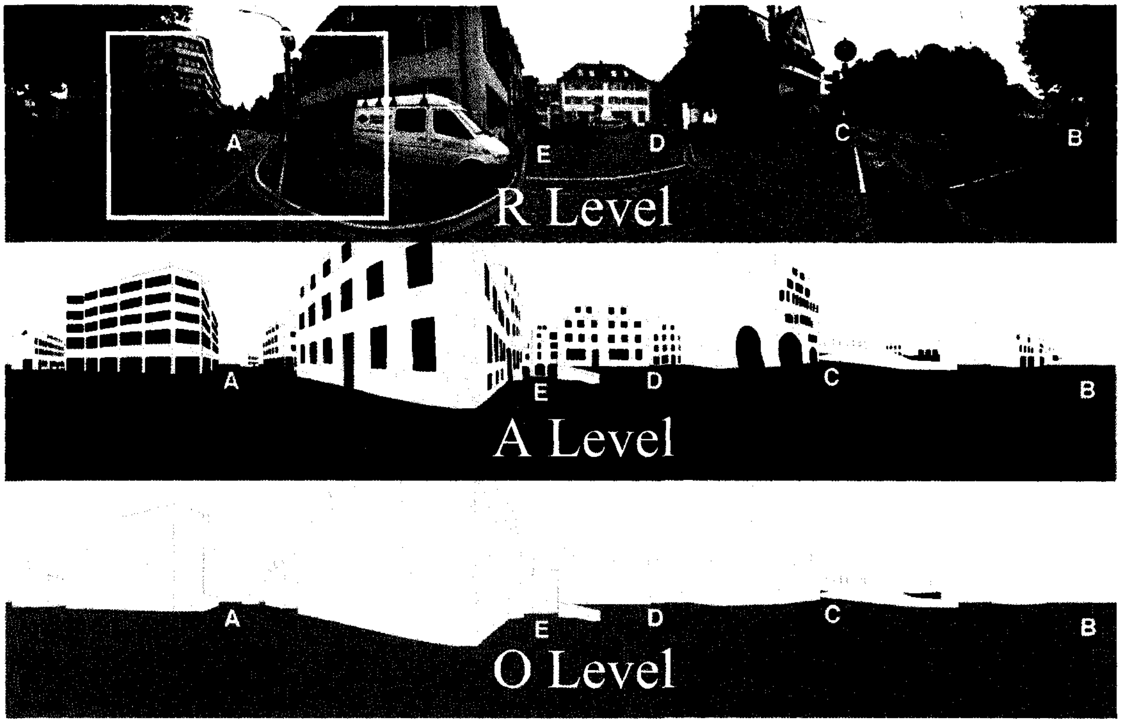

Figure 7. QTVR Movie view (represented by white boarder above)
VC panoramic images (R level, top; A level, middle; and O levels, bottom)

5.3 Levels of VC Environments

The three sets of VE with decreasing levels of VC test the effects of VC and SC on pedestrian path choice behaviours. Stamps (1999) showed that façade surface complexity was an important factor in building preference. We have adapted his surface complexity measure to create the three levels of VC, to test whether path choice behaviours are related to the amount of VC present in each path. If our path choice behaviours are only explained by SC, theoretically the path choice behaviour should stay constant across these three levels of VC, for the SC rating for each path does not change within each level. If path choice behaviours do change, then it suggests that VC measures do have an effect on pedestrian path choice behaviours. We have employed three levels to verify whether the O level, which has no reference of scale, can communicate the SC of the environment. The A level, therefore, verifies whether massing and scales are necessary to understand the structure of the environment. In this case, where the R level and A levels are more similar than the O level, it would suggest that the O level lacks the intelligibility of scale and function. If the path choices selected within the R level are significantly different from both those of within the A level and O level then it suggests that VC factors that are present in the R level is causing these changes, hence affecting path choice behaviour.

5.4 Tracing Protocol

We traced the ten QTVR panoramic images with two sets of tracing protocol to create the two VEs with different levels of VC: the A level contains a moderate level of visual information while the O level contains the least level of information. The only difference in the two tracing protocols is the tracing of the fenestration of the facades, which provides a reference to the mass of the buildings present in the VE in the A level. As one moves from the higher level of VC toward the lower level of VC, the scene is stripped away from the VC stimulus, which may affect a pedestrian's path choice behaviour. At the O- level, only the geometric and structural elements of the scene are left. The VC stimuli present within each VC levels, R, A, O is listed in Appendix 2. Figure 8 shows the process of tracing the building and fenestrations of node 2.

The A level and O level were produced following the tracing protocols described below:

A Level Tracing Protocol

1. All fenestration of the buildings that were bigger than 20 pixels in width or in height are drawn; represented by black polygons
2. All structural faces, larger than 40 pixels in width or in height, are drawn; represented by light grey polygons
3. Roof, ledges, and balconies along the paths were drawn as long as rule 1 held true.
4. All landmarks were drawn, represented by blocks of equivalent sizes.
5. Roads and sidewalk were not drawn.
6. The horizon was drawn with the ground plane represented by a dark gray polygon.

O Level Tracing Protocol

1. All structural faces, larger than 40 pixels in width or in height, are drawn; represented by light grey polygons
2. Roof, ledges, and balconies along the paths were drawn as long as rule 1 held true.
3. All landmarks were drawn, represented by blocks of equivalent sizes.
4. Roads and sidewalk were not drawn.
5. The horizon was drawn with the ground plane represented by a dark grey polygon.

Figure 8. Tracing of A level and O level for Node 2.

Chapter 6

Methodology III: Experimental Setup

In this experiment, a total of 84 student participants were divided into three testing groups. Each testing group had a different Virtual Environment (VE) setup. The three VE setups are listed in Table 1, along with the total number of participants for each environment.

	VE Setup	# of Participants
1	Photorealistic panorama print Individual setting	30
2	Photorealistic QTVR Group setting	26
3	Photorealistic QTVR Individual setting.	28

Table 1. VE Setup and Number of Participants

Before we present the setup of each testing group, the following briefing statement was used:

> You are exploring the environment for the first time. With that in mind, please choose your most preferred path, for each of nodes that are presented. With the provided response sheet, mark in the blank spaces the letter that corresponds to your choice for each node.

This briefing statement helps to imposes two conditions: one, a diversive mindset for task; two, similar testing conditions, with the exception of the independent variables. The tone of the briefing statement seeks to induce a diversive mindset, by instructing the participant to *explore* the unfamiliar environment for the *first* time. Diversive mindset increases participant's attention to the visual characteristics of the scene, for participants are more likely to scan the environment for elements that draw their attention and choose their path choice based on those same criteria, rather than seeking out information to complete a task, which an instrumental mindset would prompt (Heath, 1989). Inducing this mindset helps to efficiently test the effect spatial visual characteristics have on exploratory path choices. The briefing instruction also holds many testing conditions constant, so that changes in Path choice behaviour can be confidently linked to the independent variables to be tested, and limits other external factors. The importance of this will become apparent when we look at the analysis sections for this experiment. Now we move onto the VE setups used and their differences.

6.1 Virtual Environment (VE) Setup

There are three VE setups tested this study: photorealistic panoramic print, QTVR group, and QTVR individual. Each VE setup is presented below with the following structure: the testing protocol, testing environment, and advantages and disadvantages.

6.1.1 Panoramic Print

Testing Protocol

Thirty participants were tested individually. The participants were recruited on the 7th floor of the Hall building, with one condition; they had never been to Freiburg. Participants were first presented with an answer sheet and then the examiner would read the briefing statement out loud. The ten panoramic images were shown, one at a time. Participants were allowed to look at the image for as long as they needed to make their path choice decisions. Only after their decision was made, was the next node shown. This was repeated until a path choices preference was expressed for each node.

Testing Environment

A booklet was used as the testing medium for environment. The booklet was made up of ten R level panoramic prints bound together. These prints were each printed containing millions of colors at a resolution of 300 dpi on 11" by 17" paper. The panoramas were presented in random order.

Advantages and disadvantages

Advantages:

- Photographic prints have been shown to be a reliable representation of the real environment
- Testing can be performed at any location
- Panoramic prints are high in quality

Disadvantages:

- Choice points are in the far background and much smaller then QTVR VE; therefore, choice point and content are not as visible as the VR self-panning panoramas.

6.1.2 QTVR Group

Testing Protocol

Twenty-six participants were tested in a group setting. The participants were registered in a university course on a related topic, Environment and Behaviour. All had never been to Freiburg. Participants were first presented with an answer sheet and then the examiner read the briefing statement out loud. The three sets of QTVR VE were presented in the following order: A level, O level, and R level. Each of the QTVR VE sets was presented in random order. Participants were shown each QTVR VE node twice.

Testing environment

The three sets of QTVR VE (ten of the R level, ten of the A level, ten of the O level) were tested in this VE setup. Each node was presented as a self-panning QTVR movie. The area of view for each QTVR movie was 1200 x 800 pixels. The testing medium was projected on a 60” x 80” screen. Each movie was shown at a resolution of 1200 x 800 pixels. The white box in figure 3 shows the area of the panorama that was viewable from the QTVR movie at any one time.

Advantages and Disadvantages

Advantages:

- Large sample collected at one time
- Classes are easily arranged for testing
- High visibility of projection screen
- Controlled Environment

Disadvantages:

- Group dynamics
- Resolution dependant on projector specifications
- Different angles of view for each subject

6.1.3 QTVR Individual

Testing Protocol

Twenty-eight participants were recruited on the 12th floor of the Hall building. The participants were chosen with one condition; that they had never been to Freiburg. Participants were individually tested in a controlled room setting. Participants were first presented with an answer sheet and then the examiner read the briefing statement. The three sets of QTVR VE were presented in the following order: A level, O level, R level.

In that order, participants were shown each QTVR VE. Each node was presented twice. The nodes in each set of QTVR VE were presented in a random order.

Testing environment

The three sets of QTVR VE (Ten of the R level, ten of the A level, ten of the O level) were test in this VE setup. Each node was presented as a self-panning QTVR movie. The area of view for each QTVR movie was 1200 pixels wide by 800 pixels tall. The testing medium was displayed on a 21" Apple cinema display screen with 1600 x 1024 pixels and millions of colors. Each movie was shown at a resolution of 1200 x 800 pixels. The white box in figure 3 shows the area of the panorama that was viewable from the QTVR movie at any one time.

Advantages and Disadvantages

Advantages:

- High resolution screen
- Individual testing
- Same viewing environment (angle, distance, lighting)

Disadvantages:

- Sample data collection time

Chapter 7

Data Analysis & Conclusions

There are two main levels of analysis here: 1–Validity of VE setup for testing pedestrian path choice behaviour; 2–SC and VC effects on pedestrian path choice behaviour. Each of the levels of analysis will be presented alongside their results. They are presented in this format to avoid confusion.

7.1 Virtual Environment (VE) Setup Testing

The first examination of VE setups tested whether or not different setups resulted in different path choice behaviour. We compare the distribution of path choice behaviour of each of the three pairs of the VE environments. These three comparisons are listed in Table 2. If the distributions of path choice behaviours for each pair of testing environments are significantly different, then these changes in preference can be explained in terms of the independent variable, that is the differences between the testing setups. In comparison 1 and 2, the difference is the VE type: Panoramic Print and QTVR movies. Meanwhile, in comparison 3, the difference is the sampling method, that is whether participants were tested in a group or individual setting.

Comparison	Name	Description
A	Print VR vs. QTVR Group	Panoramic Print compared to QTVR Movie within a group testing setting (VE type)
B	Print VR vs. QTVR Ind.	Panoramic Print compared to QTVR Movie within a individual testing setting (VE type)
C	QTVR Group vs. QTVR Ind.	QTVR Movie within a group testing setting to QTVR Movie within a individual testing setting (Group vs Individual testing)

Table 2. Comparisons of testing setups

Hypothesis

The Null hypotheses and hypotheses for testing both independent element testing in the experiment on VE testing setup are listed below:

VE Type

Null Hypotheses 1-2

$H1_0$ - There are no significant differences between Print VR and QTVR Group.

$H2_0$ - There are no significant differences between Print VR and QTVR Ind.

Hypotheses 1-2

$H1_1$ - There are significant differences between Print VR and QTVR Group.

$H2_1$ - There are significant differences between Print VR and QTVR Ind.

If there are significant differences in comparisons 1 and 2, it would suggest that VE Type used in the testing setup does have an effect on the participants' path choice behaviour within the study, whereas no significant differences would suggest no such effect.

Group versus Individual Sampling method

Null Hypothesis 3

$H3_0$ - There are no significant differences between QTVR Group and QTVR Ind

Hypothesis 3

$H3_1$ - There are significant differences between QTVR Group and QTVR Ind.

If there are significant differences in comparisons 3, it would suggest that testing in a group or individual setup does have an effect on the participants' path choice behaviour within the study, and no significant differences would suggest such effect.

To prove the likelihood of each hypothesis statement, we must confidently reject their matching null hypothesis statements. We employed four tests to verify the possibility of rejecting the null hypothesis statements. These tests check for the internal validity of VE setups within this experiment. Each of the four tests defined below are applied to the three comparisons outlined in Table 2.

Analysis

Test 1

The first test was a two-tailed bi-variate correlation test, which tests the strength of the similarity of the path choices distributions of each pairing of VE testing setups. This test gives us a general idea of the type of relationship between the environments. If there is no correlation between the two environments, then we can stop at this level of testing. However, if there is a correlation, then it only tells us that the distributions of path choices among nodes are similar, but it is not fine enough to suggest that all nodes are the same.

Test 2

Second, we perform a comparison of the nodes with significantly preferred paths. If these significantly preferred paths are the same, then the differences in VE setup compared do not affect pedestrian path choices; however, if these path preferences are different then the differences in VE setup compared do affect pedestrian path choices. The first step of this test identifies the nodes with significant path preferences. A chi-square test is used. This identifies a significantly different distribution of path choice behaviour that is not likely to have happened by chance. This significant distribution shows that preferences exist in the node for a particular path or paths within that node. Then all the nodes with significant path choices in both VEs are compared. The nodes are then analyzed to verify whether or not these nodes have the same preferences of path. The ratio of similar versus different preference of path choices shows the level of the effect of either the VE type or the sampling method. If there are many differences within the set, then the effect is great; if there are few within the set, then the effect is small.

Test 3

This test verifies the strength of the relationship between two testing environments. On this multinomial distribution data set we used a Chi-squared test of independence to establish the strength of the difference among each pair of nodes. The Chi-squared test of independence is similar to the Chi-squared test, with one difference: the expected value is calculated differently. The expected valued used is the mean of the observed values of the two compared VE setup. This analysis gives us the number of nodes that are significantly different. The ratio of nodes with significantly different distribution over all nodes shows the effect of VE type and group versus independent response setting on pedestrian path choice behaviour. If there are many differences within the set, then the effect is large; if there are few within the set, then the effect is small.

Results – Virtual Environment Setup Testing

A- Print VE versus QTVR Group

Test	Results
1	**R = 0.72**
2	**Six nodes** comparable significant nodes identified. **Two of the six** show changes in preference. Therefore, the null hypothesis **is rejected, two of six times, thirty-three per cent of the time**.
3	**Three nodes** are significantly different Therefore, the null hypothesis is rejected **three of ten times, thirty per cent of the time.**

B- Print VE versus QTVR Individual

Test	Results
1	**R = 0.52**
2	**Six nodes comparable significant nodes** identified. Two of the six **show changes in preference.** Therefore, **the null hypothesis is rejected, two of six times, thirty-three per cent of the time.**
3	Three nodes are significantly different. Therefore, the null hypothesis is rejected **three of ten times, thirty per cent of the time.**

C - QTVR Group versus QTVR Ind.

Test	Results
1	R = **0.646**
2	**Five nodes comparable significant nodes** identified. One node of five **shows changes** in path preference. Therefore, **the null hypothesis is rejected one of five times, twenty per cent of the time**
3	**Three** nodes are significantly different. Therefore, the null hypothesis is **rejected three of ten times, thirty per cent of the time.**

Table 3. VE Setup Testing Summary

Type of VE

The type of VE used–print VE or QTVR within the VE testing setups–shows a medium-size effect on pedestrian path choice behaviour (Cohen, 1988). The combination of the three tests used to analyze the data shows this relationship. Test 1 shows the correlation value ranging from 0.52 to 0.72; therefore, the null hypothesis cannot be rejected. Test 2, however, in both comparisons 1 and 2, the null hypothesis can be rejected 33% of the time, since two out of six nodes show a significant change in participants' path choice behaviours. In test 3, also for both comparisons, the null hypothesis can be rejected thirty per cent of the time, since three of the ten nodes show a significant change in the participants' path choice behaviours.

Group and Individual Response Setting

There is a medium-size effect for group and individual response settings on participant path choice behaviour (Cohen, 1988). The combination of the three tests used to analyze the data shows this relationship. Test 1 shows a correlation factor of .65, so the null hypothesis cannot be rejected. Test 2 shows that the null hypothesis is rejected twenty percent of the time, since one of the five nodes show a significant change in the participants' path choice behaviour. Test 3 show that the null hypothesis can be rejected 30 percent of the time, since three nodes show significantly change in participants' path choice behaviour.

Conclusion

Both VE setup independent variables, type of VE, and Group versus individual sampling method, have a medium effect on participant path choice behaviours within this study (Cohen, 1988). It is important to further study their effects in future experiments on path choice behaviour, since studies that do employ such VE setups without controls for them, may lose much power and not be able to reliably detect the effect of their independent variables.

7.2 VC and SC effects on Path Choice Behaviour

There were a total of fifty-four participants in the two QTVR environments used in this level of analysis. Twenty-six participated in the first group (QTVR group) and twenty-eight participated in the second (QTVR individual). Since, the findings in the first level of analysis of the data show that group or individual VE setups affect path choice behaviour, the data cannot be amalgamated. Therefore, each data set was individually analyzed. The two main questions in this level of analysis were the following: Do path choice behaviours remain the same when VC is stripped away from the testing environments? Do the VC and SC measurements defined in this study have a significant relationship with path choice behaviours?

Given that this part of the experiment held two main queries, the experiment was divided in two. The first section was a comparison of path choice behaviours in different VC-level VE Environments. The second deals with SC and VC measures and measures their effect on path choice behaviour. The sections are presented with the following structure: research question, null hypothesis and hypothesis, analysis, results and conclusion.

7.2 a VC and Path Choice Behaviour

Does VC affect path choice behaviours? If path choice behaviours for the R level testing environment are the same as the A level and O level testing environments, then it would show that VC factors have no effect on path choice behaviour but, if they are not the same, then it would show that VC factors do have an effect. A comparison of the path preferences expressed by the participants in each VC level environment, listed in Table 3, identified whether or not VC affects path choice behaviours.

Comparison	Description
A	R- level versus. O- level. (Greatest VC change)
B	Real VC level vs. Architectural VC level. (Mid VC change)
C	Architectural VC level vs. Outline VC level. (Smallest VC gap)

Table 4. Comparison of VC levels

Hypothesis

The following are the null hypothesis and hypothesis statements for this study:

Null Hypothesis 1-3

HA_0 - There are no significant differences between R level and O level.

HB_0 - There are no significant differences between R level and A level.

HC_0 - There are no significant differences between A level and O level.

Hypothesis 1-3

HA_1 - There are significant differences between R level and O level.

HB_1 - There are significant differences between R level and A level.

HC_1 - There are significant differences between A level and O level.

Each null hypothesis must be confidently rejected. Therefore, we employed a step of three tests to validate whether or not each null hypothesis could be put aside with a p value of 0.1. Each of following tests was run for each of the paired testing environments as listed in Table 4.

Analysis – VC levels

Test 1

The first test was a two-tailed bi-variate correlation test, which tests the strength of the similarity of the path choices distributions of each pairing of VE testing setups. This test gives us a general idea of the type of relationship between the environments. If there is no correlation between the two environments, then we can stop at this level of testing. However, if there is a correlation, then it only tells us that the distributions of path choices among nodes are similar, but it is not fine enough to suggest that all nodes are the same.

Test 2

Second, we perform a comparison of the nodes with significantly preferred paths. If these significantly preferred paths are the same, then the differences in VE setup compared do not affect pedestrian path choices; however, if these path preferences are different then the differences in VE setup compared do affect pedestrian path choices. The first step of this test identifies the nodes with significant path preferences. A chi-squared test is used. This identifies a significantly different distribution of path choice behaviour that is not likely to have happened by chance. This significant distribution shows that preferences exist in the node for a particular path or paths within that node. Following this, all the nodes with significant path choices, in both VE, are compared. The nodes are then analyzed to verify whether or not these nodes have the same preferences of path. The ratio of similar versus different preference of path choices shows the level of the effect by the reduction of VC between the environments. If there are many differences within the set, then the effect is great; if there are few within the set, then the effect is small.

Test 3

This test verifies the strength of the relationship between two testing environments. On this multinomial distribution data set we used a Chi-squared test of independence to establish the strength of the difference among each pair of nodes. This test used the mean value from the distribution of path choices from each matching node in the VE setup comparison, which was the expected value. The distribution of path choices for each node for each environment was the observed value. This analysis gives us the number of significantly different nodes. The ratio of nodes with significantly different distribution over all nodes shows the strength of the effect of VE type used and group versus independent sampling method. If there are many differences within the set, then the effect is large; if there are few within the set, then the effect is small.

Results - VC levels

1 - R level and O level

Test	Results
1	**R = 0.66**
2	**Seven** comparable significant nodes identified **Three of the seven nodes** show **changes** in path preference. Therefore, the null hypothesis is **rejected** in **three of the seven times, twenty-nine per cent of the time.**
3	**Six nodes** are significantly different. Therefore, the null hypothesis is **rejected six of ten times, sixty per cent of the time.**

2- R level and A level

Test	Results
1	**R = 0.75**
2	**Nine comparable significant nodes** identified. **Four of the nine** show **changes** in path preference. Therefore, the null hypothesis is **rejected** in **four of nine times, forty-four per cent of the time**
3	**Three** nodes are significantly different. Therefore, the null hypothesis is **rejected three of ten times, thirty per cent of the time.**

3 - A level and O level

Test	Results
1	R = **0.88**
2	**Seven** comparable significant nodes identified **Three of the seven** show **changes** in path preference. Therefore, the null hypothesis is **rejected** in **three of the seven times, twenty-nine per cent of the time**
3	**Three** nodes are significantly different. Therefore, the null hypothesis is **rejected three of ten times, thirty per cent of the time.**

Table 5. Result summary QTVR Group VC Level

1 - R level and O level

Test	Results
1	R= **0.55.**
2	**Five** comparable significant nodes identified **Two of the five** show **changes** in path preference. Therefore, the null hypothesis is **rejected** in **two of five times, forty per cent of the time**.
3	**Six nodes are significantly different.** Therefore, the null hypothesis is **rejected** in **six** of **ten times, sixty per cent of the time**.

2- R level and A level

Test	Results
1	R= **0.646.**
2	**Four** comparable significant nodes identified **None of the four** show **changes** in path preference. Therefore, the null hypothesis cannot **be rejected.**
3	**Four nodes** are significantly different. Therefore, the null hypothesis is **rejected four** of **ten times, forty per cent of the time.**

3 - A level and O level

Test	Results
1	**R = 0.88.**
2	**Eight** comparable significant nodes identified **Two of the eight** show **changes** in path preference Therefore, the null hypothesis is **rejected** in **two of eight times, twenty five per cent of the time**
3	**Two** nodes are significantly different. Therefore, the null hypothesis is **rejected** in **two of ten times, twenty per cent of the time.**

Table 6. Result summary QTVR Individual VC Level

QTVR Group: VC level analysis

The results of the comparison with the largest gap between VC levels, between the R level and the O level, show the largest difference in path choice behaviour. At this level, the lowest bi-variate correlation is.65, but also the highest chance of rejecting the null hypothesis in test 2 is found at 29% and test 3 at 60%. The mid- and lower-sized gaps between the levels of VC diminish the difference in path choice behaviour, when compared with those present in the R level and O level comparison. In the R level and the A level comparison, the bi-variate correlation increases to 0.75 and the rate of rejecting the null hypothesis drops in both tests: in test 2 to 44%, and test 3 to 30%. In the A level and O level comparison, the bi-variate correlation increases to 0.88 and the rate of rejecting the null hypothesis drops in both tests:, in test 2 to 29%, and test 3 to 30%.

QTVR Individual Setting: VC level analysis

The results of the comparison with the largest gap between VC levels, between the R level and the O level, show the largest difference in path choice behaviour. At this level, the lowest bi-variate correlation of .55 is found, but also the highest rate of rejecting the null hypothesis in test 2, at 40% and test 3 at 60%. The mid- and lower- sized gaps between the levels of VC diminish the difference in path choice behaviour, compared with those present in the R level and O level comparison. In the R level and the A level comparison, the bi-variate correlation increases to .65 and the rate of rejecting the null hypothesis drops in both tests: in test 2 to 0%, and test 3 to 40%. In the A level and O level comparison, the bi-variate correlation increases to 0.88 and the rate of rejecting the null hypothesis drops in both tests: in test 2 to 25%, and test 3 to 20%.

General: VC levels

Two general trends suggest that VC elements do affect path choice behaviour in both the group and individual QTVR VE setups. These two trends are related to the size of gap between the VC levels. The first trend is shown in test 1, where the bivariate correlation value gets stronger as the gap between VC-level decreases. The bivariate correlation increases from an R-value of 0.65 to and 0.88 in the QTVR group, while the bivariate-correlation increases from an R-value of 0.55 to 0.88 in the QTVR individual test.

The second trend is that as the higher the likelihood of rejecting the null hypothesis for both test 2 and 3, the greater the gap in VC level, with just one exception. The exception is in QTVR individual setup, test 2 of the R level and A level comparison, where the likeness of rejecting the null hypothesis is zero. This exception, however, may be explained by the reduced amount of comparable significant nodes. In the R level and A level comparison in QTVR individual setup, where there are only four comparable significant nodes, all sharing the path choice behaviour, five of the remaining six nodes express different path preferences.

Conclusion

Both SC and VC were found to influence path choice behaviours. Overall, VC had a moderate to large effect on path choice behaviour (Cohen, 1988). As the levels of VC increase, the likelihood of rejecting the null hypothesis increases, to a maximum of

60%. With this finding it is possible to infer, that while SC does have a large effect overall, VC still has a significant role to play in our path choice behaviours (Cohen, 1988). Since both SC and VC factors play a role in pedestrian path choice behaviour, it would be important to continue this line of research to isolate the particular SC and VC elements and find their specific role in this cognitive process.

The differences present in the participants' behaviours between the A level and the O level suggest that the VC information that is present in the A level, mainly the doors and the fenestration opening, that are missing in the O level, have a significant effect on pedestrian path selection. Hence, the massing and the scale of the buildings that are present in the environment are an important element in pedestrian path choice behaviour. This is an interesting finding that warrants more clarification and further studies.

Given the low power level of the QTVR individual setup, it would be a good candidate to increase the sample size and follow up this portion of the study, since many of the nodes seem to be lacking participants to reach statistical significance in expressing a preference in path.

7.2 b Measures of SC and VC and their effect on Path Choice Behaviour

The next query of the study tests the effects of the highlighted SC and VC measurements on path choice behaviours expressed in the two testing environments. The protocol for each SC measurement and its calculations are defined below, followed by the null hypothesis and hypothesis for each of these measures. In turn, the same can be done for the VC measures. For a more complete definition of each term, please consult the literature review section on SC and VC measures, which defines each term and explains the expected direction of the relationship expressed in the hypothesis statements.

Assessment of SC and VC Measure Protocol and Hypothesis Statements

Protocol for SC measures

Figure 9. Diagram of SC Measures

Angle of View – The angle of view that each path choice takes of the 360 deg view of the panoramic image. (Figure 9)

Isovists – The viewshed area of each path choice. This was calculated using the two-dimensional plan view of the CAD map provided by the city of Freiburg, where each of the axis points for each node was marked. (Appendix 5)

Openness/Enclosure - The amount of sky that is visible in each path choice area. (Figure 9)

Adjusted Openness/Enclosure – The amount of sky that is visible in each path choice minus the greenery in the foreground.

Occluded edges – Number of visible edges that hide a part of the scene.

Links – Number of links that are seen in the area of the path choice.

Path Legibility – defined by three interval states:

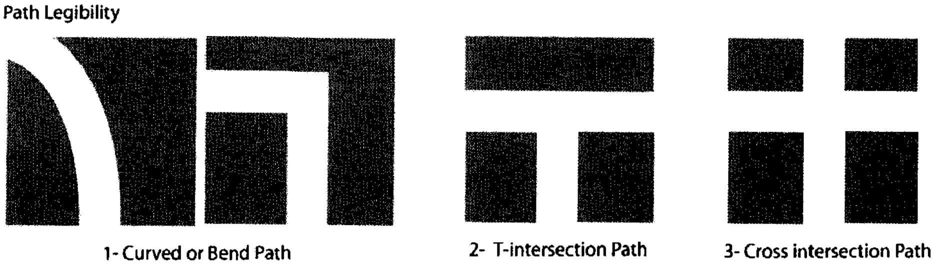

Figure 10. Path Legibility

1- *Curved path*, which shows a view of the curving path ahead, with no visible end leaving much information about the path to be inferred. It is not possible to visually confirm the number of possible path choices available.
2- *T-intersection*, which shows two visible links, with no visible information about the paths themselves, but still contains more legibility and requires fewer inferences than the curved path.

3- *Cross intersection*, which shows three or more links and contains the most legibility of the environment ahead and the least number of inferences that need be made about the paths that lie ahead.

SC Null Hypotheses and Hypotheses

SC Null Hypotheses and Hypotheses for Experiment 2 are listed below. The level of significance is set at $p < 0.1$ for a one tailed test, where p is set at <0.1 for these factors are in preliminary stages to establish an effect size for further testing.

H-S1_0 – There is no significant positive relationship between path choice behaviours and Angle of View measure.

H-S1_1 – There is a significant positive relationship between path choice behaviours and Angle of View measure.

H-S2_0 – There is no significant positive relationship between path choice behaviours and Isovist measure.

H-S3_1 – There is a significant positive relationship between path choice behaviours and Isovist measure.

H-S3_0 – There is no significant positive relationship between path choice behaviours and Openness/Enclosure measure.

H-S3_1 – There is a significant positive relationship between path choice behaviours and Openness/Enclosure measure.

H-S4_0 – There is no significant positive relationship between path choice behaviours and Adjusted- Openness/Enclosure measure.

H-S4_1 – There is a significant positive relationship between path choice behavioursand Adjusted- Openness/Enclosure measure.

H-S5_0 – There is no relationship positive between path choice behaviours and Occluded Edges measure.

H-S5_1 – There is a relationship positive between path choice behaviours and Occluded Edges measure.

H-S6_0 – There is no significant positive relationship between path choice behaviours and Link measure.

H-S6_1 – There is a significant positive relationship between path choice behaviours and Link measure.

H-S7_0 – There is no significant relationship between path choice behaviours and Legibilitys measure.

H-S7_1 – There is a significant relationship between path choice behaviours and Legibility measure.

Protocol for VC measures

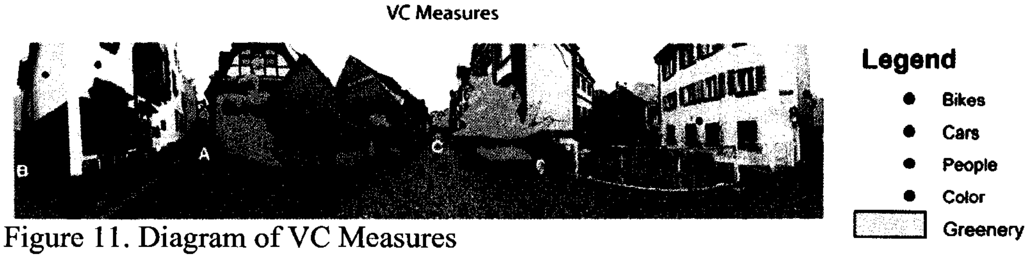

Figure 11. Diagram of VC Measures

Cars – Number of visible cars in each path choice's area.

People – Number of visible people in each path choice's area.

Bicycles – Number of visible bikes in each path choice's area.

Greenery – Amount of area that the greenery covers in each path choice.

Façade Colour – Number of visible changes in façade colors on each path choice's area.

Cobblestone – Number of visible kinds of cobblestone treatment in each path choice's area. They consist of three levels:

0- no cobblestones,

1- one type of cobblestone treatment of street,

2- two types of cobblestone treatment of street.

Signs – Presence of signs in path choice area:

0- signs are not present.

1- signs are present.

VC Null Hypotheses and Hypotheses

VC Null Hypotheses and Hypotheses for Experiment 2 are list below, the level of significance is set at $p < 0.1$ for a one tailed test, where p is set at <0.1 for these factors are in preliminary stages to establish an effect size for further testing.

H-V1_0 – There is no significant positive relationship between path choice behaviours and Car Presence measure.

H-V1_1 – There is a significant positive relationship between path choice behaviours and Car Presence measure.

H-V2_0 – There is no significant positive relationship between path choice behaviours and People presence measure.

H-V2_1 – There is a significant positive relationship between path choice behaviours and People presence measure.

H-V3_0 – There is no significant positive relationship between path choice behaviours and Bicycle presence measure.

H-V3_1 – There is a significant positive relationship between path choice behaviours and Bicycle presences measure.

H-V4_0 – There is no significant positive relationship between path choice behaviours and Greenery measure.

H-V4_1 – There is a significant positive relationship between path choice behaviours and Greenery measure.

H-V5_0 – There is no significant positive relationship between path choice behaviours and Façade Color measure.

H-V5_1 – There is a significant positive relationship between path choice behaviours and Façade Color measure

H-V6_0 – There is no significant positive relationship between path choice behaviours and Cobble stone measure.

H-V6_1 – There is a significant positive relationship between path choice behaviours and Cobble stone measure.

H-V7_0 – There is no significant positive relationship between path choice behaviours and Signs presence measure.

H-V7_1 – There is a significant positive relationship between path choice behaviours and Signs presence measure.

Analysis

Bi-variate Correlations

First a bi-variate correlation analysis was run between each measure and path choice distributions for each of the two setups and for each the VC levels. This test identified the factors that were related to path choice behaviour. R level holds both VC and SC measures within each path choice, so all the variables were analyzed, while the A level and O level, stripped of VC only holds the SC measures within each path choice, so only those elements were analyzed. A bi-variate correlation of the visual factors was also included to look at the potential of visual factors that are not independent of one another.

Multiple Regression

Multiple Regression was employed for three reasons: 1- to find a significant model to describe path choice behaviour, 2- to identify the strength and significance of the factors that affect path choice behaviour, 3- to correct for possible partial correlations and co-variance among measures. All factors were included in the multiple regression models in the R level environment, since it holds both the measures of VC and SC within each path choice. In the multiple regression analysis for the A level and O level only the SC measures were used since the VC content has been removed from the environments. If VC has no effect on path choice behaviours, then there should be no change in the regression models between the R level and A or O level models, since only SC factors should be salient in all the models. If this is not the case then VC had an effect on pedestrian path choice behaviour.

Results

Bi-variate Correlation

The table 7 summarized the bi-variate correlation results, which only shows the variables that have a significant correlation with path choice data. The complete bi-variate correlation tables are presented as appendix 6.

Table 7. Table of bi-variate analysis, significant measures of SC and VC

VE Setups	**Independent Variables**	**R value**
Group R level	*Occluded Edges*	.33**
Individual R level	*Occluded Edges*	.28*
	Isovist	-.28**
	Cars	-.22*
	Bicylces	-.23*
	Cobble	.25*
Group A level	*Occluded Edges*	.25*
Individual A level	*Occluded Edges*	.37**
	Isovist	. 21^{ns}
Group O level	*Occluded Edges*	.38**
Individual O –level	*Occluded Edges*	.29**

*$p < 0.1$, ** $p<0.05$, ns = near significant

Multiple Regression Analysis for Factors in the Environment

The tables below show the significant variables in the multiple regressions. The full multiple regression models are shown as Appendix 7.

Group *R level*

R = .785   R^2 = .616   p = .044

Variables	Std. Error	Beta	Sig[a]	Partial cor.
Angle of View	.451	-.458	.052*	-.420
Occluded Edges	.027	.408	.054*	**.416**
Legibility	.058	-.828	.005***	**-.575**
Color	.019	.432	.066*	**.399**
Cobble	.052	.417	.058*	**.410**
Signage	.094	-.386	.076*	**-.386**

Ind. *R level*

R = .756   R^2 = .572   p = 0.091

Variables	Std. Error	Beta	Sig[a]	Partial cor.
Occluded Edges	.027	.417	.061*	**.405**
Legibility	.060	-.520	.076*	**-.386**
People	.009	-.332	.093*	-.367
Color	.054	.555	.082*	**.378**
Cobble	.052	-.417	.020**	**.493**
Signage	.097	-.531	.024**	**-.479**

Table 8. *R level* Multiple Regressions (Group and Individual)

a = Note: * = p < 0.1 ** = p < 0.05 *** = p < 0.01

Group *A level*

R = .573   R^2 = .328   p = .064

Variables	Std. Error	Beta	Sig[a]	Partial cor.
Occluded Edges	.035	.457	.036**	**.385**
Links	.083	.50	.087*	**.318**
Legibility	.068	-.723	.008***	**-.473**

Ind *A level*

R = .585   R^2 = .342   p = .051

Variables	Std. Error	Beta	Sig.	Partial cor.
Occluded Edges	.032	.483	.026**	**.407**
Links	.076	.403	.159[ns]	.264
Legibility	.063	-.689	.011**	**-.459**

Table 9. A level Multiple Regressions (Group and Individual)

a = Note: * = p < 0.1 ** = p < 0.05 *** = p < 0.01 ns = near significance

Group *O level*
R = .584 R^2 = .342 p = .052

Variables	Std. Error	Beta	Sig[a]	Partial cor.
Occluded	.033	.468	.030**	**.396**
Links	.079	.548	.059*	**.348**
Legibility	.065	-.658	.014**	**-.442**

Ind. *O level*
R = .551 R^2 = .304 p = .094

Variables	Std. Error	Beta	Sig[a]	Partial cor.
Occluded	.038	.448	.042**	**.373**
Links	.091	.511	.086*	**.319**
Legibility	.074	-.641	.020*	**-.424**

Table 10. O level Multiple Regressions (Group and Individual)
a = Note: * = $p < 0.1$ ** = $p < 0.05$ *** = $p < 0.01$

Conclusion

Bi-variate Correlation

Within the bi-variate correlation, we can identify that the SC elements are important factors in the pedestrian path choice selection process. The SC factors that show significant correlations at $p < 0.1$ include: occluded edges, which has a positive correlation value ranging from 0.25 to 0.37 that is present in all testing environments; and isovist, whose direction of correlation flip-flops from -.28 ($p< 0.1$) to .21(near significant) and is only present in the individual response setting of the R level and A levels.

Since only the R level VC environment contains VC factors, the R-level analysis shows the potential effects of VC. Within the R level environment, the individual response setting displayed effect of VC factors on path choice behaviour, which were the following where $p < 0.1$: Cars = -.22, Bicycles = -.23 and Cobblestones = .25.

Multiple Regression Model

The multiple regression models overall are quite strong at $p < 0.1$. The multiple regression model for the R level model explains 62 to 57 per cent of variance, since at the A level the variance drops from .34 to .32, and for the O level from .34 to .30. These results suggest that the reduction of the VC from environment reduces the model's strength. Without the VC factor the model gets weaker, hence VC variables affect path choice behaviour. If we were to estimate from the models above the variance attributed to the SC measures used within this study, it would be equal either to the A level or O level models, which would be approximately a variance of 30 to 35 per cent. This suggests that VC can potentially account for the remaining variance in the R level model, which would be a variance of 30 to 32 percent. This means that both SC and VC play a major role in path choice behaviour within this testing setup.

We further examine the multiple regression by looking at the partial correlation of each factor that is included in the model. The most significant factors across all levels of VC environment there are two significant SC factors: occluded edges, and legibility, whose coefficients are interesting. Occluded edges is quite strongly positive, while legibility is strongly negative, both of these values carried across all the testing environments and matching their hypothesis statements. The R level Multiple Regression model also shows three significant VC factors: colour, cobblestones and signage.

The multiple regression models of the R level for both the group and individual response settings show five common factors with significant correlations to the expressed path choices. Two are SC measures, occluded edges and legibility, while three are VC measures: colour, cobblestones, and signage. A summary of these findings is presented below organized by the VC level models. The factors that are not mentioned are not significant at a $p < 0.1$ and hence their null hypothesis cannot be rejected confidently.

R level – Both Response Groups

SC

-**Occluded Edges** shows a strong positive correlation value ranging from 0.416 to 0.405 in the R level. The null hypothesis for Occluded Edges is rejected and the hypothesis statement is accepted.

-**Legibility** shows a strong negative correlation value, ranging from -0.575 to -0.386 in the R level. The null hypothesis for occluded edges is rejected and **the hypothesis statement is accepted.**

VC

-**Colour** shows a strong positive correlation value, ranging from 0.399 to 0.378 in the R level. The null hypothesis for Colour is rejected and the hypothesis statement is accepted.

-**Cobblestones** show a strong positive correlation value, ranging from 0.41 to 0.493 in the R level. The null hypothesis for Cobblestones is rejected and the **hypothesis statement is accepted.**

-**Signage** shows a strong negative correlation value, ranging from –0.386 and -0.479 in the R level. The null hypothesis for Signage cannot be rejected since the direction of the relationship is opposite to that of the hypothesis, so the hypothesis statement is rejected.

R level - one Response group Two other factors, Angle of View and People, are also significant; however, only in one of the two R level response settings.

-**Angle of View**, which is significantly correlated in the R level group response setting, shows a correlation of -0.420. The direction, however, is opposite to its stated hypothesis; therefore, the null hypothesis cannot be rejected and the hypothesis statement is rejected.

-People, which is only significantly correlated in the individual response setting, shows a correlation of -0.367. The direction, however, is opposite to its stated hypothesis; therefore, the null hypothesis cannot be rejected and the hypothesis statement is rejected.

A level and O level

The Multiple regression models of the A level and O level for both the Group and Individual response settings show three common factors with significant correlations to the expressed path choices: occluded edges, legibility, and links.

-Occluded Edges shows a strong positive partial correlation value ranging from 0.407 to 0.373 in all the A and O level models. The null hypothesis for occluded edges is rejected and the hypothesis statement is accepted.

-Legibility shows a strong negative partial correlation value, ranging from -0.473 to –0.424 in all the A and O level models. The null hypothesis for legibility is rejected and the hypothesis statement is accepted.

-Links shows a strong positive partial correlation value, ranging from 0.348 to 0.318 in the three of the four models, with the exception of the A level individual response setting, which holds a non significant positive correlation value of .264. The null hypothesis for links is rejected in three of four testing environment and the hypothesis statement is accepted in those cases.

The bi-varite correlation of visual factors shows that these three factors are not completely independent of each other. The correlations for legibility with occluded edges and links are clearly positive, while the directions of their partial correlation point in different directions, where legibility is negative, occluded edges and links are positive. Even though these factors are not independent of each other in value, their differences in how they measure spatial properties are distinct enough that legibility is independent of occluded edges and link in how it affects path choice behaviour.

These results support the previous section's report on findings that both VC and SC have moderate to large effect on path choice behaviour (Cohen, 1988). Another interesting finding is that in the lower VC environment, A level and O level, where VC information has been removed, an additional SC factor–links–becomes significant, suggesting that if VC content is removed from or is not present within the pedestrian space more SC factors come into play in deciding one's path choice.

Chapter 8

Discussion

8.1 Virtual Environment (VE)

The two types of VE have a medium effect on our expressed pedestrian path choice behaviour (Cohen, 1988). This finding suggests that the utility for different VE environments is not equal. Future studies using these two types of VE to test spatial preferences need to be careful in selecting the type of VE that best suits their needs.

The photorealistic print environmentsp is said to have an increased "isovist depths" due to the flat representation of this type of VE (Franz and Wiener, 2007). Therefore as a research tool, it would be poor in measuring the effect of visual factors available in the space. For example, a car at the end of a path would look much farther away in the Photorealistic Print then it would in the QTVR VE. It may be more useful if used to measure the preference of the overall structure of the space and its layout, as in Kaplan's study (1988).

Comparatively, the QTVR VE should be a more reliable research tool to test for the effect of visual factors in behavioural testing, since the problems of different depth perception and the parallax that occurs with a photorealistic print is avoided. This type of VE has a high level of visual realism, with relatively low construction time in comparison with other VE. Overall, it is a good and flexible research tool for this type of research.

8.2 Group and Individual Settings

The comparison between the two sampling methods, group and individual setting, showed that testing environment has a large effect on pedestrian path choices (Cohen, 1988). Further testing is necessary to confirm this finding, as it suggests that the researcher must apply care with regards to response setting in the methodology of the experiment. If this holds, findings that are drawn from a group response setting should only be used to infer on DFT that is limited to groups, while findings drawn from individual testing setups only be used to infer on DFT that is limited to individuals. Expanding this question to all behavioural experiments should be pursued to better control the effects of response setting in such experimental setups.

8.3 SC and VC

There is much empirical data that support the notion that both SC and VC affect path choice behaviour. The multiple regression models suggest that the variance of VC is approximately 30 per cent, and that SC is also in the same range of 34 to 32 per cent. This suggests that SC and VC variable are closely matched in their effect size on path choice behaviour during the exploration of pedestrian environments. All levels of testing on SC and VC measures continue to reinforce this same finding. A number of SC and VC measures were significant in the bi-variate correlation and multiple regression analysis, showing the effect that SC and VC have over pedestrian path choice behaviour.

Two particularly strong SC measures are occluded edges and legibility. Together these SC variables could account for the whole of the SC variance detected by the multiple regression model. These two factors strongly support the theory of mystery, suggesting that exploratory motion is linked to constant information-seeking. Information-seeking acts in a way that verifies one's inferred information that they have extrapolated by the visual factors available in the space. The weaker factor, links, also can be used to convey this relationship. More links in the space ahead suggests that there is more potential information that could be encoded. But it is interesting how this factor only became significant after the VC factor was removed from the environment. This fact supports the idea of the hierarchical encoding of spatial information, as well as its employment in decision-making.

On the side of VC, colour, cobblestones, and signage were the significant variables. Colour and cobblestones are in line with their hypothesis statements. The materials and textures of the pedestrian space often frame or attach meaning to the environment and helps to differentiate one path from another (Baskaya, Wilson and Özcan; 2004). This finding gives weight to the argument that these heuristic elements not only give meaning to the spaces, but that these elements are encoded initially from the environment into our spatial representation of the environment. Therefore, schematic knowledge is derived from space, and encoded as part of our image of the space. These elements promote differentiation; so how important is it in an exploratory and diversive task? Does differentiation of spaces create more amicable pedestrian environments? Do transient elements add to the logic of the pedestrian environment; e.g. can these elements alone create a sense of place without any other visual characteristics?

These inquiries are the logical next steps. More studies are needed to better understand these complex relationships. Once we better understand the relationships, guidelines for the conception, creation and design of urban pedestrian spaces can be set forth. Planners, urban designers, architects, psychologists, and others interested in the development of pedestrian environment will then also have at their disposal tools to assess how SC and VC factors affect pedestrian dynamics. Such knowledge will empower cities and municipalities set on creating healthy and sustainable pedestrian developments that are feasible and functional.

8.4 Difficulties and Limitation

Overall, the difficulties and limitation of this project were three-fold: 1- possible fatigue of participants during experiment, 2- the lack of normal distribution of certain visual factor variables and 3 –time needed to create the VC levels.

Toward the end of the QTVR VE experiments participant showed visual signs of fatigue, especially within the O level environments. The O level environment, being stripped of all the visual data, was described as visually uninteresting and empty. If I were to do this test again, I would only used two levels of VC, and reduce the testing time by one third of the original.

Some of the visual factors did not have a normal distribution, which may have affected the statistical analysis of those particular factors, mainly the transient factors of cars and bicycles. At the time of the data collection for the VE creation, we wanted to retain the character of the space as much as possible, so we documented the environment as is without controlling for those visual factors. In future testing, it would be necessary to verify these elements in the setup process of the experiment to maximize the power and the strength of its statistical analysis.

Another element that was quite cumbersome was the time it took to create the VC level environment. Initially I wanted to use Adobe Illustrator CS's live trace function to create the VC levels, which would have taken only a batch script and the computer running overnight to produce, however, it was impossible to extract the building structure without the visual elements. The live tracing would have only reduced the VC factor by its colours; therefore, each image had to be traced by hand to create the VC levels, which was a lengthy and tedious process. For future studies that deal with this type of manipulation of the environment it may be worthwhile to spend some time and effort in finding an automated procedure that would produce such images.

Even with these difficulties, the findings and conclusion of this study are quite fruitful. It was a worthwhile venture and I have enjoyed the work and the process. I look forward to pursuing the demanding questions that this study leaves and to help instill the form of sustainable and healthy cities by first and foremost understanding the underlying relationships behind pedestrian behaviour and needs.

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Appendix 1

Assessment of VE as a Tool for Environment Behaviour Research

Assessment of Types of VE as a Path Choice Behaviour Research Tool

I. Objectives

The primary purposes of the study are to test the validity of VE as a research tool by determining whether virtual path choices are the same as those made in the actual environment. Secondly, to determine whether path choices made in a virtual environment are the same as those of the real environment.

II. Virtual reality (VE) in planning

There are many types of computer-based virtual representation of the real environment. The main differences of these VE are the construction methods, the level of realism, and the time needs for creation. They can be considered in three groups: Photo realistic image based VE, Digital Video Environment VE, and Computer Based VE.

A. Photo image based VEs

Photo realistic images scanned into the computer for projection are a widely used VE imaging tool, highly used as research environments in the past decade (Lange, 2001; Zacharias, 2000; Bishop, 1989). These photo-images are applied to show views of existing spaces and places. They are quickly produced a give a realistic view of space with pictures taken with digital cameras.

B. Video VEs

a. Video Recorded VEs

Video Recorded VE uses sequence of recorded video footage, from a digital video camera, of the real environment that mimics a walkthrough of the space.

b. Camera & scale model VE

This type of VE simulator uses digital video feed from a camera, set in a scaled model of a space, where a Head Mounted Display (HMD) is connected to the camera, the motion of the camera is linked to the head motion of the participant, and to move forward or backward is dependant on the click of the left or right button of the mouse.

C. Computer generated VEs

a. QuickTime VE Authoring Studio

A program called QuickTime VE Authoring Studio allows one to create a VE tour of a real environment, generating a QuickTime VE. A 360-degree view of an area is created by stitching 12 digital pictures together each taken at 30 degree from each other. These views and the choices within them are linked together so that individuals may navigate each space and proceed to the next one with the correct orientation.

b. 3D CAD VEs

There are different levels of 3D CAD that may be used to create VE simulations. Each requires different construction elements. The use of each is usually dependent on the initial goal of the simulation. These different models are as follows:

Wire-frame (WF), lowest level of 3 dimensional modeling, made up of the skeleton of the environment, as a series of vectors and points, where the vectors and points that would not normally be visible are hidden; Surface Model (SM), the same as the WF, but where the surfaces are painted with the colours of the modeled environment, the colours then can easily be manipulated later to test various design ideas; Combination of surface model images with scanned photographic images (COMB), integrates SM with photographic images, using them as a background. The SM model is cut and pasted into the digital images of an existing environment; Image Processing (IP), uses real images and builds model using those images as a base for the construction process. The images are manipulated using imaging programs such as Photoshop or Corel Draw. They borrow images and textures from the real world to make a highly realistic simulated model. IP is used especially where performance-task and navigation is a focus of the study. (Oh, 1994)

D. Reliability and validity of VE as a planning tool

VE popularity is increasing rapidly, and it seems to have many possible uses. Architect and planners are using such environments to help communicate their visions. It is a tool used to quickly assess the visual impact of new buildings or developments. Evaluation of the validity and the reliability of such VE is need; the use of these types of VE must be carefully considered for what they are intended to portray, for when used correctly these methods offer a wide variety of possible tools for visualizing the future environment (Oh, 1994). The question put forth is what are the limitations of each type of VE.

The high level of realism from Photo images VE gives high validity in representing what is viewed within the images. The high colour resolution and quality of images with little or no need of adjustment is the high point of this type of VE (Lange, 2001). A possible validity issue relates to the static image and pre-selected views taken by the camera. Results suggest that if participants are given full motion views that the paths selected may be different (Bishop, 1989). Digital video VE also has high level of realism, an important advantage of such a research tool, but the view of a camera is not exactly reflective of what is seen in a real space. The view is much narrower then that of human vision and there is the effect of lens distortions. Pre-arranged trip, set by the researcher, is seen limiting the amount and type of information that is available. This type of VE proves to be a useful tool for guided tours or for an introduction to the environment, but if the goal is to allow an open search of space, this type of VE hold many constraints and is difficult to manipulate (Norhara, 2002). The digital camera and scaled model VE contains high levels of realisms in both the motion and the views, but the realism of the image relies solely on the scale model. The drawback of this type of VE at the substantial initial cost (which includes, the camera setup, headset and scaled model) is also very time consuming to create (Soeda, 2002).

QuickTime VE offers an advantage of realism, which is quite high, by employing real pictures of the environment. This method allows one to view the space as they do in the real environment, maintaining a correct orientation when moving from node to node. The amount of time need to construct the environment is relatively short; it is dependant on the size of the area to be built. It requires only that at every intersection point, a set of 12 pictures to be taken. The computer program quickly creates 360-degree panoramic views of every intersection point within the site and connects all them together.

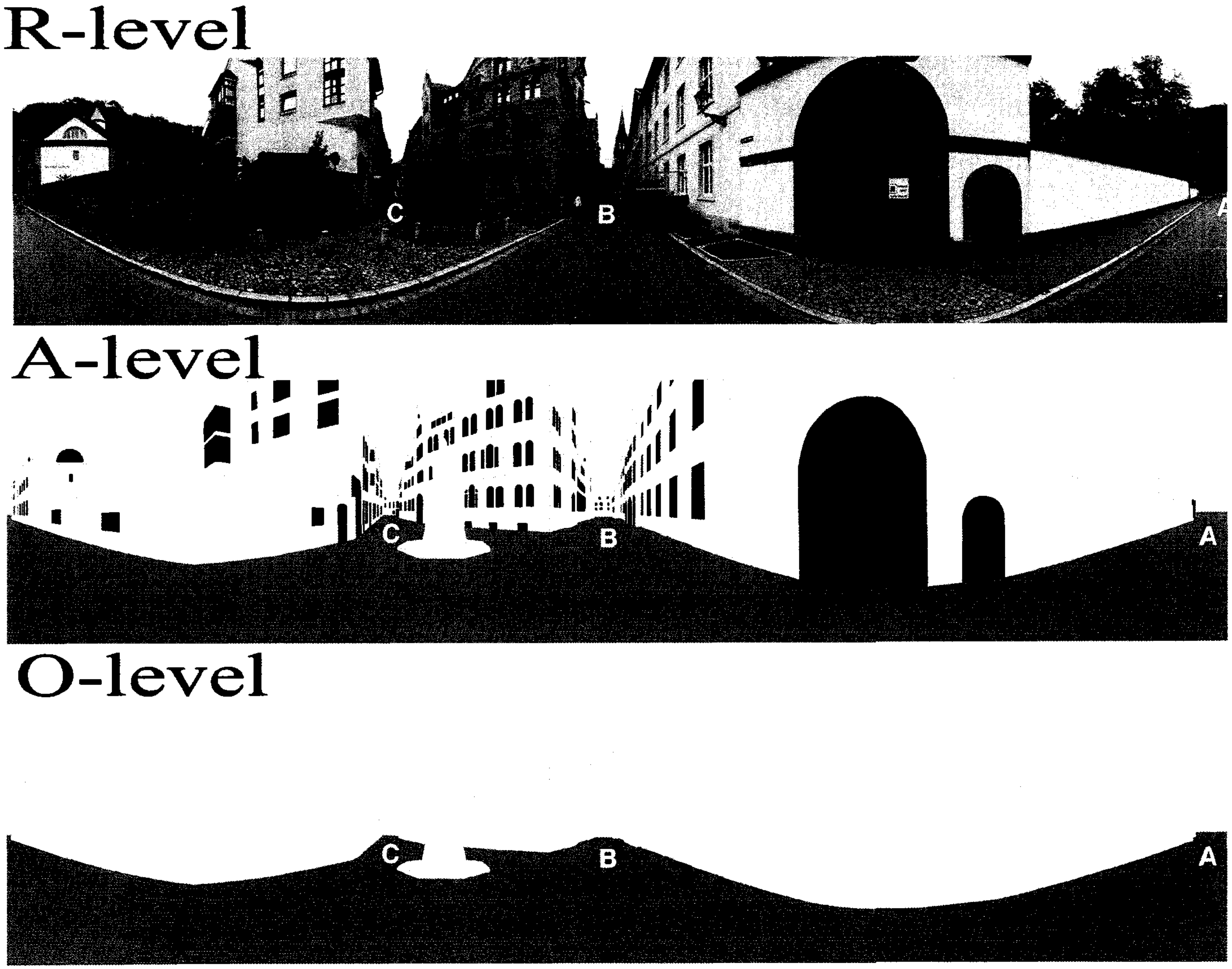
Out of all the types of 3D CAD VEs shown, IP is the most accurate and representative simulation of the real environment. Where the SM and Comb have almost similar results in how they represent the real world, they are still abstract, but more representative of the Real environment then that of the WF. SM and Comb VE may be useful when high levels of realism are not needed. The WF VE is the most abstract and lest representative of the real world.

From these evaluations, the type of research that is embarked upon, decides on the type of VE needed. VE is currently used for research on spatial behaviour and cognitive studies, which raises the question; how well does VE represent the real environment in these types of complex studies? This study focuses on this particular question, by comparing the same study conducting in the real and the VE environment, to confirm or reject the validity of VE as a research tool for spatial behaviour and cognitive studies. Our study suggests the use of QuickTime VE for two reasons: 1- it has a high level of realism and the correctly oriented view allows one to observe views of intersections as they would in the real space. 2- it is an economic choice in both time and cost.

Appendix 2

Nodes 1-10 Panoramic Prints
VC levels

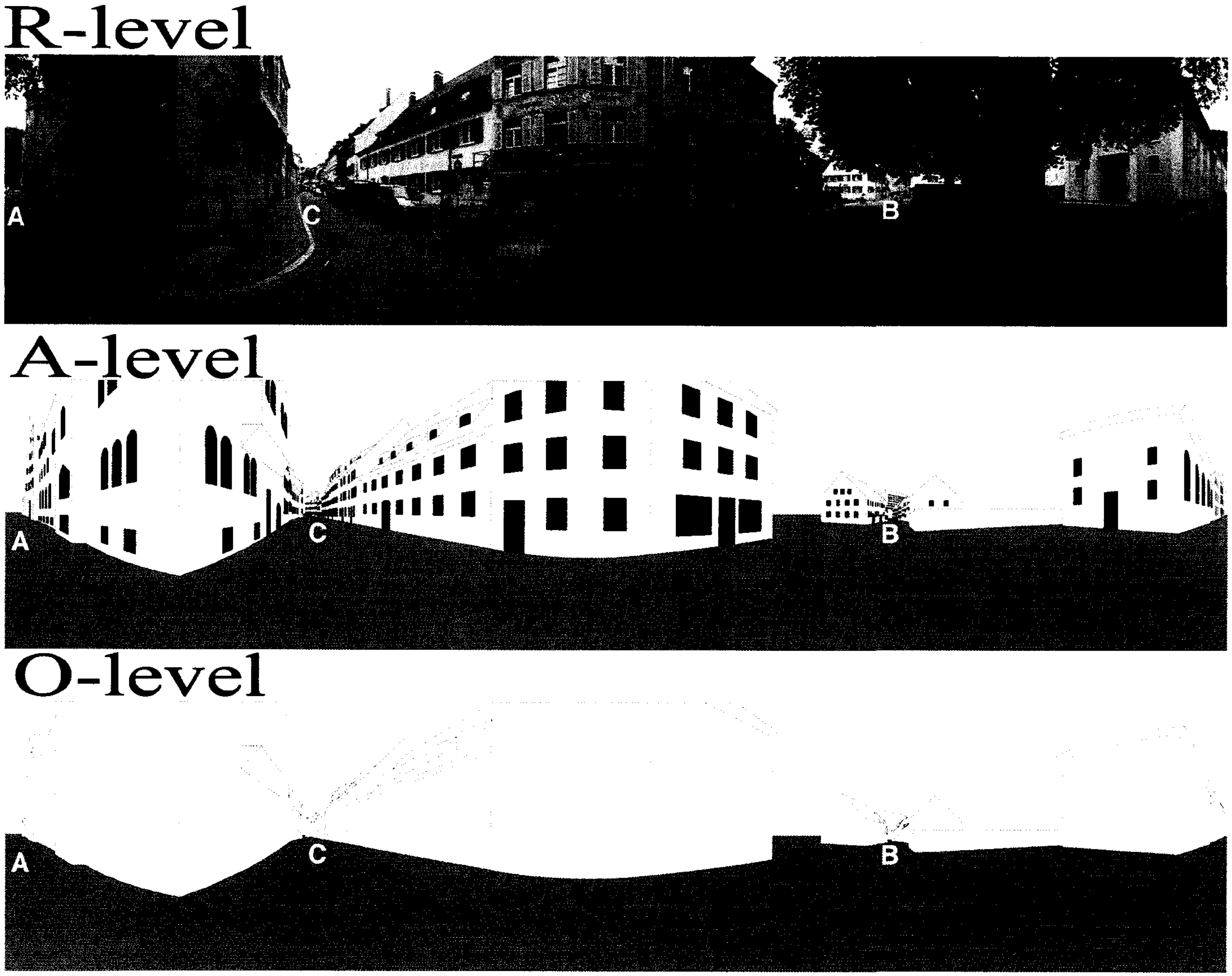
Node 1 - VC levels


R-level

A-level

O-level

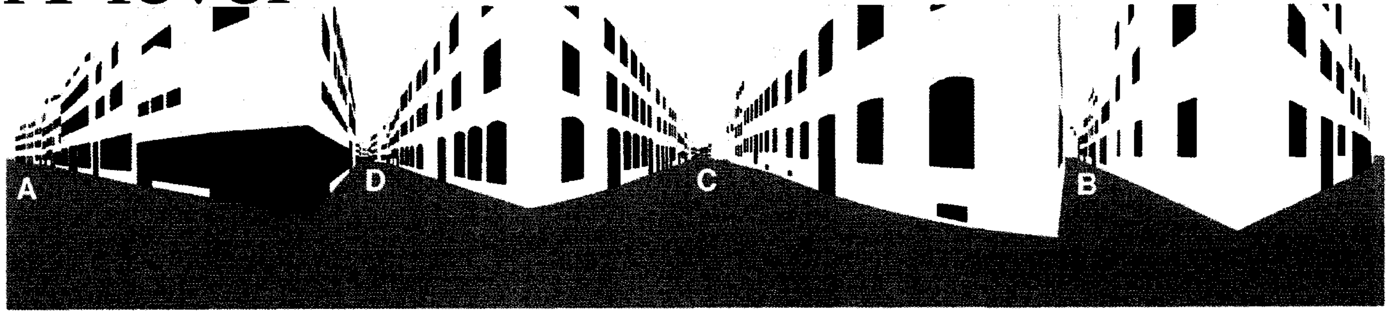
Node 2 - VC levels



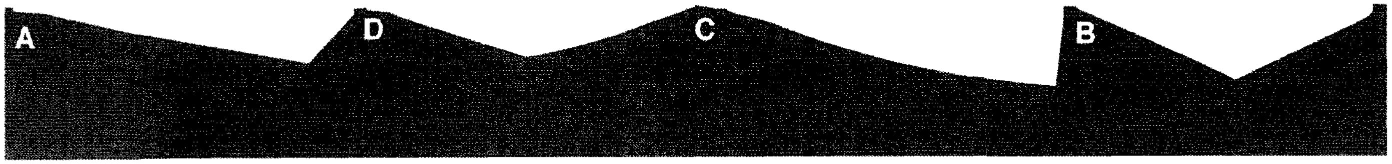
Node 3 - VC levels

R-level

A-level



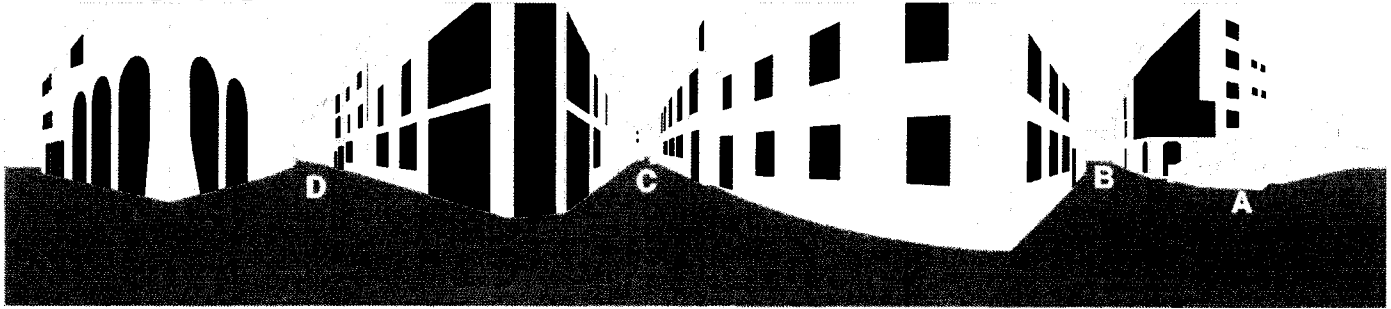
O-level



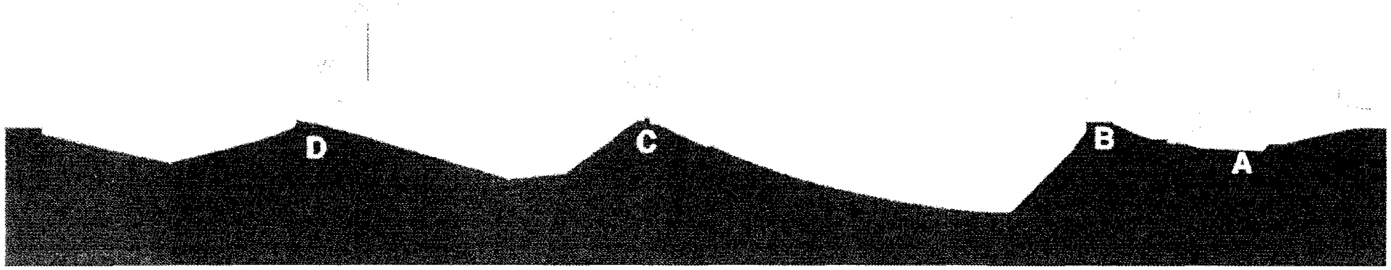
Node 4 - VC level

R-level

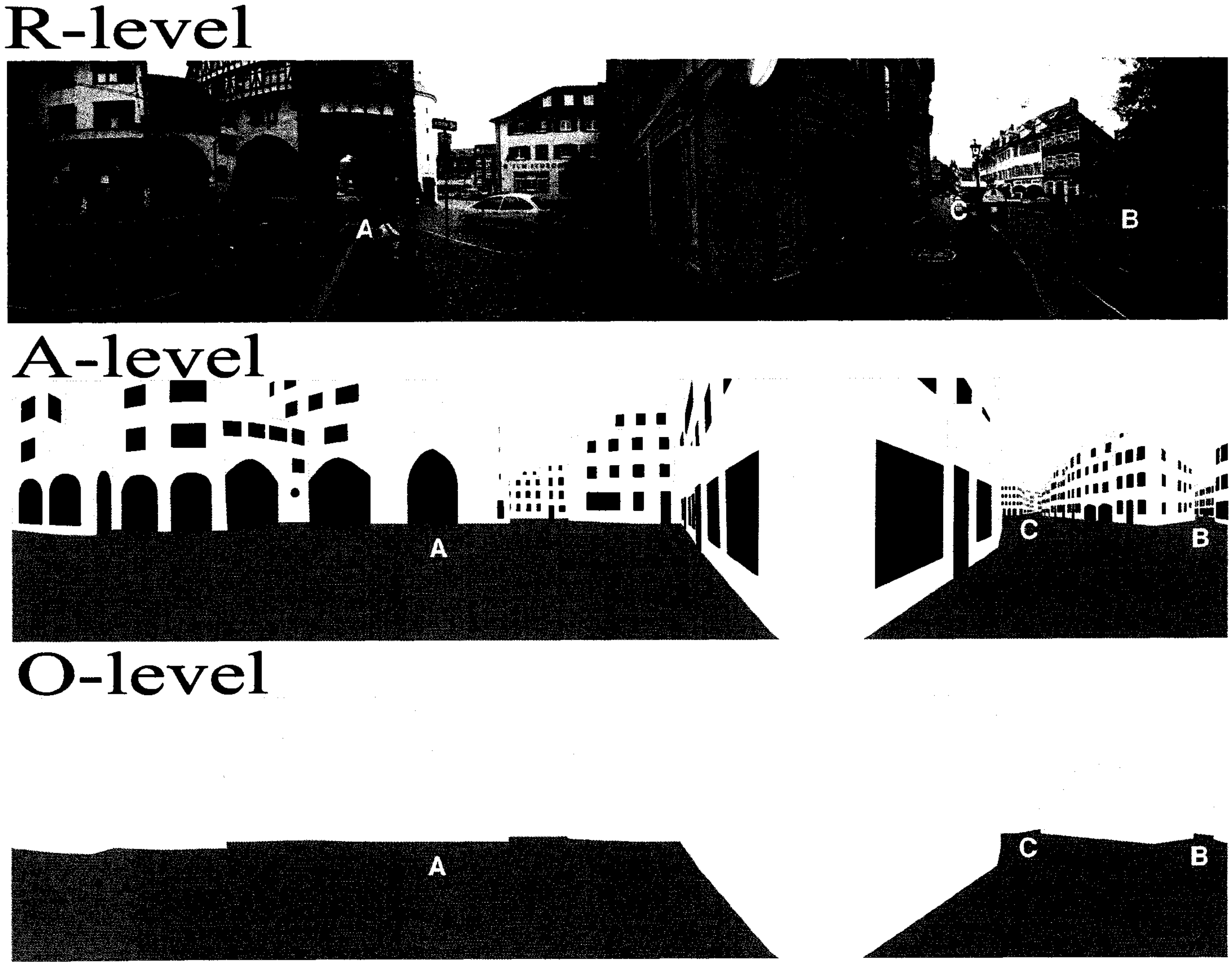
A-level



O-level

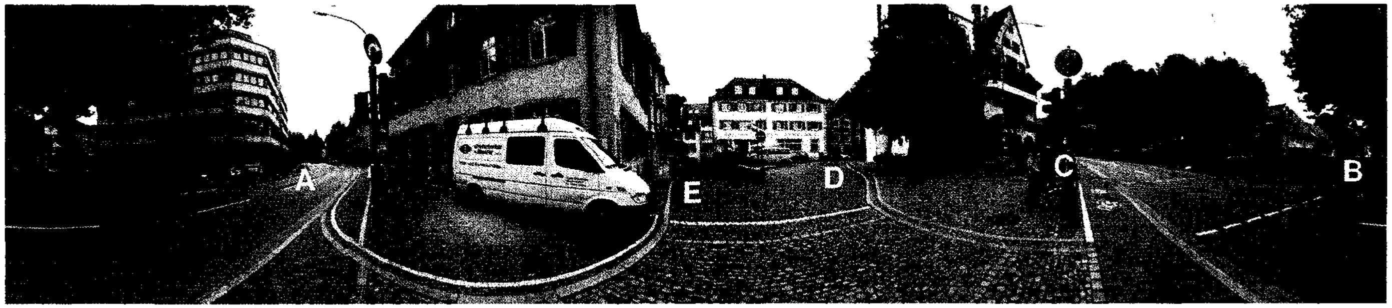


Node 5 - VC level

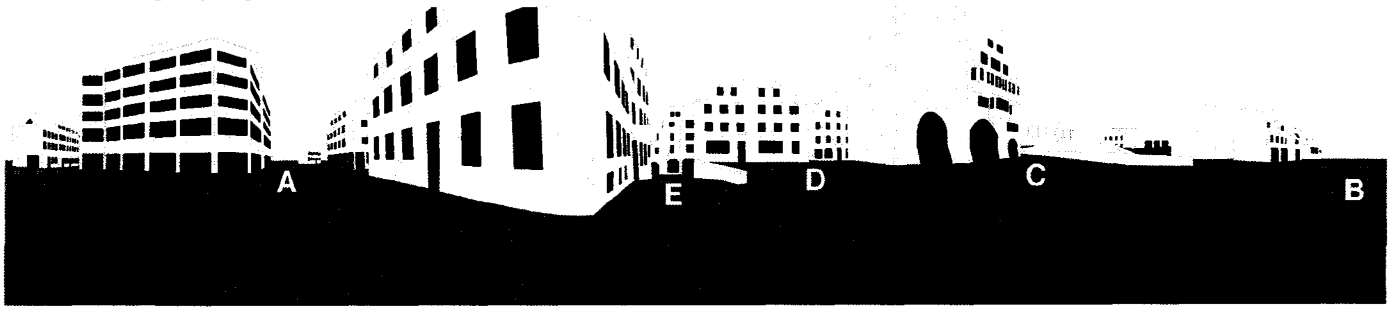


Node 6 - VC level

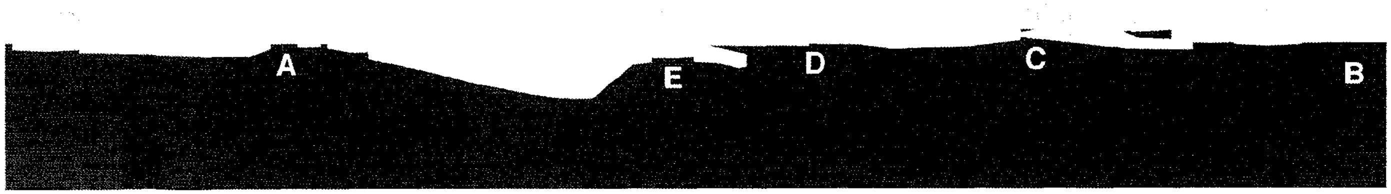
R-level



A-level

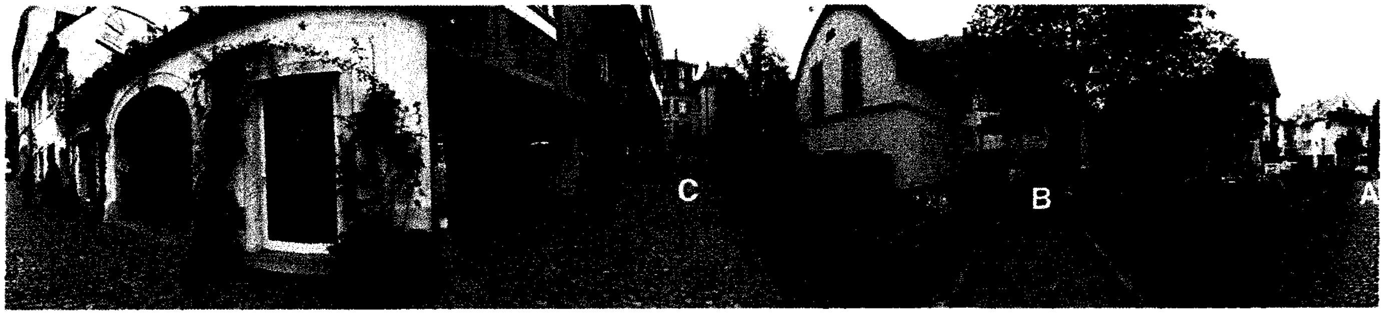


O-level

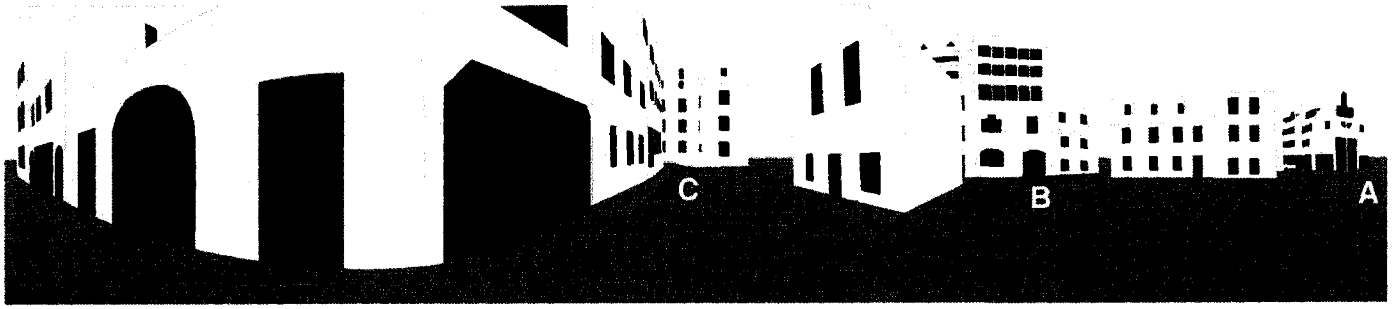


Node 7 - VC level

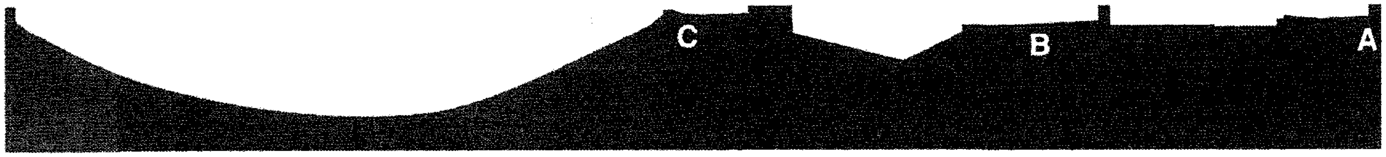
R-level



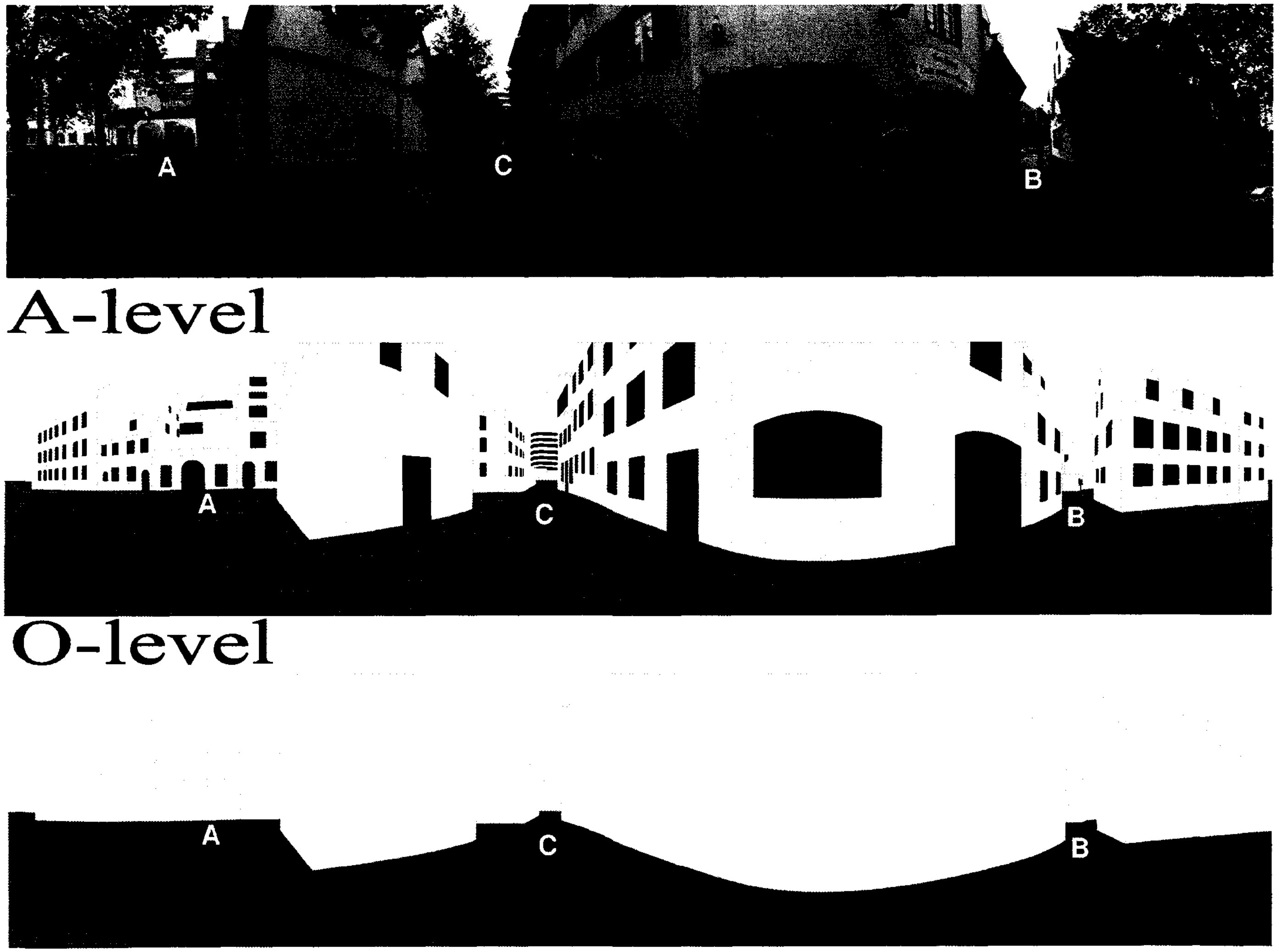
A-level



O-level



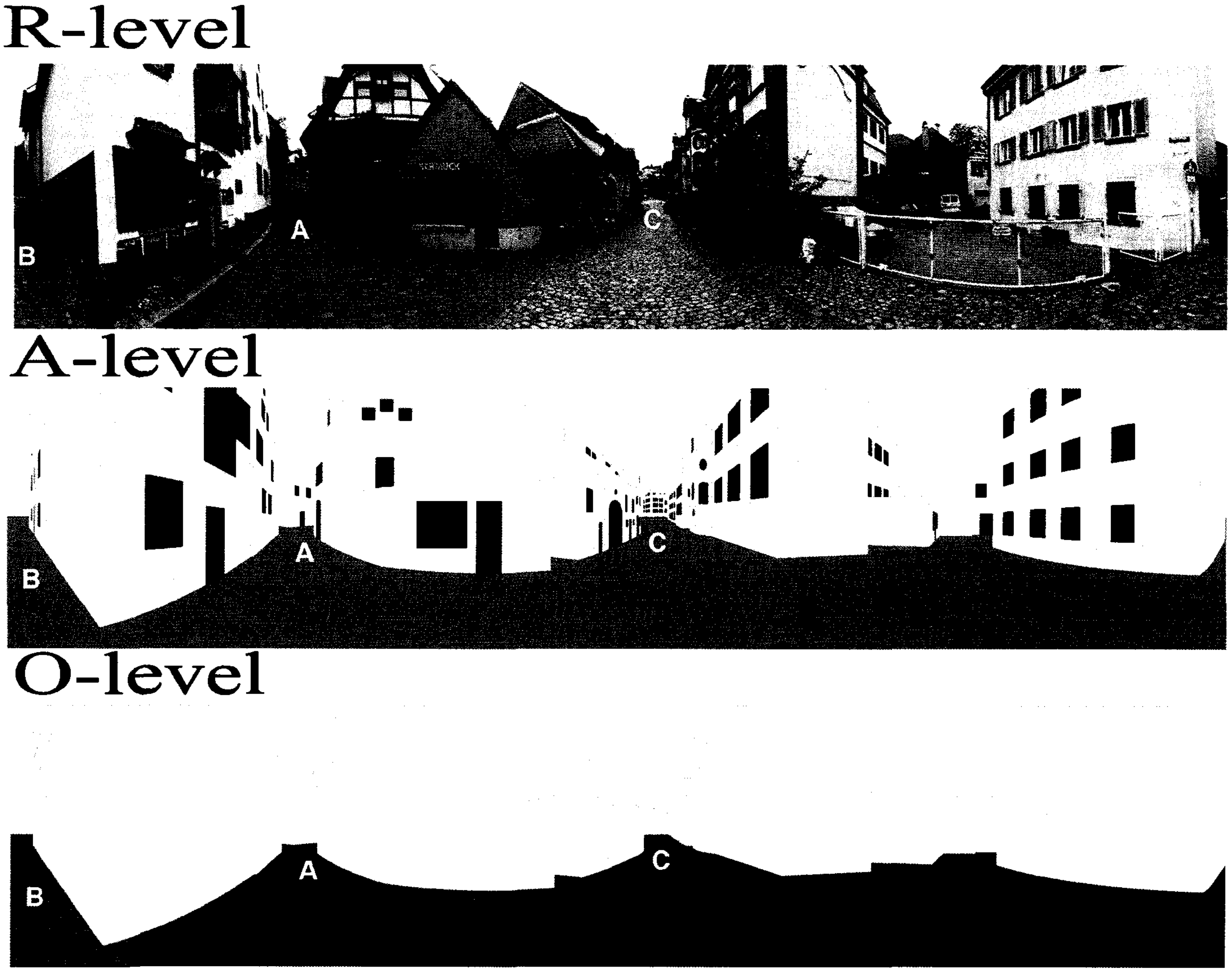
Node 8 - VC level


R-level

A-level

O-level

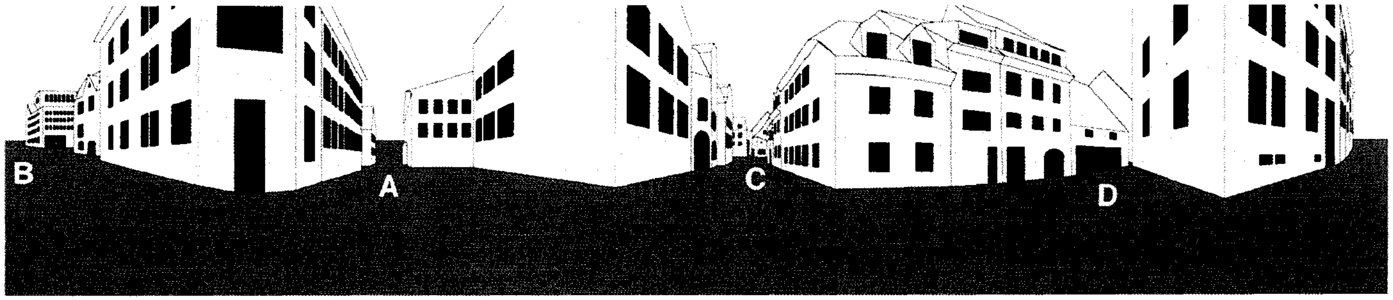
Node 9 - VC level



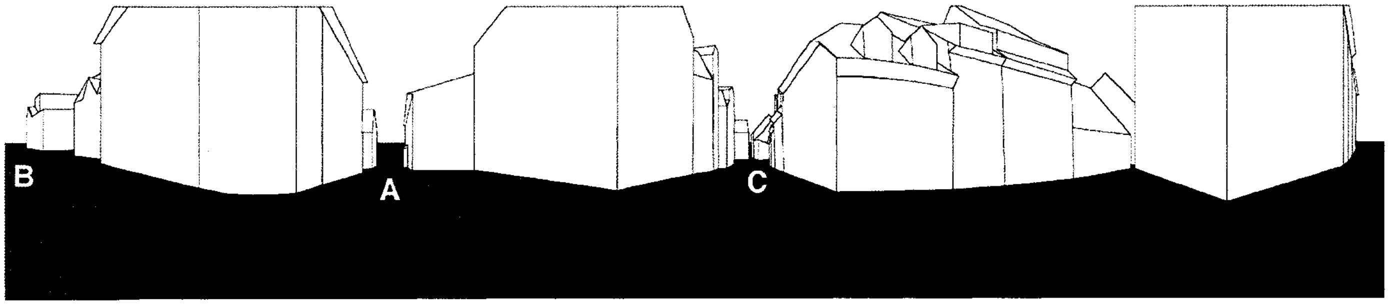
Node 10 - VC level

R-level

A-level

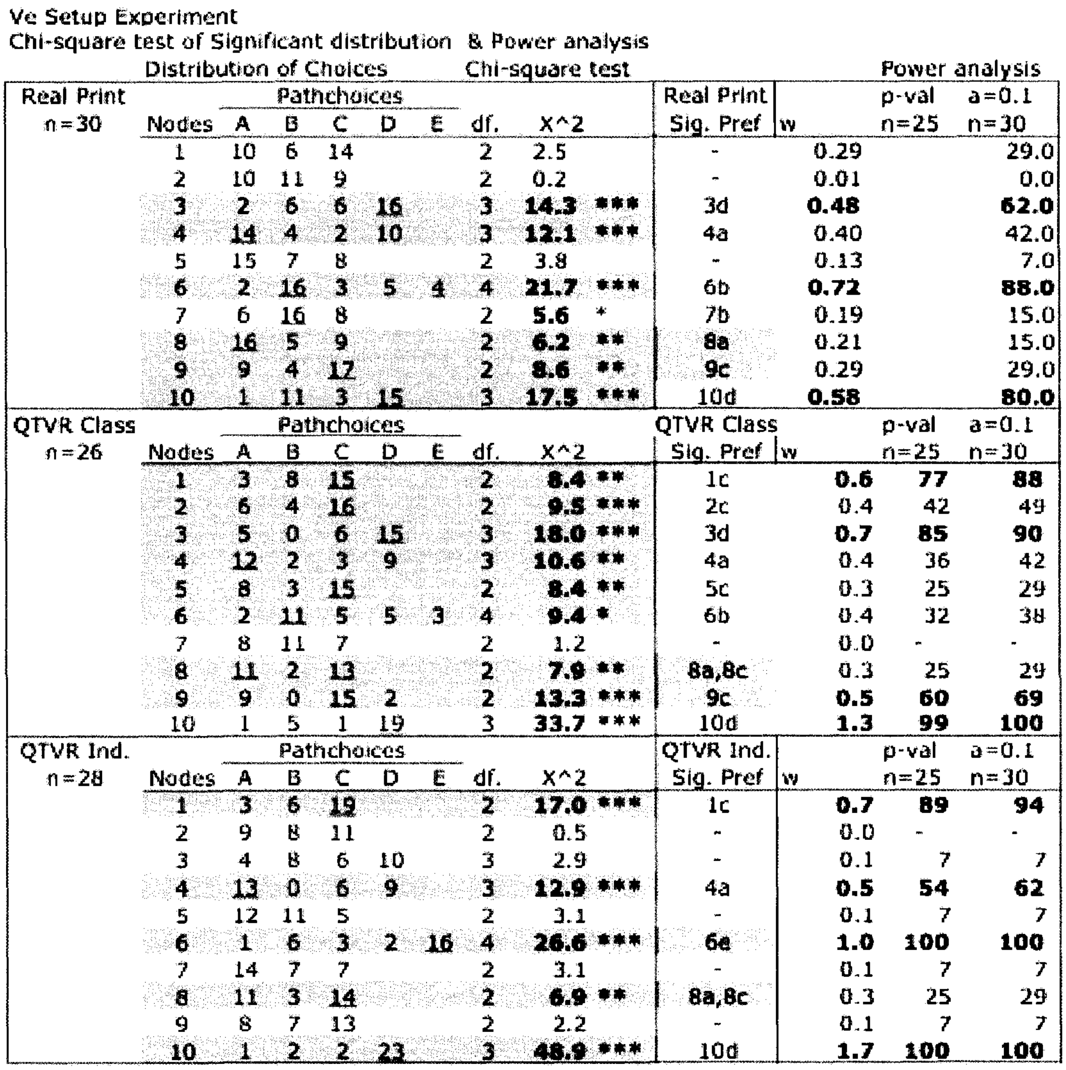


O-level



Appendix 3

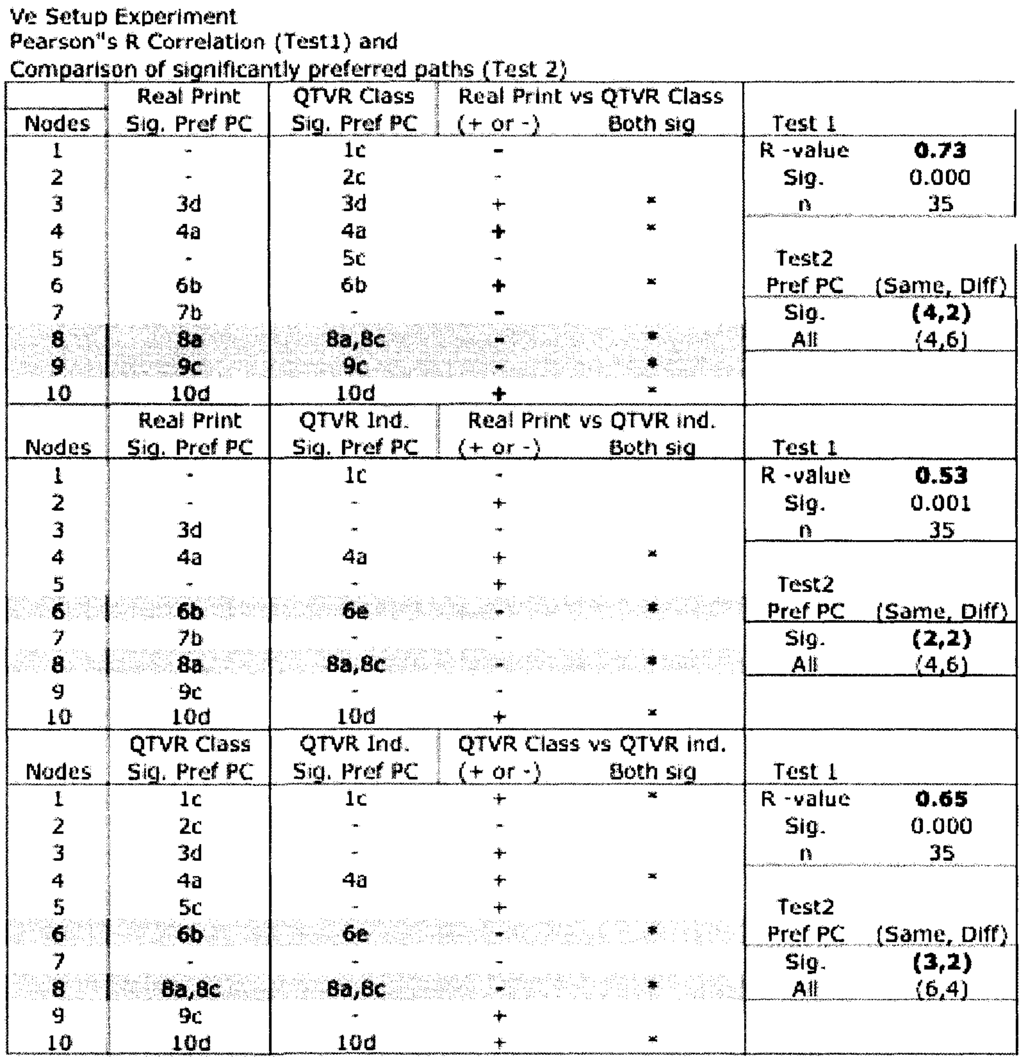
VC Testing Setup Analysis



Ve Setup Experiment

Chi-square test of Significant distribution & Power analysis

	Distribution of Choices						Chi-square test					Power analysis	
Real Print		Pathchoices								Real Print		p-val	a=0.1
n=30	Nodes	A	B	C	D	E	df.	X^2		Sig. Pref	w	n=25	n=30
	1	10	6	14			2	2.5		-	0.29		29.0
	2	10	11	9			2	0.2		-	0.01		0.0
	3	2	6	6	16		3	14.3	***	3d	0.48		62.0
	4	14	4	2	10		3	12.1	***	4a	0.40		42.0
	5	15	7	8			2	3.8		-	0.13		7.0
	6	2	16	3	5	4	4	21.7	***	6b	0.72		88.0
	7	6	16	8			2	5.6	*	7b	0.19		15.0
	8	16	5	9			2	6.2	**	8a	0.21		15.0
	9	9	4	17			2	8.6	**	9c	0.29		29.0
	10	1	11	3	15		3	17.5	***	10d	0.58		80.0
QTVR Class		Pathchoices								QTVR Class		p-val	a=0.1
n=26	Nodes	A	B	C	D	E	df.	X^2		Sig. Pref	w	n=25	n=30
	1	3	8	15			2	8.4	**	1c	0.6	77	88
	2	6	4	16			2	9.5	***	2c	0.4	42	49
	3	5	0	6	15		3	18.0	***	3d	0.7	85	90
	4	12	2	3	9		3	10.6	**	4a	0.4	36	42
	5	8	3	15			2	8.4	**	5c	0.3	25	29
	6	2	11	5	5	3	4	9.4	*	6b	0.4	32	38
	7	8	11	7			2	1.2		-	0.0	-	-
	8	11	2	13			2	7.9	**	8a,8c	0.3	25	29
	9	9	0	15	2		2	13.3	***	9c	0.5	60	69
	10	1	5	1	19		3	33.7	***	10d	1.3	99	100
QTVR Ind.		Pathchoices								QTVR Ind.		p-val	a=0.1
n=28	Nodes	A	B	C	D	E	df.	X^2		Sig. Pref	w	n=25	n=30
	1	3	6	19			2	17.0	***	1c	0.7	89	94
	2	9	8	11			2	0.5		-	0.0	-	-
	3	4	8	6	10		3	2.9		-	0.1	7	7
	4	13	0	6	9		3	12.9	***	4a	0.5	54	62
	5	12	11	5			2	3.1		-	0.1	7	7
	6	1	6	3	2	16	4	26.6	***	6e	1.0	100	100
	7	14	7	7			2	3.1		-	0.1	7	7
	8	11	3	14			2	6.9	**	8a,8c	0.3	25	29
	9	8	7	13			2	2.2		-	0.1	7	7
	10	1	2	2	23		3	48.9	***	10d	1.7	100	100



Ve Setup Experiment
Pearson"s R Correlation (Test1) and
Comparison of significantly preferred paths (Test 2)

	Real Print	QTVR Class	Real Print vs QTVR Class			
Nodes	Sig. Pref PC	Sig. Pref PC	(+ or -)	Both sig	Test 1	
1	-	1c	-		R -value	**0.73**
2	-	2c	-		Sig.	0.000
3	3d	3d	+	*	n	35
4	4a	4a	+	*		
5	-	5c	-		Test2	
6	6b	6b	+	*	Pref PC	(Same, Diff)
7	7b	-	-		Sig.	**(4,2)**
8	**8a**	**8a,8c**	**-**	*****	All	(4,6)
9	**9c**	**9c**	**-**	*****		
10	10d	10d	+	*		

	Real Print	QTVR Ind.	Real Print vs QTVR ind.			
Nodes	Sig. Pref PC	Sig. Pref PC	(+ or -)	Both sig	Test 1	
1	-	1c	-		R -value	**0.53**
2	-	-	+		Sig.	0.001
3	3d	-	-		n	35
4	4a	4a	+	*		
5	-	-	+		Test2	
6	**6b**	**6e**	**-**	*****	Pref PC	(Same, Diff)
7	7b	-	-		Sig.	**(2,2)**
8	**8a**	**8a,8c**	**-**	*****	All	(4,6)
9	9c	-	-			
10	10d	10d	+	*		

	QTVR Class	QTVR Ind.	QTVR Class vs QTVR ind.			
Nodes	Sig. Pref PC	Sig. Pref PC	(+ or -)	Both sig	Test 1	
1	1c	1c	+	*	R -value	**0.65**
2	2c	-	-		Sig.	0.000
3	3d	-	+		n	35
4	4a	4a	+	*		
5	5c	-	+		Test2	
6	**6b**	**6e**	**-**	*****	Pref PC	(Same, Diff)
7	-	-	-		Sig.	**(3,2)**
8	**8a,8c**	**8a,8c**	**-**	*****	All	(6,4)
9	9c	-	+			
10	10d	10d	+	*		

Ve Setup Experiment
Chi-square test of independence (test 3)

Real Print vs QTVR Class			Test of indep		Real Print vs QTVR Class	
Nodes	df	(+ or -)	X^2	Sig.	Test 3	
1	**2**	**-**	**9.7**	***	Test of indep Sig. Diff	
2	2	-	1.3		# Sig.	**6**
3	3	+	5.1			
4	**3**	**+**	**12.9**	***		
5	2	-	4.2			
6	**4**	**+**	**47.6**	***		
7	**2**	**-**	**16.8**	***		
8	**2**	**-**	**5.4**	*		
9	2	-	3.4			
10	**3**	**+**	**12.7**	***		
Real Print vs QTVR ind.			Test of indep		Real Print vs QTVR ind.	
Nodes	df	(+ or -)	X^2	sig.	Test 3	
1	**2**	-	**6.4**	**	Test of indep Sig. Diff	
2	2	+	**12.7**	***	# Sig.	**5**
3	**3**	-	**11.6**	***		
4	3	+	1.6			
5	**2**	**+**	**12.9**	***		
6	4	-	3.0			
7	2	-	2.1			
8	**2**	-	**5.3**	*		
9	2	-	3.7			
10	3	+	5.9			
QTVR Class vs QTVR ind.			Test of indep		QTVR Class vs QTVR ind.	
Nodes	df	(+ or -)	X^2	sig.	Test 3	
1	2	+	2.2		Test of indep Sig. Diff	
2	**2**	-	**5.5**	*	# Sig.	**6**
3	**3**	**+**	**11.4**	***		
4	3	+	5.2			
5	**2**	**+**	**29.1**	***		
6	**4**	-	**23.1**	***		
7	**2**	-	**5.1**	*		
8	2	-	0.3			
9	**2**	**+**	**7.5**	**		
10	3	+	6.0			

Appendix 4

QTVR Class Analysis

QTVR Classroom VC levels

Chi-square test of Significant distribution & Power analysis

	Distribution of Choices						Chi-square test				Power analysis		
R-Level	Path Choice									R-Level		p-val	a=0.1
n=26	Nodes	A	B	C	D	E	df.	X^2	Sig.	Sig. Pref PC	w	n=25	n=30
	1	3	8	15			2	8.4	**	1c	1	77	88
	2	6	4	16			2	9.5	***	-	0	42	49
	3	5	0	6	15		3	18.0	***	-	1	85	90
	4	12	2	3	9		3	10.6	**	4a	0	36	42
	5	8	3	15			2	8.4	**	-	0	25	29
	6	2	11	5	5	3	4	9.4	*	6e	0	32	38
	7	8	11	7			2	1.2		-	0	-	-
	8	11	2	13			2	7.9	**	8a,8c	0	25	29
	9	9	0	15	2		2	13.3	***	-	1	60	69
	10	1	5	1	19		3	33.7	***	10d	1	99	100
A-Level	Pathchoices									A-Level		p-val	a=0.1
n=26	Nodes	A	B	C	D	E	df.	X^2		Sig. Pref PC	w	n=25	n=30
	1	4	9	13			2	4.7	*	1c	0	42	49
	2	1	5	20			2	23.2	***	2c	1	99	100
	3	3	0	12	11		3	16.2	***	3c, 3d	1	71	80
	4	11	8	1	6		3	8.2	*	4a	0	21	25
	5	1	3	22			2	31.0	***	5c	1	99	100
	6	0	2	6	6	12	4	16.3	***	6e	1	66	75
	7	12	7	7			2	1.8		-	0	-	-
	8	6	6	14			2	4.9	*	8c	0	13	15
	9	2	1	23	0		2	35.6	***	9c	1	100	100
	10	1	3	3	19		3	32.5	***	10d	1	100	100
O-level	Pathchoices									O-level		p-val	a=0.1
n=26	Nodes	A	B	C	D	E	df.	X^2		Sig. Pref PC	w	n=25	n=30
	1	5	10	11			2	2.4		-	0		
	2	7	2	17			2	13.5	***	2c	1	60	85
	3	1	1	14	10		3	19.8	***	3c	1	93	97
	4	14	4	8	0		3	16.5	***	4a	1	71	80
	5	2	3	21			2	26.4	***	5c	1	100	100
	6	4	1	9	3	9	4	10.2	**	6c,6e	0	32	38
	7	19	5	2			2	18.8	***	7a	1	89	94
	8	8	7	11			2	1.0			0		
	9	3	2	21	0		2	26.4	***	9c	1	100	100
	10	3	3	2	18		3	27.2	***	10d	1	100	100

QTVR ClassroomVC levels
Pearson''s R Correlation (Test1) and
Comparison of significantly preferred paths (Test 2)

	R-Level	A-Level	R-level Vs A-level		Test 1	
Nodes	Sig. Pref PC	Sig. Pref PC	(+ or -)	Both sig	**R -value**	**0.75**
1	1c	1c	+	*	Sig.	0.000
2	2c	2c	+	*	n	35
3	**3d**	**3c,3d**	-	*		
4	4a	4a	+	*	Test 2	
5	5c	5c	+	*	Pref PC	(Same, Diff)
6	**6e**	**6e**	-	*	Sig.	**(6,3)**
7	-	-	+		All	(7,3)
8	**8a,8c**	**8c**	-	*		
9	-	9c	+	*		
10	10d	10d	+	*		

	R-Level	O-Level	R-level vs O-level		Test 1	
Nodes	Sig. Pref PC	Sig. Pref PC	(+ or -)	Both sig	**R -value**	**0.66**
1	1c	-	-		Sig.	0.000
2	2c	2c	+	*	n	35
3	**3d**	**3c**	-	*		
4	**4a**	**4b**	-	*	Test 2	
5	5c	5c	+	*	Pref PC	(Same, Diff)
6	**6e**	**6c, 6e**	-	*	Sig.	**(4,3)**
7	-	7a	-		All	(4,6)
8	8a,8c	-	-			
9	9c	9c	+	*		
10	10d	10d	+	*		

	A-Level	O-Level	A-level vs O-level		Test 1	
Nodes	Sig. Pref PC	Sig. Pref PC	(+ or -)	Both sig	**R -value**	**0.88**
1	1c	-	-		Sig.	0.000
2	2c	2c	+	*	n	35
3	**3c,3d**	**3c**	-	*		
4	**4a**	**4b**	-	*	Test 2	
5	5c	5c	+	*	Pref PC	(Same, Diff)
6	**6e**	**6c, 6e**	-	*	Sig.	**(4,3)**
7	-	7a	-		All	(5,5)
8	8c	-	-			
9	9c	9c	+	*		
10	10d	10d	+	*		

QTVR Classroom VC levels
Chi-squared test of independence (test 3)

R-level Vs A-level		Test of indep		R-level Vs A-level	
Nodes	df	X^2	**Sig.**	Test 3	
1	2	0.3		Test of indep Sig. Diff	
2	2	4.1		# Sig.	**3**
3	3	3.1			
4	3	5.2			
5	**2**	**6.8**	**		
6	**4**	**13.8**	***		
7	2	1.69			
8	2	3.5			
9	**2**	**8.9**	**		
10	3	1.5			

R-level vs O-level		Test of indep		R-level vs O-level	
Nodes	df	X^2	**sig.**	Test 3	
1	2	1.3		Test of indep Sig. Diff	
2	2	0.8		# Sig.	**6**
3	**3**	**7.9**	**		
4	**3**	**12.1**	***		
5	2	4.6	*		
6	**4**	**13.6**	***		
7	**2**	**9.51**	***		
8	2	3.4			
9	**2**	**7.6**	**		
10	3	1.9			

A-level vs O-level		Test of indep		A-level vs O-level	
Nodes	df	X^2	**sig.**	Test 3	
1	2	0.3		Test of indep Sig. Diff	
2	**2**	**6.0**	**	# Sig.	**3**
3	3	2.2			
4	**3**	**13.1**	*		
5	2	0.4			
6	4	5.4			
7	**2**	**4.69**	*		
8	2	0.7			
9	2	0.6			
10	3	1.2			

QTVR ind. VC levels

Chi-square test of Significant distribution & Power analysis

	Distribution of Choices						Chi-square test			Power analysis		
R-Level		Path Choice							R-Level		p-val	a=0.1
n=28	Nodes	A	B	C	D	E	df.	X^2	Sig. Pref PC	w	n=25	n=30
	1	**3**	**6**	**19**			**2**	**17.0 *****	**1c**	**0.75**	**89**	**94**
	2	9	8	11			2	0.5	-	**0.02**	**-**	**-**
	3	4	8	6	10		3	2.9	-	0.10	7	7
	4	**13**	**0**	**6**	**9**		**3**	**12.9 *****	**4a**	0.46	54	66
	5	12	11	5			2	3.1	-	0.11	7	7
	6	**1**	**6**	**3**	**2**	**16**	**4**	**26.6 *****	**6e**	**0.95**	**100**	**100**
	7	14	7	7			2	3.1	-	0.13	7	7
	8	**11**	**3**	**14**			**2**	**6.9 ****	**8a,8c**	0.25	25	29
	9	8	7	13			2	2.2	-	0.08	7	7
	10	**1**	**2**	**2**	**23**		**3**	**48.9 *****	**10d**	**1.74**	**100**	**100**
A-Level		Pathchoices							A-level		p-val	a=0.1
n=28	Nodes	A	B	C	D	E	df.	X^2	Sig. Pref PC	w	n=25	n=30
	1	**6**	**6**	**16**			**2**	**5.8 ***	**1c**	**0.51**	**60**	**69**
	2	**2**	**12**	**14**			**2**	**8.0 ****	**2b,2c**	0.32	25	29
	3	**5**	**2**	**7**	**14**		**3**	**11.9 *****	**3d**	0.40	36	42
	4	**15**	**1**	**3**	**9**		**3**	**19.0 *****	**4a**	**0.61**	**71**	**80**
	5	**3**	**5**	**20**			**2**	**16.3 *****	**5c**	**0.67**	**89**	**94**
	6	**2**	**1**	**8**	**0**	**17**	**4**	**32.0 *****	**6e**	**1.28**	**100**	**100**
	7	14	3	11			2	5.2	-	0.25	25	29
	8	5	11	12			2	4.1	-	0.11	7	7
	9	**6**	**2**	**20**			**2**	**17.0 *****	**9c**	**0.69**	**89**	**94**
	10	**1**	**0**	**2**	**25**		**3**	**57.0 *****	**10d**	**2.21**	**100**	**100**
O-level		Pathchoices							O-Level		p-val	a=0.1
n=28	Nodes	A	B	C	D	E	df.	X^2	Sig. Pref PC	w	n=25	n=30
	1	**7**	**4**	**17**			**2**	**9.0 ****	**1c**	**0.60**	**77**	**85**
	2	**1**	**10**	**17**			**2**	**12.3 *****	**2c**	**0.50**	**60**	**69**
	3	**3**	**4**	**7**	**14**		**3**	**8.7 ****	**3d**	0.38	36	42
	4	**15**	**1**	**9**	**3**		**3**	**16.7 *****	**4a**	**0.61**	**71**	**80**
	5	**0**	**3**	**25**			**2**	**36.7 *****	**5c**	**1.44**	**100**	**100**
	6	**1**	**3**	**11**	**0**	**13**	**4**	**23.1 ****	**6c,6e**	**0.91**	**97**	**99**
	7	15	6	7			2	2.7	-	0.30	25	29
	8	**4**	**6**	**18**			**2**	**11.8 *****	**8c**	0.44	42	49
	9	**1**	**1**	**26**			**2**	**41.2 *****	**9c**	**1.61**	**100**	**100**
	10	**1**	**3**	**4**	**20**		**3**	**34.7 *****	**10d**	**1.17**	**100**	**100**

QTVR ind. VC levels
Pearson''s R Correlation (Test1) and
Comparison of significantly preferred paths (Test 2)

	R-Level	A-Level	R-level Vs A-level		Test 1	
Nodes	Sig. Pref PC	Sig. Pref PC	(+ or -)	Both sig	R -value	**0.65**
1	1c	1c	+	*	Sig.	0.000
2	-	2b,2c	-		n	35
3	-	3d	-			
4	4a	4a	+	*	Test 2	
5	-	5c	-		Pref PC	(Same, Diff)
6	6e	6e	+	*	Sig.	(4,0)
7	-	-	+		All	(5,5)
8	8a,8c	-	-			
9	-	9c	-			
10	10d	10d	+	*		
	R-Level	O-Level	R-level vs O-level		Test 1	
Nodes	Sig. Pref PC	Sig. Pref PC	(+ or -)	Both sig	R -value	**0.55**
1	1c	1c	+	*	Sig.	0.000
2	-	2c	-		n	35
3	-	3d	-			
4	4a	4a	+	*	Test 2	
5	-	5c	-		Pref PC	(Same, Diff)
6	**6e**	**6c,6e**	**-**	*****	Sig.	(3,2)
7	-	-	-		All	(3,7)
8	**8a,8c**	**8c**	**-**	*****		
9	-	9c	-			
10	10d	10d	+	*		
	A-Level	O-Level	A-level vs O-level		Test 1	
Nodes	Sig. Pref PC	Sig. Pref PC	(+ or -)	Both sig	R -value	**0.88**
1	1c	1c	+	*	Sig.	0.000
2	**2b,2c**	**2c**	**-**	*****	n	35
3	3d	3d	+	*		
4	4a	4a	+	*	Test 2	
5	5c	5c	+	*	Pref PC	(Same, Diff)
6	**6e**	**6c,6e**	**-**	*****	Sig.	(6,2)
7	-	-	-		All	(6,4)
8	-	8c	-			
9	9c	9c	+	*		
10	10d	10d	+	*		

QTVR ind. VC levels
Chi-square goodness of fit test (test 3)

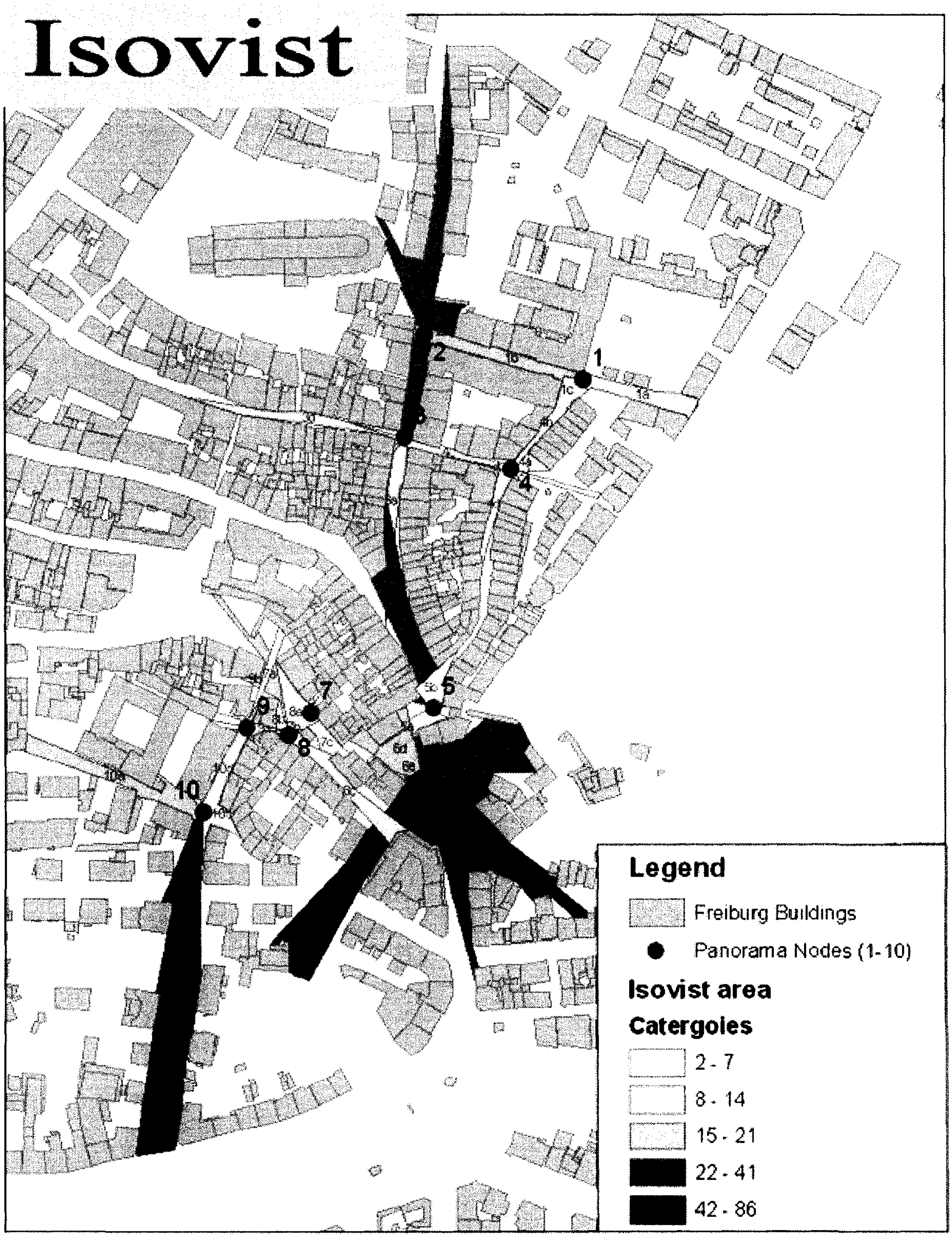
R-level Vs A-level			Test of indep		R-level Vs A-level	
Nodes	df	(+ or -)	X^2	**Sig.**	Test 3	
1	2	+	1.3		Test of indep Sig. Diff	
2	**2**	**-**	**5.6**	*	# Sig.	**4**
3	3	-	4.5			
4	3	+	2.1			
5	**2**	**-**	**16.7**	***		
6	**4**	**+**	**8.2**	**		
7	2	+	2.49			
8	**2**	**-**	**7.0**	**		
9	2	-	4.5			
10	3	+	2.1			

R-level vs O-level			Test of indep		R-level vs O-level	
Nodes	df	(+ or -)	X^2	**Sig.**	Test 3	
1	2	+	2.1		Test of indep Sig. Diff	
2	**2**	**-**	**7.9**	**	# Sig.	**6**
3	3	-	2.2			
4	**3**	**+**	**4.7**	*		
5	**2**	**-**	**29.9**	***		
6	**4**	**-**	**7.9**	*		
7	2	-	0.1			
8	**2**	**-**	**4.8**	*		
9	**2**	**-**	**14.3**	***		
10	3	+	1.1			

A-level vs O-level			Test of indep		A-level vs O-level	
Nodes	df	(+ or -)	X^2	**Sig.**	Test 3	
1	2	+	0.5		Test of indep Sig. Diff	
2	2	-	0.8		# Sig.	**3**
3	3	+	1.2			
4	**3**	**+**	**6.0**	*		
5	2	+	13.1	*		
6	4	-	2.3			
7	2	-	1.9			
8	2	-	2.8			
9	**2**	**+**	**4.7**	*		
10	3	+	4.2			

Appendix 5

Isovist Diagram


Isovist
1
2
3
4
5
7
8
9
10
Legend
Freiburg Buildings
● Panorama Nodes (1-10)
Isovist area
Catergoies
2 - 7
8 - 14
15 - 21
22 - 41
42 - 86

Appendix 6

SC and VC: Bi-variate Correlation

SC and VC Bi -variate Correlation Table R-level

		REAL1	REAL2
ISOVIST	Pearson Correlation	-.038	-.288*
	Sig. (1-tailed)	.413	.047
	N	35	35
LINKS	Pearson Correlation	.114	.049
	Sig. (1-tailed)	.256	.389
	N	35	35
OCCLUDED	Pearson Correlation	.331*	.278
	Sig. (1-tailed)	.026	.053
	N	35	35
ENCLOSE	Pearson Correlation	.055	-.170
	Sig. (1-tailed)	.376	.164
	N	35	35
AREA	Pearson Correlation	-.006	-.070
	Sig. (1-tailed)	.487	.345
	N	35	35
TYPE_PC	Pearson Correlation	-.199	-.068
	Sig. (1-tailed)	.126	.348
	N	35	35
CARS	Pearson Correlation	.168	-.224
	Sig. (1-tailed)	.168	.098
	N	35	35
PEOPLE	Pearson Correlation	.051	-.093
	Sig. (1-tailed)	.386	.298
	N	35	35
BIKES	Pearson Correlation	-.160	-.231
	Sig. (1-tailed)	.180	.091
	N	35	35
GREENNOR	Pearson Correlation	-.031	-.148
	Sig. (1-tailed)	.431	.198
	N	35	35
ENC_WO_G	Pearson Correlation	.208	-.069
	Sig. (1-tailed)	.115	.346
	N	35	35
COLOR	Pearson Correlation	.215	.202
	Sig. (1-tailed)	.107	.122
	N	35	35
COBBLE	Pearson Correlation	.077	.251
	Sig. (1-tailed)	.330	.073
	N	35	35
SIGNS	Pearson Correlation	-.041	-.086
	Sig. (1-tailed)	.408	.312
	N	35	35

**. Correlation is significant at the 0.01 level (1-tailed).

*. Correlation is significant at the 0.05 level (1-tailed).

Note:

Real1 = Group R-Level
Real 2 = Individual R-Level
Type PC = Legibility
Enc_wo_g = Enclosure without greenery

SC Bi-variate Correlation Table – A-Level and O--Level

		ARCH1	OUT1	ARCH2	OUT2
ISOVIST	Pearson Correlation	-.103	-.045	-.225	-.064
	Sig. (1-tailed)	.277	.399	.097	.357
	N	35	35	35	35
LINKS	Pearson Correlation	.093	.252	.044	.162
	Sig. (1-tailed)	.298	.072	.400	.177
	N	35	35	35	35
OCCLUDED	Pearson Correlation	.254	.378*	.219	.298*
	Sig. (1-tailed)	.070	.012	.103	.041
	N	35	35	35	35
ENCLOSE	Pearson Correlation	-.137	-.036	-.155	-.100
	Sig. (1-tailed)	.217	.419	.187	.285
	N	35	35	35	35
AREA	Pearson Correlation	-.070	.113	-.016	-.080
	Sig. (1-tailed)	.344	.260	.463	.323
	N	35	35	35	35
TYPE_PC	Pearson Correlation	-.166	-.020	-.201	-.082
	Sig. (1-tailed)	.171	.454	.124	.321
	N	35	35	35	35

**. Correlation is significant at the 0.01 level (1-tailed).

*. Correlation is significant at the 0.05 level (1-tailed).

Note:

Arch 1 = Group A - level
Arch 2 = Individual A - level
Out1 = Group O - Level
Out 2 = Individual O – Level

Bi-variate Correlations of Visual Factors

Correlations

		ISOVIST	LINKS	OCCLUDED EDGES	ENCLOSE	AREA OF VIEW	LEGIBILITY	CARS	PEOPLE	BIKES	GREENERY	ENC_WID_G	COLOR	COBBLE	SIGNS
ISOVIST	Pearson Correlation	1	.207	.327	.541**	.020	.194	.481**	.267	.420*	.214	.222	-.072	-.469**	.014
	Sig. (2-tailed)	.	.232	.055	.001	.909	.264	.003	.121	.012	.217	.200	.680	.004	.938
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
LINKS	Pearson Correlation	.207	1	.619**	.330	.309	.782**	.200	.055	-.185	.185	.117	.260	-.259	.162
	Sig. (2-tailed)	.232	.	.000	.053	.071	.000	.249	.754	.287	.286	.503	.132	.133	.353
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
OCCLUDED EDGES	Pearson Correlation	.327	.619**	1	.271	.256	.542**	.234	.106	-.125	.068	.166	.249	-.236	-.008
	Sig. (2-tailed)	.055	.000	.	.116	.137	.001	.175	.545	.473	.699	.341	.150	.173	.965
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
ENCLOSE	Pearson Correlation	.541**	.330	.271	1	.345*	.161	.304	.232	.290	.631**	.082	.049	-.316	.180
	Sig. (2-tailed)	.001	.053	.116	.	.043	.355	.075	.179	.091	.000	.638	.778	.065	.301
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
AREA OF VIEW	Pearson Correlation	.020	.309	.256	.345*	1	.207	.353*	-.251	-.247	.054	.285	.241	-.054	.052
	Sig. (2-tailed)	.909	.071	.137	.043	.	.232	.035	.147	.153	.759	.097	.164	.758	.767
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
LEGIBILITY	Pearson Correlation	.194	.782**	.542**	.161	.207	1	.000	-.066	-.160	.170	.025	.058	-.171	.016
	Sig. (2-tailed)	.264	.000	.001	.355	.232	.	1.000	.705	.358	.328	.887	.739	.326	.925
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
CARS	Pearson Correlation	.481**	.200	.234	.304	.353*	.000	1	.082	.392*	-.122	.592**	.062	-.118	.035
	Sig. (2-tailed)	.003	.249	.175	.075	.035	1.000	.	.639	.020	.484	.000	.725	.500	.840
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
PEOPLE	Pearson Correlation	.267	.055	.106	.232	-.251	-.066	.082	1	.158	.033	.056	.021	-.223	-.133
	Sig. (2-tailed)	.121	.754	.545	.179	.147	.705	.639	.	.364	.850	.755	.905	.198	.458
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
BIKES	Pearson Correlation	.420*	-.185	-.125	.290	-.247	-.160	.392*	.158	1	.192	.027	-.201	.008	.084
	Sig. (2-tailed)	.012	.287	.473	.091	.153	.358	.020	.364	.	.268	.879	.248	.961	.632
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
GREENERY	Pearson Correlation	.214	.185	.068	.631**	.054	.170	-.122	.033	.192	1	.505**	-.234	-.087	-.103
	Sig. (2-tailed)	.217	.286	.699	.000	.759	.328	.484	.850	.268	.	.002	.176	.619	.555
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
ENC_WID_G	Pearson Correlation	.222	.117	.166	.082	.285	.025	.592**	.056	.027	.505**	1	.108	-.097	.161
	Sig. (2-tailed)	.200	.503	.341	.638	.097	.887	.000	.755	.879	.002	.	.534	.580	.354
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
COLOR	Pearson Correlation	-.072	.260	.249	.049	.241	.058	.062	.021	-.201	-.234	.108	1	-.360*	.445**
	Sig. (2-tailed)	.680	.132	.150	.778	.164	.739	.725	.905	.248	.176	.534	.	.033	.007
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
COBBLE	Pearson Correlation	-.469**	-.259	-.236	-.316	-.054	-.171	-.118	-.223	.008	-.087	-.097	-.360*	1	.087
	Sig. (2-tailed)	.004	.133	.173	.065	.758	.326	.500	.198	.961	.619	.580	.033	.	.620
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
SIGNAGE	Pearson Correlation	.014	.162	-.008	.180	.052	.016	.035	-.133	.084	-.103	.161	.445**	.087	1
	Sig. (2-tailed)	.938	.353	.965	.301	.767	.925	.840	.458	.632	.555	.354	.007	.620	.
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix 7

Multiple Regressions

Classroom R-Level Regression Model

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	SIGNS, OCCLUDED, GREENNOR, PEOPLE, CARS, COBBLE, ANGLE_V, LEGIB, BIKES, COLOR, ADJ_O_E, ISOVIST, LINKS, OPE_ENC[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: REAL1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.785[a]	.616	.347	.16332

a. Predictors: (Constant), SIGNS, OCCLUDED, GREENNOR, PEOPLE, CARS, COBBLE, ANGLE_V, LEGIB, BIKES, COLOR, ADJ_O_E, ISOVIST, LINKS, OPE_ENC

b. Dependent Variable: REAL1

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.855	14	.061	2.290	.044[a]
	Residual	.533	20	.027		
	Total	1.388	34			

a. Predictors: (Constant), SIGNS, OCCLUDED, GREENNOR, PEOPLE, CARS, COBBLE, ANGLE_V, LEGIB, BIKES, COLOR, ADJ_O_E, ISOVIST, LINKS, OPE_ENC

b. Dependent Variable: REAL1

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			Correlations		
Model		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part
1	(Constant)	9.494E-02	.201		.472	.642			
	ANGLE_V	-.934	.451	-.458	-2.068	.052	-.006	-.420	-.287
	ISOVIST	5.542E-04	.002	.055	.224	.825	-.038	.050	.031
	OPE_ENC	2.448E-04	.001	.119	.313	.758	.055	.070	.043
	ADJ_O_E	1.433E-03	.001	.406	1.571	.132	.208	.332	.218
	OCCLUDED	5.602E-02	.027	.408	2.046	.054	.331	.416	.284
	LINKS	.128	.072	.528	1.784	.090	.114	.371	.247
	LEGIB	-.182	.058	-.828	-3.143	.005	-.199	-.575	-.436
	CARS	2.112E-03	.021	.026	.101	.920	.168	.023	.014
	PEOPLE	-1.066E-02	.009	-.214	-1.199	.245	.051	-.259	-.166
	BIKES	-1.918E-02	.017	-.239	-1.159	.260	-.160	-.251	-.161
	GREENNOR	5.196E-04	.001	.277	.775	.447	-.031	.171	.107
	COLOR	3.770E-02	.019	.432	1.946	.066	.215	.399	.270
	COBBLE	.104	.052	.417	2.012	.058	.077	.410	.279
	SIGNS	-.176	.094	-.386	-1.873	.076	-.041	-.386	-.260

a. Dependent Variable: REAL1

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.0098	.6566	.2840	.15858	35
Residual	-.2369	.3187	.0000	.12526	35
Std. Predicted Value	-1.729	2.350	.000	1.000	35
Std. Residual	-1.450	1.951	.000	.767	35

a. Dependent Variable: REAL1

Classroom A-level Regression Model

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: ARCH1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.573[a]	.328	.185	.22169

a. Predictors: (Constant), LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS

b. Dependent Variable: ARCH1

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.673	6	.112	2.283	.064[a]
	Residual	1.376	28	.049		
	Total	2.049	34			

a. Predictors: (Constant), LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS

b. Dependent Variable: ARCH1

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			Correlations		
Model		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part
1	(Constant)	.278	.133		2.085	.046			
	ANGLE_V	-.306	.433	-.124	-.707	.486	-.070	-.132	-.109
	ISOVIST	-1.337E-03	.002	-.109	-.551	.586	-.103	-.104	-.085
	OPE_ENC	-4.820E-04	.001	-.193	-.934	.358	-.137	-.174	-.145
	OCCLUDED	7.622E-02	.035	.457	2.204	.036	.254	.385	.341
	LINKS	.147	.083	.500	1.776	.087	.093	.318	.275
	LEGIB	-.193	.068	-.723	-2.839	.008	-.166	-.473	-.440

a. Dependent Variable: ARCH1

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.0063	.6064	.2863	.14070	35
Residual	-.4119	.4555	.0000	.20118	35
Std. Predicted Value	-1.990	2.275	.000	1.000	35
Std. Residual	-1.858	2.055	.000	.907	35

a. Dependent Variable: ARCH1

Individual A-level Regression Model

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: OUT1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.584[a]	.342	.201	.21155

a. Predictors: (Constant), LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS

b. Dependent Variable: OUT1

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.650	6	.108	2.421	.052[a]
	Residual	1.253	28	.045		
	Total	1.903	34			

a. Predictors: (Constant), LEGI8, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS

b. Dependent Variable: OUT1

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			Correlations		
Model		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part
1	(Constant)	.107	.127		.843	.407			
	ANGLE_V	6.275E-02	.414	.026	.152	.880	.113	.029	.023
	ISOVIST	-9.699E-04	.002	-.082	-.419	.678	-.045	-.079	-.064
	OPE_ENC	-4.544E-04	.000	-.189	-.923	.364	-.036	-.172	-.141
	OCCLUDED	7.525E-02	.033	.468	2.281	.030	.378	.396	.350
	LINKS	.156	.079	.548	1.965	.059	.252	.348	.301
	LEGIB	-.169	.065	-.658	-2.610	.014	-.020	-.442	-.400

a. Dependent Variable: OUT1

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.0323	.6328	.2866	.13828	35
Residual	-.3677	.4258	.0000	.19198	35
Std. Predicted Value	-1.839	2.504	.000	1.000	35
Std. Residual	-1.738	2.013	.000	.907	35

a. Dependent Variable: OUT1

Individual R-level Regression Model

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	SIGNS, OCCLUDED, GREENNOR, PEOPLE, CARS, COBBLE, ANGLE_V, LEGIB, BIKES, COLOR, ADJ_O_E, ISOVIST, LINKS, OPE_ENC[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: REAL2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.756[a]	.572	.272	.16865

a. Predictors: (Constant), SIGNS, OCCLUDED, GREENNOR, PEOPLE, CARS, COBBLE, ANGLE_V, LEGIB, BIKES, COLOR, ADJ_O_E, ISOVIST, LINKS, OPE_ENC

b. Dependent Variable: REAL2

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.760	14	.054	1.909	.091[a]
	Residual	.569	20	.028		
	Total	1.329	34			

a. Predictors: (Constant), SIGNS, OCCLUDED, GREENNOR, PEOPLE, CARS, COBBLE, ANGLE_V, LEGIB, BIKES, COLOR, ADJ_O_E, ISOVIST, LINKS, OPE_ENC

b. Dependent Variable: REAL2

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant)	.193	.208		.927	.365			
	ANGLE_V	-.738	.466	-.370	-1.583	.129	-.070	-.334	-.232
	ISOVIST	-4.630E-04	.003	-.047	-.181	.858	-.288	-.040	-.026
	OPE_ENC	1.167E-03	.001	.581	1.442	.165	-.170	.307	.211
	ADJ_O_E	-8.024E-05	.001	-.023	-.085	.933	-.069	-.019	-.012
	OCCLUDED	5.605E-02	.028	.417	1.982	.061	.278	.405	.290
	LINKS	.105	.074	.441	1.412	.173	.049	.301	.207
	LEGIB	-.112	.060	-.520	-1.871	.076	-.068	-.386	-.274
	CARS	-2.928E-02	.022	-.366	-1.361	.189	-.224	-.291	-.199
	PEOPLE	-1.619E-02	.009	-.332	-1.763	.093	-.093	-.367	-.258
	BIKES	-3.644E-04	.017	-.005	-.021	.983	-.231	-.005	-.003
	GREENNOR	-8.801E-04	.001	-.480	-1.272	.218	-.148	-.274	-.186
	COLOR	3.659E-02	.020	.429	1.829	.082	.202	.378	.268
	COBBLE	.136	.054	.555	2.536	.020	.251	.493	.371
	SIGNS	-.237	.097	-.531	-2.442	.024	-.086	-.479	-.357

a. Dependent Variable: REAL2

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.0326	.7552	.2860	.14952	35
Residual	-.2246	.2681	.0000	.12935	35
Std. Predicted Value	-1.695	3.138	.000	1.000	35
Std. Residual	-1.332	1.590	.000	.767	35

a. Dependent Variable: REAL2

Classroom A-level Regression Model

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: ARCH2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.585[a]	.342	.201	.20389

a. Predictors: (Constant), LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS

b. Dependent Variable: ARCH2

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.606	6	.101	2.428	.051[a]
	Residual	1.164	28	.042		
	Total	1.770	34			

a. Predictors: (Constant), LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS

b. Dependent Variable: ARCH2

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			Correlations		
Model		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part
1	(Constant)	.283	.123		2.305	.029			
	ANGLE_V	-.168	.399	-.073	-.421	.677	-.016	-.079	-.065
	ISOVIST	-2.998E-03	.002	-.263	-1.344	.190	-.225	-.246	-.206
	OPE_ENC	-2.946E-04	.000	-.127	-.621	.540	-.155	-.117	-.095
	OCCLUDED	7.490E-02	.032	.483	2.355	.026	.219	.407	.361
	LINKS	.111	.076	.403	1.447	.159	.044	.264	.222
	LEGIB	-.171	.063	-.689	-2.735	.011	-.201	-.459	-.419

a. Dependent Variable: ARCH2

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-.0702	.5664	.2860	.13346	35
Residual	-.3021	.4270	.0000	.18503	35
Std. Predicted Value	-2.669	2.101	.000	1.000	35
Std. Residual	-1.482	2.094	.000	.907	35

a. Dependent Variable: ARCH2

Individual O-level Regression Model

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: OUT2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.551[a]	.304	.155	.24248

a. Predictors: (Constant), LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS

b. Dependent Variable: OUT2

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.719	6	.120	2.038	.094[a]
	Residual	1.646	28	.059		
	Total	2.365	34			

a. Predictors: (Constant), LEGIB, OPE_ENC, ANGLE_V, OCCLUDED, ISOVIST, LINKS

b. Dependent Variable: OUT2

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			Correlations		
Model		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part
1	(Constant)	.243	.146		1.666	.107			
	ANGLE_V	-.431	.474	-.162	-.910	.371	-.080	-.169	-.143
	ISOVIST	-1.325E-03	.003	-.100	-.500	.621	-.064	-.094	-.079
	OPE_ENC	-4.387E-04	.001	-.164	-.777	.444	-.100	-.145	-.123
	OCCLUDED	8.039E-02	.038	.448	2.126	.042	.298	.373	.335
	LINKS	.162	.091	.511	1.782	.086	.162	.319	.281
	LEGIB	-.184	.074	-.641	-2.475	.020	-.082	-.424	-.390

a. Dependent Variable: OUT2

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.0148	.6003	.2860	.14541	35
Residual	-.4317	.4986	.0000	.22005	35
Std. Predicted Value	-1.865	2.161	.000	1.000	35
Std. Residual	-1.780	2.056	.000	.907	35

a. Dependent Variable: OUT2

Glossary

VE – Virtual Environment

IRN – Internal Representation Network

DFT – Decision Field Theory

SC – Shape Complexity

VC – Visual Content

QTVR – QuickTime Virtual Reality

R level – Real Level

A level – Architectural Level

O level – Outline Level