University College London

THE COGNITIVE ROOTS OF SPACE SYNTAX

a dissertation submitted to the Faculty of the Built Environment, The Bartlett
in candidacy for the degree of Doctor of Philosophy

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September 2009

to Isabel

Abstract

During the last twenty-five years of research and real-world studies accomplished all over the globe, space syntax has consistently shown that movement patterns in cities and buildings tend to be strongly related to configurational properties of their respective spatial layouts. It has also been shown that individuals' trajectories in virtual worlds are affected by the syntactic properties of these environments, and that the resulting emergent patterns may explain the detected correlations between configurational properties of space and movement patterns in real-world scenarios.

However, none of these studies have so far attempted to elicit why these regularities occur at a more fundamental, cognitive level. In other words, they have not yet answered how the idea of spatial configuration shapes a person's qualitative assessments and subsequent usage of spatial networks. This is the topic of this thesis. What kind of information do people extract from spatial configurations? How is this information used when assessing a spatial network qualitatively? How is this information used when one has to use such a network? These are some of the questions that this thesis will attempt to answer.

This thesis will focus on map usage. By analysing how people interact with maps, this thesis will attempt to shed light on the processes by which people internalise configurational information and are able to define qualitative judgements that may be use in real-world scenarios. As a result, this thesis aims to be a further step in the ongoing process of linking space syntax with cognitive theory and therefore to contribute in the search of the cognitive roots of space syntax.

Acknowledgements

My gratitude is first with Ruth Conroy-Dalton for her permanent support throughout this thesis, with professor Bill Hillier, for his stimulating comments and help in crucial moments, and with Margarita Greene, for her friendship and invaluable advice in moments of hesitation.

Many thanks to Claire Davies from Ordnance Survey and David Peebles from the university of Huddesfield for inviting me to participate in an experiment that resulted fundamental for this research, to Alasdair Turner for his technical support in this task , and to Lucas Figueiredo for his friendship and lucid advice.

To UCL for its generous funding and to UTFSM, my university, for its support through these years.

Finally, to Isabel, for her support and love.

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Introduction

Abstract

During the last twenty-five years of research and real-world studies accomplished all over the globe, space syntax has consistently shown that movement patterns in cities and buildings are strongly related to configurational properties of space (Peponis, Hadjinikolau E. et al. 1989; Hillier, Penn et al. 1993; Read and Budiarto 2003; Hillier and Iida 2005). It has also been shown (Conroy-Dalton 2001) that individual's trajectories in virtual worlds are affected by the syntactic properties of these environments. As a result, space syntax's theory and techniques seems to "work" (Hillier 1999) , thus permitting to predict changes in movement patterns derived from changes in an environment's spatial configuration.

However, few studies have so far attempted to elicit why these regularities occur at a more fundamental, cognitive level. In other words, they have not yet answered if the idea of spatial configuration is cognitively internalized in people's minds and, if this is the case, how this process might take form.

This is the topic of this thesis. What kind of information do people extract from spatial configurations?, how is this information used when persons are asked to assess a network qualitatively (e.g. to retrieve a network's structure)?, how do geometric properties of environments influence these assessments?

These are some of the questions that this thesis will attempt to answer.

1.1.- Theoretical preliminaries

The ability to move and orientate oneself in space is perhaps one of the most intriguing aspects of the human mind. It encompasses, amongst other skills, to recognise, to memorise and to recall environmental information, as well as to define action plans that enable people in reaching their destinations (Garling, Book et al. 1984). Despite the obvious complexities of the matter, in most cases humans perform these tasks unconsciously, as though this behaviour were nothing more than the *natural way of acting in the world*.

Since the 70`s a new area of research has studied the mental processes behind these behaviours. Using methods and techniques firstly borrowed from the fields of Geography and Psychology and lately from Computer Science, Spatial Cognition has persistently analysed the cognitive processes involved in the interactions between people and space. Some of its most compelling questions in are, for example, how is spatial orientation gained? What are the environmental factors that affect its development?: How do people perceive distance in real environments? But perhaps the fundamental preoccupation of this discipline could be summarized as: How is spatial knowledge formed in individuals?

From the seminal work of Tolman (1948) on rats and the comprehensive theories proposed by Piaget and colleagues on children (Piaget 1956; Piaget, Inhelder et al. 1960), to the more recent theories and models of spatial learning (Lynch 1960; Golledge, Smith et al. 1985; Montello 1992), huge efforts have been put in disentangling the processes involved in the formation of what has been called a “cognitive map”, or the mental representation of a system of spaces.

During the same period, coincidentally, Bill Hillier and colleagues were developing space syntax; a family of techniques and theories that investigate the relationship between space and society. In the last fifteen years, space syntax has progressively become immersed in a fruitful dialogue with cognitive science, which has resulted in an increasing co-operation between both disciplines. This thesis is part of this effort. By using space syntax’s theoretical framework and techniques for spatial analysis and spatial cognition’s methodologies, it hopes to broaden the scope of both disciplines, while at the same time, to overcome some of its respective limitations.

1.2.- The notion of spatial configuration

Space syntax, a theory concerned with the interaction between space and society, is due to celebrate its 35th anniversary. Its pivotal book, *The Social Logic of Space* (Hillier and Hanson 1984) developed a novel way to understand the space and its influence in society, one that started looking as a primary unity of analysis, that is, prior to any explanatory theory, in order to investigate both the role of space in the construction of social structures, and at the same time, the spatial mechanisms employed by societies to reproduce their social structures. *"The idea was to look at the society–space relation 'space first' by examining the patterns of real space found in the built environment and asking in what sense these could be seen to be the outcome of social and economic processes"* (Hillier 2008:224).

Initially the theory was preoccupied with the emergence of complex spatial patterns, created by the cumulative effect of individual behaviours constrained by a set of (implicit) discrete rules. As Hillier and Hanson declared: *"given a real spatial pattern, say a settlement form, then what ways and to what degree would it be necessary to restrict a random process in order to arrive at that form"* (Hillier and Hanson 1984:11). Space syntax then attempted to discover the spatial logics of these built forms and to retrieve these rules to the internal organization of their respective societies.

A fundamental aspect of this logic is the idea of spatial configuration[1]. A configuration, understood as the relation between a space A with a space B taking into account at least a third space C (Hillier 1996), means that the "properties" of a given space are not local, that is, belonging to the space's own realm, but non local, or related by its relations to the rest of the spaces in that system. Figures 1.1a and 1.1b exemplify this idea by showing two adjacent indoor spaces connected to the outside world. In the first example (figure 1.1a), both spaces have links to the outside. However, in the second figure (1.1b), a person has to pass through space A in order to reach space B. A graph (known as a j-graph)[2]

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[1] Hillier defined configuration as a "set of interdependent relations in which each is determined by its relation to all the other" (*Space is the machine*, p35)

[2] A j-graph (a justified graph) is a method aimed to rank the relative position of a space

located below each figure depicts these layouts in a relational way. As it can be seen, figure 1.1a is, in relational terms, symmetrical in the sense that permits spaces A and B to access space C independently. The same cannot be said of figure 1.1b, whose linkages are asymmetrical.

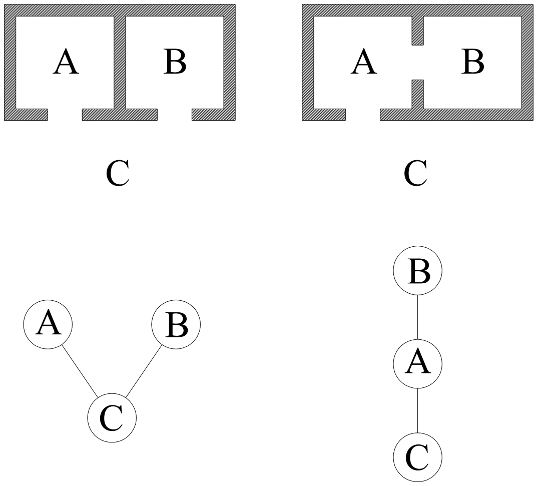

Figure 1.1a (right): three adjacent spaces linked symmetrically and the respective j graph
Figure 1.1b(left): the same spaces linked asymmetrically and the respective j graph
Source: Bill Hillier (Space is the machine)

By studying space from a configurational point of view, space syntax has dismissed the influence of architectural styles and ornaments on the analysis of the built form and, instead it has became interested in how architecture allows (or does not allow) people to access certain spatial domains. This conceptual shift set the ground for a more objective analysis of cities and buildings, enabling researchers to shed light on the pattern of encounters and avoidances that different spatial layouts seem to preclude. As a result, space syntax has furthered the understanding of the interdependence between societies and their built environment. The lucid title of the seminal book, *The social logic of space*, seems to embody the theory's ultimate goal: space syntax aimed, originally, to be a sociology of space.

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from a root node.

1.3.- Other implications of spatial configurations

Although the initial focus of configurational analysis was more anthropological and sociological, it soon became clear that studying space configurationally had practical implications. Perhaps the most important of these was the relation between a layout's spatial configuration and the movement patterns through it.

Different studies around the world (Peponis, Hadjinikolau E. et al. 1989; Hillier, Penn et al. 1993; Penn, Hillier et al. 1998; Read and Budiarto 2003) have shown that configurational properties of space consistently relate to movement patterns of buildings and cities. This phenomenon, incorporated into the "theory of natural movement", postulates that *"in urban systems, configuration is the primary generator of pedestrian movement, and, in general, attractors are either equalisable or work as multipliers on the basic pattern established by configuration"* (Hillier, Penn et al. 1993:31). It follows that a city's spatial configuration is the main force in shaping the city's vehicular and pedestrians` movement patterns. According to Hillier, the fact that more people will move along certain streets of the system, results in the gradual growth of land uses that depend on this kind of movement, like retail, catering or shops. This, in turn, encourages movement to these areas, becoming a cyclical process resulting in the formation of centres and sub centres in cities around the world (Hillier 2000).

By understanding space not only as a product of human activity but also as a generator of potential movement, space syntax has challenged the way the built environment was traditionally thought it: that it was as an effect (rather than also a cause) of human activity. Now the basics of configurational analysis will be explained.

1.4.- Analyzing configurations

In order to study space as a primary unit of analysis, space syntax has developed different spatial representations. The most widely known of them is called the "axial map", a map constructed by tracing the fewest number of straight lines (axial lines) passing through the accessible space of a spatial system. Public space, in space syntax's terminology[3], refers to the system of streets of a city (what is also known as a "grid"), and its adjacent open spaces (squares, pedestrians precincts, boulevards, alleys and the like) accessible to all inhabitants. In order to construct an axial map, all axial lines should be intersected at least once, so to produce a web of interconnected entities upon which configurational values are then calculated.

A simple measure in syntactic analysis is Connectivity, or the absolute number of intersections of a given axial line. It follows than that, if an axial line is said to have a Connectivity value of seven, it means that this line is intersected by seven other lines. It is also possible to assess the relative "depth" of each axial line in the system, that is, how many changes of direction a person has to make, on average, if he has to go from line X to any other line in network. This is achieved by considering all lines that intersect line X as a "topological step" (in this case, step one) from this line. Accordingly, further intersections of these lines will be considered one step away from line X. A j-graph representing the "topological depth" of each line can then be constructed for any layout. The same procedure is then carried out for all lines in a system, resulting in an assessment of the topological "depth" of each axial line. This measure is called "Global Integration", and it is probably the most relevant of all syntactic measures. According to Hillier and Hanson (1984) "Global Integration" reflects how likely it is for an axial line to be selected as a destination, and this has proved to be a good predictor of movement patterns in cities (Peponis, Hadjinikolau E. et al. 1989; Hillier, Penn et al. 1993; Penn, Hillier et al. 1998; Read and Budiarto 2003) and buildings (Conroy-Dalton 2001; Haq and Girotto 2004).

Other syntactic measures of space syntax are, for example, "Local integration",

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[3] Hillier (1996) uses the term "open space", spaces accessible to all inhabitants, to construct axial maps.

which results from limiting a depth graph to just two changes of direction. Local Integration reflects how “embedded” a line is within its vicinity. Finally, the syntactic measure of “Choice” reflects the degree in which an axial line is likely to be chosen as a route between a pair origin and destination.

1.5.- Space syntax and spatial cognition

Sixteen years have passed since Peponis and colleagues (1990) published the first search for the cognitive roots of space syntax. The case was a hospital setting that, according to the authors, was well-known for producing spatial confusion among its users. The research tested the wayfinding behavior of fifteen individuals in two stages: first, when they had no previous knowledge of the setting, and second, once they have gained some experience inside the building and had to go to specific locations. The former was named “open search”, the latter “directed search”.

During open searches individuals were allowed to walk freely around the setting for fifteen minutes, exploring any corridor, waiting room or public space they wanted. During directed searches individuals were asked to go to specific locations of the building as directly as possible. Individuals were forbidden to ask others for directions or to read signage.

In parallel to these tasks, Peponis and colleagues constructed an axial map of the setting that then was compared against behavioral data. In order to do so, they first decomposed all internal space into a set of nodes, called *choice nodes*, nodes in which people had the choice to proceed or amend their trajectories, and which resulted from the intersection of two or more axial lines. Configurational values of each node were then calculated by summing up the syntactic values of all lines concurring to a given node, and dividing this value by the number of concurring lines. For example, if line A and B encounter at location N, the corresponding value would be sum of configurational values of Lines A and B divided by two.

Peponis et al discovered that in open searches people tended to circulate along integrated spaces, and therefore used the most integrated nodes of the setting. In explaining why these places were employed most frequently by subjects, they suggested that integrated nodes permitted subjects to collect large amounts of information about the environment, making it possible to proceed with amending their searches.

Peponis et al concluded by contending that subjects seemed to have formed an allocentric image of the environment [4], or a bird-like image of it, *before* the selection of landmarks, not after retrieving them. In other words, Peponis suggested that configurational information was mentally captured by persons as a sort of scheme that was confirmed through direct exposure to the environment.

Another interesting study is that of Haq and Zimring's (2003). This tested the spatial performance of a large number of individuals in three complex American hospitals. As Peponis, Haq and Zimring asked people to perform open and directed searches in the buildings, and then compared these trajectories with the settings` configurational properties coming from the analysis of their respective axial maps. They also asked subjects to draw sketch maps of each of the buildings, one of the commonest methods to assess a person`s spatial understanding[5].

The results showed that there was a relation between the configurational properties of the plans, and the way in which these plans were used and encoded by people. For example, the authors demonstrated that the configurational measure of Connectivity robustly predicted people´s movement patterns in the building, meaning that the more connected an axial line, the higher the chances of this line of being occupied as a route between a given pair of locations. Moreover, Haq and Zimring proved that Connectivity was a powerful predictor of the likeliness of a space to appear in sketch maps too, meaning that those spaces more connected to their vicinities, were more frequently depicted in sketch maps than those spaces with fewer connections with their vicinities. But perhaps the most compelling part of Haq and Zimring`s argument refers to the role of local, and non-local, properties of space in permitting humans to comprehend the environment. According to the authors *"as a person moves from open exploration to directed searches, namely, becomes more and more familiar with the setting, his or her reliance on what can be immediately seen and recognized decreases on*

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[4] In cognitive science, this concept is known as "survey knowledge". It will be explained in more detail in chapter Two.

[5] A more detailed review of these methods is presented in the following chapter.

one hand, and understanding of the setting increases on the other hand. Therefore, it can be said that cognitive understanding had progressed from local variables to global ones " (Haq and Zimring 2003:157).

Concordant with Peponis et al, Haq and Zimring´s study also suggested that people developed a configurational map of their settings in a rapid manner, shifting from a local to a global comprehension of space in *"a time gap of about 10 to 15 minutes"* (Haq and Zimring 2003:157). This led the authors to claim the importance of topological representations of space, as those proposed by space syntax, in forming a person's allocentric representation of space[6].

The suggestive ideas proposed in these works were further explored by Young and Penn (2003), who employed sketch mapping, a popular technique in cognitive studies, to disclose how configurational information of space was mentally internalized by people. Young randomly chose seventy-six residents of Hampstead Garden Suburb, in London, and asked them to draw sketch maps of their local areas. Individuals were instructed to depict as many streets and landmarks as possible in a well-defined manner, so to preserve their geometrical appearance. The authors then started analyzing the drawings. First, they constructed axial maps of them, and second, they recorded all environmental information existing in maps. Next, they contrasted the configurational information derived from people's sketch maps, with configurational information coming from the axial map of London. The results indicated that a strong association between these two sources existed, that is, that the amount of contextual information appearing in sketch maps was highly associated to the configurational value of these maps. Perhaps more interestingly, participants´ axial maps strongly preserved configurational properties derived from the entire axial map of the city.

It was also discovered that Local Integration was the measure that most reliably predicted the likeliness of a street to be depicted in a person's sketch map. As a consequence, Young Ook and Penn claimed that individuals' mental representations of the environment were guided by topological, rather than by metric, aspects of space. This led them to argue that *"the spatial configuration is at the root of the way we cognize built environments"* (Young Ook and Penn

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[6] A more comprehensive review of this concept is presented in the following chapter.

2003:502).

The encoding of configurational information was also investigated by Conroy-Dalton and Bafna in 2003, in a work that attempted to link some of the ideas of Lynch`s influential book, *The image of the city (Lynch 1960)*, with space syntax. For such purpose, the authors performed an analysis to see whether the five elements that, according to Lynch, were responsible for forming a city's image (edges, paths, nodes, landmarks and districts), had syntactic correlates. After analyzing the mutual correspondences between these elements and the axial map of Boston, USA, Conroy-Dalton and Bafna concluded that there was a "syntactic" image of the city, that is, that all of Lynch`s elements had syntactic counterparts.

Another important study is the analysis realized by Chang and Penn (1998) on a multilevel complex. Puzzled by the fact that movement patterns were poorly associated with configurational values of the building, the authors started a series of observations in the setting. The result was multivariable explanatory model (or IMCM), which could robustly predict the movement's patterns in the compound. The model considered among other things, the degree of enclosure of spaces,, the frequency of connections to surrounding streets and type of vista potentially observable at decision points. Chang and Penn also demonstrated that configurational properties of space played a key role in determining movement's patterns.

In spite of the recursive association between configurational properties of space and movement patterns, space syntax`s techniques have been subject of some criticisms in the last years (Ratti 2004). Ratti maintained that axial representations of space impose an exaggerated cost on minor, slight deviation of streets, and that this cost diminished the realism of these representations. Also, he suggested that space syntax disregards the role of metric information of space, which, he contended, is a central aspect of a person's spatial understanding.

Part of Ratti`s arguments seemed to be shared by people inside the syntactic community. Dalton`s (2001)[7], for example, questioned the assumption posed by axial analysis that a straight street should be considered a single spatial entity

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[7] A very interesting development of spatial analysis has been created by Figueiredo (2002, 2004) under the name "continuity lines".

regardless of its length. According to him, people do not consider a mile-length street as part of a single space, not do they consider a topologically-simple but extended trip, in the same manner as a more complex but shorter trip. In other words, he suggested that both metric and geometric aspects of space are fundamental in shaping people`s understanding of space. Dalton proposed what he called "fractional configurational analysis", a method that combines geometrical *and* configurational aspects of space for constructing the axial maps. Fractional analysis has been fundamental to the development of recent applications of space syntax, as proposed by Turner and his "Segment analysis" (2005).

Hillier and Iida (2005) recently employed Segment analysis to compared configurational properties of space against movement patterns in a large area of London. Interestingly, they compared metric, geometric and topological variables of networks against movement data, discovering that the first two dimensions were more highly associated than metric aspects of space. They therefore suggested that *"reading the urban network in geometrical and topological rather than metric terms. We might say that the structure of the graph governs networks effects on movement and how distance is defined in the graph governs cognitive choices"* (Hillier and Iida 2005:562) [8].

1.6.- The problem of emergence

In her doctoral thesis, Ruth Conroy-Dalton (2001) argued that, although space syntax has been consistently successful in predicting movement patterns in cities and buildings on the basis of their configurational properties, the same cannot be said about why these patterns emerge. In other words, space syntax has predicted but not yet "explained" movement, making any possible linkage between the theory and cognitive science a matter of speculation. In order to overcome this gap, she decided to look at people's spatial behavior in detail, so to avoid the

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[8] The idea of representing spatial layouts with depth graph lies at the roots of space syntax. It implies that each space in a system is assimilated to a node in a graph and each connection between spaces is a step away from the graph's root. By using j-graphs one may compare, for example, different spatial systems or the relative depth of each space in a certain layout.

aggregation problem she considered intrusive.

Conroy-Dalton constructed seven virtual worlds and asked thirty individuals to navigate on them during ten minutes. Each environment was different from the others, both in terms of their appearance and in terms of their spatial structure. Thus, while some of them resembled real-world scenarios (e.g. the one simulating London's Barnsbury area), others were highly artificial (e.g. the triangular world). Since Conroy-Dalton had also constructed axial maps of these worlds, she then compared both sources of data (behavioral and environmental).

The author discovered that both visual properties and configurational properties of space were associated with people's movement patterns. She found out, for example, that people tended to pause at places of large visual fields, which in which they could obtain large amounts of environmental information in a rapid way. It was also shown that people moved linearly, that is, that they preferred those routes of lesser angles of deviation. However, what is perhaps the most interesting finding of her research is the fact that she demonstrated that movement patterns observed in virtual scenarios strongly resembled those observed in space syntax´s studies.

Another interesting study is that of Brösamle and Hölscher`s (2007), who, puzzled by the recursive regularities of some of the above studies, asked people to navigate in two different virtual worlds that possessed distinct levels of intelligibility[9]. This time, however, subjects were told in advance what they could expect from these environments. Thus, in the first scenario subjects were informed that they would explore an office layout, whereas in the second they were advised to find a sort of labyrinth.

Brösamle and Hölscher discovered that, as a result of these advices, subjects explored each world differently. In the first (the most intelligible scenario), they preferred well-connected corridors, whereas in the second (the least intelligible scenario) they chose integrated ones. They then concluded that *"human exploration behavior is not simply a network effect as scenario two does suggest. Instead they actively adapt their exploration activity in such a way that conceptually important axes where emphasized while "add-on axes" where de-*

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[9] The concept of intelligibility was defined by Hillier in the book "Space is the machine" (1996)

emphasized. It remains unclear however, if and how spatial properties are read exactly and how they are interpreted"(Brösamle and Hölscher 2007:130.6).

These studies show the increasing willingness from inside and outside the syntax community to address some of the recursive regularities found in syntax studies and perhaps more important, to attempt to explain them. There are, however, two relatively untouched aspects in most of these efforts.

1.7.-Towards a syntactic theory of cognition

In a recent article, Daniel Montello (2007) contended that, although space syntax has made important contributions to the analysis of the built form in an objective way, it has failed in providing an uncontroversial theory of spatial understanding. The reason for that is what was he called the circularity problem. According to Montello, the usual claim that space syntax should reflect people's spatial understanding, because it ultimately captures how they move in space, is not necessarily true, since people could be using configurationally salient spaces in cities and buildings simply because they learned to act this way, not because they inferred the configurational properties of space. Montello´s argument could be exemplified this way. Imagine child X is three years-old. Imagine he/she has to get new shoes and clothes. It is likely that child´s X´s parents decide to go to the city´s centre (which are highly integrated areas in most cases), to make the purchase, since in this area a large proportion of shops tend to concentrate. Repeated over time, child X will learn, by experience, that in centres he or she will get what he or she wants. Confronted with similar requirements in later, more autonomous stages of life, he or she might decide to go to the same place. In other words, Montello sustained that there is a **causal shortcoming** in a large part of space syntax studies, that makes it difficult to affirm that configurational aspects of space ultimately shapes people's spatial reasoning.

Here it will be argued that if space syntax is to establish a more prosperous conversation with cognitive studies, it needs to investigate whether persons can retrieve configurational information of space *without* incurring in any causal shortcoming, as those posed by Montello. It has, therefore, to investigate if *there is syntax in our minds*, as figure 1.2 shows. After all, this is the fundamental question in Hillier`s quotation; *"the fact that our minds recognized configurations shows that our ability to recognize and understand configuration is prior to the assignment of names"* (Hillier and Hanson:29)

This thesis will attempt to fill these gaps. By asking people to retrieve hierarchical information of spatial networks, this research will avoid the circularity problem posed by Montello, while at the same time, it will complete one of the uncontested issues in space syntax theory.

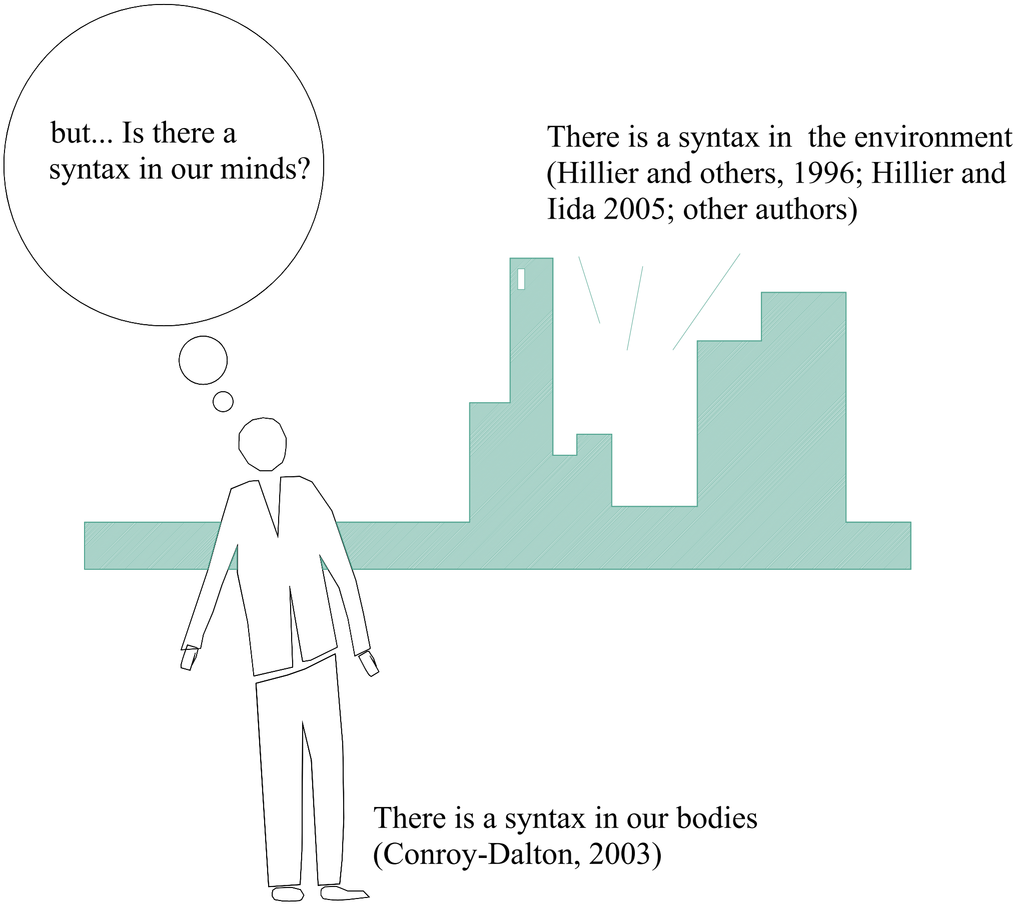

Figure 1.2: this thesis` fundamental question

chapter Two

Literature review

Abstract

This chapter will focus upon the body of literature review concerned with spatial cognition and the ways in which people's spatial understanding has been historically studied and measured.

The chapter is divided in three parts. Part One will briefly present the theories that have studied how spatial knowledge is gained in humans from the fifties to nowadays. Special attention will be given to present these ideas in context, stressing the current theoretical debates about the way in which spatial learning takes place in people. Part Two will critically examine the methods and techniques most commonly used for assessing how people gain spatial understanding, focusing on their respective advantages and limitations. It will be shown that these techniques have historically emphasized the role of landmarks as the fundamental piece of spatial learning. This, it will be argued, is due to the physical nature of landmarks that serve to disambiguate speech. By comparison, it will be contended, the role of configurational aspects of space has been somehow neglected by most cognitive theories.

Part Three will present one possible solution for this shortcoming, which consists in presenting maps to people, asking them to retrieve hierarchical information appearing in maps. Finally, some literature regarding this methodology will be examined and commented.

PART ONE

2.1.- The idea of spatial configuration in spatial cognition

It is normally agreed that the beginnings of spatial cognition as a discipline preoccupied with the ways in which space is mentally internalized, transmitted and occupied by subjects can be traced back to the seminal work of the American psychologist Edward Tolman (1948). Tolman published in 1948 an influential paper called *"Cognitive maps in rats and humans"* that described a series of experiments realized in deprived rats that had to look for food in mazes. Figure 2.1 shows what is perhaps the most famous of these experiments.

Consisting in a circular space upon which two paths of different length were constructed, the experiment started when a rat was placed at the entrance of the maze to freely explore the environment. Since the rat was hungry, it rapidly started moving around the maze, which lead it to find the food at the end of the longest alley. At that moment, Tolman took the animal out of the setting. Tolman repeated this procedure during four days, at a rate of three times per day, noting that after that period the deprived rat no longer explored the setting, but that, once installed in the maze, it rapidly took the longest alley in order to reach the food.

Tolman then made a clever move. He modified the maze by putting not one, but several alleys spreading in all directions, as figure 2.1b illustrates. At the same time, he blocked the path that in the previous scenario allowed the rat to satisfy their hunger. Next, he observed its behavior. To his surprise, Tolman discovered that one diagonal alley (shown in figure 2.1c) received far more visits than the others alleys. What was more interesting perhaps was the fact that had it been opened, this path would have permitted the animal to reach the food. He then concluded suggesting *"these results seem to indicate that the rats in this experiment had learned not only to run rapidly down the original roundabout route but also, when this was blocked and radiating paths presented, to select one pointing rather directly towards the point where the food had been or else at least to select a path running perpendicularly to the food-side of the room"* (Tolman 1948:44-45).

Attempting to explain this phenomenon, Tolman contended that the rat had developed a *"cognitive map"* of the environment, that is, a mental representation of the world de-centred from the animal itself that enabled the animal to have a sort of "bird-eye" view of the world .

Contemporary to Tolman but studying children rather than animals, the work of the Swiss psychologist Jean Piaget (1896-1980) is fundamental to understand the emergence of modern theories of spatial understanding. Piaget (1956; Piaget, Inhelder et al. 1960) maintained that spatial learning in the child is gained through a sequence of well-defined cognitive stages. These stages, Piaget suggested, were deeply related to the child's own sensorimotor apparatus.

In the first of these stages, spanning between years 0 to 2, the child would commence perceiving the elements and forms that surround him, forming as a result a set of elementary spatial concepts such as front-back or up-down. In the next stage, spanning from years 2 to 5-6, the infant would start exploring his environment, which permitted him to gain some confidence in his spatial abilities. During these explorations, Piaget affirmed that the child would start noticing that some distinctive features, like shops, squares or playgrounds, exist in the environment. The infant would then use such features to gain a sense of orientation in the world, by organizing them in mental sequences. Finally, around the age of six the child would start assembling these spatial sequences in a more comprehensive structure that worked in a similar fashion and Tolman's cognitive map.

Both Tolman and Piaget were fundamental for the development of subsequent theories of spatial learning in humans. The next points will show why.

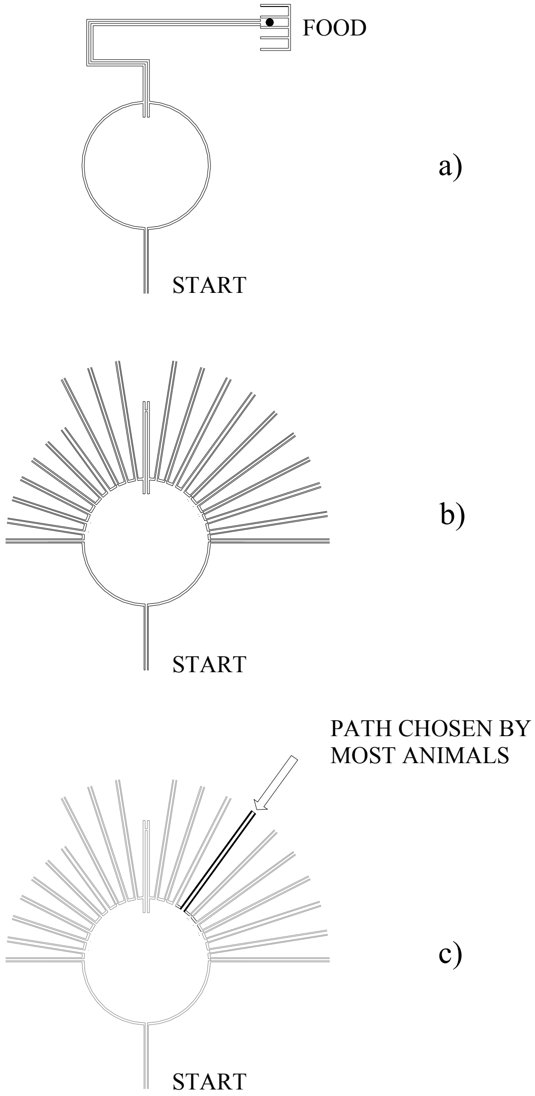

Figure 2.1a to c: Tolman`s most famous experiment

2.1.2.- Cognitive maps in adults and children

In 1975 Siegel and White formally refined Piaget's ideas, producing what is normally considered as the "classic" view of spatial learning. This contends that spatial knowledge follows an ontogenetic principle, from a state of relative globality and lack of differentiation to a state of increasing differentiation and hierarchic integration. In simpler words, this means that Siegel and White adhered to the sequential development of spatial learning proposed by Piaget twenty years earlier, suggesting that during infancy children naturally select and memorize distinctive features of their environments, and that this understanding gains complexity as they grow. However, the main contribution of Siegel and White`s theory was to extend this theory to adults, which lead them to state that a standard sequence governs people's spatial understanding of the environment. *"There may be a standard sequence of stages governing the organization of any human adaptation over time, regardless of age-time span of circumstances"* (Siegel and White 1975:46).

Siegel and White`s spatial sequence involved three distinct and well-defined stages: the landmark knowledge phase, the route knowledge phase, and the survey or configurational knowledge phase. During the first stage, Siegel and White suggested, individuals would unconsciously pay attention to distinctive features of the environment, the landmarks, in order to *anchor* their memories. *"A person's account of his spatial representations generally begins with landmarks and these landmarks are strategic foci to and from the persons modes of travel"* (Siegel and White 1975:46). In the second stage people would start memorizing the landmarks existing in some of their most familiar routes, forming as a result a "route knowledge". To Siegel and White, routes were sensorimotor routines *"for which one has expectations about landmarks and other decision points*" (Siegel and White 1975:46). Finally, repeated exposure to the world would produce an assembly of these routes, forming what they called configurational or survey knowledge. Like Tolman and Piaget, this understanding was of allocentric nature, as if the environment was seen "from the sky" (a bird's eye perspective). Moreover, Siegel and White contended that such understanding reflected people's ability to retrieve the underlying structure of the environment. *"The process of* *going from landmarks, to route-maps, to survey maps is a process of going from association to structure, and of deriving simultaneity from successively"* (Siegel and White 1975:46).

Another influential work belonging to the first phase of cognitive theories is that of Kevin Lynch. He maintained that cities produce certain *images* in their inhabitants, and that these images could give them a sense of emotional security (in case of a well-articulated one), or deter persons from exploring their environments (in case of a poor one). In order to create well-articulated images, he contended, an environment should be legible. Legibility, or *"the ease with which its parts can be recognized and can be organized into a coherent pattern"* (Lynch 1960:2-3), resulted from the interaction of five elements: paths, edges, districts, nodes and landmarks.

According to Lynch, paths were those elements like streets, passages or boulevards that channeled movement of good and individuals. Edges, on the other hand, corresponded to the boundaries between different urban areas or districts. Nodes were defined as strategic spots where two, or more than two, paths converged. Districts were large and recognizable sections of a city possessing a particular character. Finally, landmarks, the last of these elements, were distinctive and singular elements of a city whose role was to serve as reference points in the environment.

Lynch suggested that landmarks and paths were the most important elements in permitting humans to navigate in cities. Thus, while landmarks permitted subjects to determine their position in the environment, paths were considered crucial in permitting people to retrieve a city's structure. In Lynch's words, *"the paths, the network of habitual or potential lines of movement through the urban complex, are the most potent means by which the whole can be ordered"* (Lynch 1960:96).

Concordant with Tolman and Siegel and White, Lynch suggested that a city's image is not a precise, miniaturized reflection of the world, but a simplification of it made by reducing, distorting and modifying its parts. Further, he observed, people normally acquire a city's image in a fragmentary, mixed way, combining physical attributes (e.g buildings, facades) with non physical ones, like people, smells, textures or colors. Second, he also declared that in spite of these distortions, one's image of the city must preserve some topological invariance of places. *"It was as if the map were drawn on an infinitely flexible rubber sheet; directions were twisted, distances stretched or compressed, large forms changed so much from their accurate scale projection as to be at first unrecognizable. But the sequence was usually correct, the map was rarely torn and sewn back together in another form. This continuity is necessary if the image is to be of any value"* (Lynch 1960:87).

Another relevant perspective of the initial phase of cognitive theories is that of Golledge`s and colleagues. Known as the *anchor point theory* (Golledge, Smith et al. 1985; Golledge, Ruggles et al. 1993), Golledge suggested that spatial learning unfolds around *anchor places*, or areas where people are more likely to spend large parts of their lives. He distinguished three main anchor points: workplace, residence and leisure premises. According to Golledge, people will tend to explore the vicinities of anchor points more often than other places in cities, which means that these places will be known more profusely than the latter. This in turn would increase people`s willingness to make further explorations, forming an incremental process that could terminate with the spatial assemblage of routes.

The last theory to be presented here was proposed by the Swedish psychologist T. Gärling. Unlike Golledge, Gärling postulated that locomotion, rather than landmark knowledge, is the primary force behind spatial learning (Gärling, Book et al. 1984). He proposed that route knowledge precedes landmark knowledge or, in other words, that a path (and therefore all the procedural knowledge that this implies) is learnt before any landmark is mentally stored. According to Gärling, spatial learning demands people to define and execute travel plans, consisting in well-defined sequences in which people recursively have to move along a segment and pause at certain decision points. Although the author reckoned that some kind of spatial knowledge regarding the location of landmarks was necessary for travel plans, he contended that this knowledge could be inexact and superficial.

The aforementioned framework of spatial learning based on the successive addition of stages began to be nonetheless questioned since the eighties. In perhaps the most direct criticism to the traditional school, Montello (1992) argued that there is no time in which pure landmark or route knowledge exists. He proposed instead that spatial knowledge progresses in accuracy and resolution in a parallel way, that is, that metric and relational information of an environment gain definition simultaneously. Montello admitted that survey maps represent a qualitative change in the understanding of spatial knowledge, one that corresponds to the transition from feature-based mechanism to a more abstract thought. *"The process of acquiring spatial knowledge of large-scale environments is primarily one of quantitative accumulation and refinement of metric knowledge rather than qualitative shifts from non metric to metric forms of knowledge"* (Montello 1992:150).

The shakeup produced by Montello has had a tremendous impact in cognitive literature since the eighties. Proof of that is the series of theories that have emerged in the field, most of which share a less deterministic approach to how spatial learning develops in humans. Broadly speaking, these theories' main preoccupation has been to observe people's strategies to construct cognitive maps, rather than to attempt to delimit universal mechanisms for this commitment. As a result, the new focus has studied the distortions, exaggerations and incompleteness of people's mental representations of space.

It would be nonetheless unfair to sustain that the idea that cognitive representations of space are ultimately imperfect was proposed only by those scholars belonging to the so-called contemporary school of spatial cognition. The truth is that such idea can be traced back to authors like Downs and Stea, Kevin Lynch or Siegel and White themselves. Dows and Stea (1973), for example, argued that *"cognitive mapping are not acute. Precision in cognitive mapping cannot be related to metric distance but to spatial solving"* (Downs and Stea 1973:13), thus suggesting that these representations are far from being exact copies of the world. Lynch, on the other hand, contended that the image of a city is not a *"precise, miniaturized model of reality, reduced in scale and consistently abstracted. As a purposive simplification, it was made by reducing, eliminating or even adding elements to reality, by fusion or distortion"* (Lynch 1960:86). Lastly, Siegel and White declared that *"studies of adults` knowledge about their macro environment suggest that human "maps" are not literally maps. Rather, they tend to be fragmented, distorted protectively and are often several "mini spatial representations"* (Siegel and White 1975:46). What seems to have changed is nonetheless the idea that these constructions are the final stage of a process that, once completed, remains relatively stable over time. Instead, contemporary perspectives have tended to conceive spatial learning as an adaptive and ever evolving process whose role is to facilitate humans to adapt themselves to a changing world (Kaplan and Kaplan 1982).

Seeing it this way, it is unsurprising that Montello suggested that *“even in mature form, the knowledge is not particularly cartographic-like, insofar as it is typically imprecise, incomplete, fragmented and inaccurate to some considerable degree”* (Montello 1998:150), or that Golledge contended that cognitive maps are a *"series of knowledge consisting of different levels of detail and integration"* (Golledge and Stimson 1997:235) that might be equated to a sort of mental atlas. Further, it has been argued that *“there is no guarantee that spatial knowledge is internally consistent. Cognitive maps may be impossible figures”* (Tversky 1982:432).

2.1.3.- Bounded rationality, hierarchical reasoning and categorization, the principles of modern theories of spatial understanding

One of the earliest attempts to explain how human reasoning takes place in a context of imperfect and incomplete information was posed by the American economist Herbert Simon (1957). According to Simon, a complete picture of reality is rarely at hand when persons are forced to make decisions in the world, which lead them to seek reasonable, rather than perfect, solutions to their problems. Simon called this mechanisms a *bounded rationality*, a reasoning that uses simplified models of the world in order to “make sense” of it. Kaplan (1982), on the other hand, contended that people construct simplified models of the environment because the environment itself is sometimes a threat to their survival. To Kaplan, the primitive man could not wait in order to recognize the entire set of features of dangerous animals (e.g elephants), but to take some actions (e.g to run away) based on inferences,

To some degree, the idea that individuals use simplified representations of the world to deal with an ever-changing environment has been accepted as truism by most cognitive theories. Further, it can be argued that this idea has distilled into a more comprehensive theory: that human reasoning is categorical, that is, that environmental information is encoded into super ordinate structures by people in order to simplify its recalling. Categorical theories could be divided into three main schools: the memory constraint, the information retrieval and the embodied schools.

The memory-constraint school has argued that some psychological constrains existing in the human mind limit a person`s capacity to store information. According to this view, categorical reasoning is an innate strategy employed by people to increase the amount of information to be stored. Especially relevant in this context is the work of Johnson- Laird (1988), who suggested that two distinct memories coexist in the mind; the Long Time Memory (LTM) and the Short Time Memory (LTM), which are responsible, respectively, for storing past experiences or recent information. Depending on the relative proximity of events, environmental information would ignite the functioning of either LTM or STM, which would provide information to a third memory mental device, the Working Memory, to trigger the corresponding behavioral response.

The memory-constrain school has found several adherents in the cognitive sphere. Miller (1956), for example, argued that human memory is limited to the *magical number* of seven, beyond which a person's performance would decline. Cowan (2000) has questioned Millier`s number, contending instead that better performances in memory storing can be obtained if no more than four elements are to be memorized. Golledge (1985) has found out that repetitive environmental exposure to the environment results in more information canalized from STM into LTM. This in turn would terminate in forming a more robust spatial understanding, like the aforementioned survey knowledge.

The second school supporting people`s categorical thinking sustains that the environment itself can help people to organize information. Its roots can be traced back to the work of Goodman, who contended that humans are *worldmakers* (Goodman 1978), that is, they are always selecting and adjusting elements existing in the world in order to produce "plausible" meanings of it. This would demand individuals to organize information into classes, thus establishing common principles behind different phenomena. In Goodman`s words *"induction* *requires taking some classes to the exclusion of others as relevant kinds"* (Goodman 1978:10). Norman (1988) has further developed Goodman`s argument, sustaining that not all environmental knowledge required from precise behavior has to be in the head but that it can be distributed in the environment, that is, that human reasoning can be shaped by what exists in the world. A slightly different path seems to have been taken by Haken and Portugali`s (2003), who suggested that categorization starts when individuals recognize the existence of "unique" and "redundant" information in an environment by paying attention to both qualitative and quantitative characteristics of it.

The third line of thinking supporting categorization is linked to what is known as the embodied school. Epitomized by the work of Rosch (1975) and Lakoff (1987; Lakoff and Johnson 1999), this view sustains that certain categories of things (say, the category "tables") have prototypical exponents in which the crucial properties of the category are represented. To Rosch, prototypical elements will be considered as hierarchical in their respective categories, meaning that people would judge non prototypical elements of these categories in relation to prototypical references. For example, the number nine would be judged close to the number ten, but the opposite is unlikely. In other words, categorical thinking is an innate way in which persons make sense of the world.

There is psychological evidence that prototypical thinking is to some extent embodied. Tversky, argued that there is a "space of the body" (Tversky 1982), in which people will their own body`s axes (front/back, left/right and top/down) as coordinates references to convey directions and make angular estimations. She demonstrated that verbal descriptions of space are likely to be affected by these coordinates, for subjects tend to ignore minor deviations occurring to these coordinates. Tversky has suggested that categorical thinking occurs at other spheres of the human mind too. For example, individuals tend to encode spatial information in high-order structures which leads them to systematically exaggerate, omit, rotate, align and displace places and regions according to their position within super ordinate regions (Tversky 1992). Thus, Santiago de Chile would be judged by most people as being east of New York (in spite of being slightly west of it), because the former is located near the west coast of South America, while the latter is located in the east coast of North America (Tversky and Lee 1998).

Categorical theories have been fundamental for the development of modern paradigms aimed to capture how spatial reasoning occurs in humans. As Freksa has argued (1992), in the last years an increasing number of models belonging to the field of Artificial Intelligence (AI) have used categorical theories as heuristics to mirror people's understanding of space. Some of them have focused on the mental processes activating the different types of memory (Barkowsky 2001), whereas others have stressed the role of distinctive features on an environment (or its landmarks, (Chown, Kaplan et al. 1995)), or the pictorial characteristics of an environment in facilitating people's navigation (Raubal and Worboys 1999). This has distilled into a new series of theories whose main aim is to disguise "common sense" strategies used by people in their interaction with the environment. In Golledge`s words *"people just develop a sort of "common sense" configurational understanding of spatial phenomena, which accounts for incomplete and fuzzy cognitive representations of environments"* (Golledge 1992:2)

The quintessential nature of modern theories of human reasoning can be seen in Egenhofer and Mark`s "Naïve Geography" (1995), a set of principles aimed to capture human instinctive spatial reasoning. *"Naïve geography captures and reflects the way people think and reason about space and time, both consciously and unconsciously. Naive stands for instinctive or spontaneous"* (Egenhofer and Mark 1995:4). Here are some of the most relevant principles of this theory:

- Space is perceived as a two-dimensional entity: people reason about space as seen from the sky.
- The earth is flat: uneven terrain is usually dismissed in people's mental representations of the world.
- Distance assessment is asymmetric: people calculate distance differently according to trip direction.
- Topology matters, metric refines: people conceive space based on topologic factors, which are then "weighted' by metric factors.

Irrespective whether classic or modern theories or modern theories of spatial learning are to be believed, the truth is that spatial reasoning has physiological correlates. O'Keefe and Nadel`s (1978) have investigated this idea by analyzing the role of the hippocampus in determining how the sense of orientation is gained in mammals. According to this view, some cells (called "place cells") existing in the hippocampus fire when the animal is at a specific location of an environment. O`Keefe and Nadel showed that this firing is caused by proximity to walls and relative distance to surrounding boundaries, making possible for rats to develop an external and independent frame of reference of the world. "*The cognitive map in infra-humans should be viewed as a spatial map in which representations of objects experienced in the environment are ordered within a framework generating an unitary space"* (O'Keefe and Nadel 1978:380).

Nearly twenty years after Nadel and O'Keefe's work, Burgess et al (1999), also working at University College London, published another comprehensive review on the physiology of spatial cognition and perception. Supporting the theories of their colleagues, Burguess et al sustained that the parietal cortex also plays a fundamental role in permitting animals to gain an understanding of space. According to them, the hippocampus and the parietal cortex assist each other in developing human orientation and navigation, although the extent of this co-operation remains unclear. Broadly speaking, though, it seems that these systems are responsible for identifying elements and subjects in space (the *"what"* question*),* as well as for determining their locations (the *"where"* question). What is perhaps more interesting is the fact that the authors demonstrated that these findings could be seen in the human brain.

But how has this capacity been studied?, What are the commonest ways to study a person's spatial understanding? , Why are people's mental representations of space imperfect and incomplete?, Why do they change?

The following section will briefly attempt to respond to these questions.

PART TWO

2.2.- A revision of the techniques used to measure spatial knowledge

There are multiple techniques to assess a person's spatial knowledge, ranging from asking him to draw a picture of his environment or to recall its elements, to point at some of its locations or to estimate the distance between a pair of points. All depends on whether subjects are asked to physically navigate an environment (e.g. to traverse one of its routes), or to experience it indirectly, either by watching films, slides or pictures of it. The reader should be nonetheless cautioned that in most cases these techniques have been combined (e.g. subjects being asked to navigate in an environment and then to point at directions and to draw sketch maps of it, or participants being tested on sketch mapping and verbal recalling at the same time), which impedes the definition of a clear, unambiguous classification of methods. The list of papers presented here should be read as a brief compendium of the commonest ways in which spatial understanding in people has so far been assessed.

A typical form to measure a person's spatial knowledge in real-world scenarios is to ask him to perform directional or distance tasks. Directional tasks require subjects to point (either using their own body or some purposefully-built equipment), to some non visible landmarks or locations on it. These estimations are compared with the real position of these places (in terms of angular and distance correctness), which permits the researcher to assess the accuracy of these assessments. Distance estimations tasks, on the other hand, consists of asking individuals to determine the Euclidean, metric, or travel distance between two points of an environment.

A well-known example of the former category can be found in Montello and Pick's experiment on a medical setting (Montello and Pick, 1993). Consisting in two phases, in the experiment twenty-four individuals were asked to navigate two complex, large and partially overlapped routes. In the first phase of the experiment subjects were led along these routes and asked to pay attention to several landmarks located on them. This was achieved by a rather fictitious mechanism, in which individuals were told to stop during five seconds and to observe each landmark. At these points, subjects were ordered to speak these landmarks' names twice. Once both routes were entirely traversed, individuals were asked to recall all landmarks in the exact order they appeared. They were then asked to commence the pointing task, which demanded them to go to one landmark and to indicate other non visible ones in the setting. Montello and Pick found that people's judgments were more precise in the case of same-route landmarks, than in the case of different-route landmarks. Perhaps more important is the fact that pointing at landmarks was considered as an effective method to measure a person's spatial knowledge, for *"it requires people to recognize the place where they are located, access configurational knowledge of the route that includes the location of the target "extract", the straight-line direction between their current location and question and translate this into a response"* (Montello and Pick 1993:471).

Pointing tasks have been used in subjects lacking normal vision too. Passini et al (1990), for example, asked congenitally totally blinds subjects, adventitiously totally blinds subjects and visually impaired individuals with a residual sight to point, to a series of places in a confusing layout. Passini found that to some extent all groups could successfully perform the duty (although those who could see at least some of the environment outperformed the others), thus supporting the idea that to point at locations is a reliable way to asses a person`s spatial understanding.

Another common method to study spatial knowledge in people (frequently used in conjunction with pointing estimates) consists in asking them to determine the distance between a pair of points. A classic example of that is Kirasic et al`s experiment on a university campus (Kirasic, Allen et al. 1984), in which forty-eight students (half of whom were novice, the other half with at least three years in the campus), were asked to make distance estimations from three sighting locations (SLs) to nine target places (TPs) in the college. In the first phase of the experiment, individuals were asked to go to the SLs to estimate, using a piece of paper provided for such aim, the relative distance between them and the TPs. In the second part of the experiment, individuals were moved to an isolated room (from which they could not observe the rest of the building), and asked to imagine themselves in each of the SLs previously mentioned. They were then asked to make the distance estimates again. Kirasic et al found that both groups were equally effective when judgments were done in the real world, but that more experienced individuals outperformed novices when estimates were realized in the lab. According to the authors the fact that novice individuals could successfully point to non visible landmarks in routes demonstrated that they had acquired configurational knowledge, for *"pointing to landmarks within a route is a complex task, because it requires people to recognize the place where they are located, access configurational knowledge of the route that includes the location of the target, to "extract" the straight-line direction between their current location and question and finally to translate this into a response"* (Kirasic, Allen et al. 1984:479).

In another well-known experiment, Montello (1991) asked individuals to make angular estimates about the location of some landmarks existing in a city in two different situations: one demanded to make such estimates in streets that did not followed the city`s grid, while the other demanded people to infer the position of landmarks in streets that followed the city`s grid. Montello discovered that those who contested the task in oblique streets were less efficient than those who responded the queries in streets concordant with the city's structure.

Angular estimates could be affected by our own body too (Tversky 2003). In an interesting experiment carried out by Sadalla and Montello in 1989, it was demonstrated by the fact that people are more efficient in remembering angles close to the 0 and 90 degrees. It seems therefore that "*one of the first things we can observe about directional knowledge is that we do not conceptualize every potential direction that exists in our environments or to which our bodies could turn. That is, we do not demonstrate infinitely precise directional information. For most situations, qualitative information about directions—in the sense of a fairly small number of equivalence classes—is sufficient"* (Klippel and Montello 2007:354).

Criticisms regarding distance assessments are diverse as those concerned with angular ones. Foley and Cohen (1984), for example, have argued that estimations are more precise in shorter than in longer distances. Others (Canter and Kagg 1975; McCormack, Cerin et al. 2008), have shown that people systematically overestimate distance between non-proximal places but underestimate distance between proximal locations. In the same vein, Sadalla and others have demonstrated that distance estimations could be affected by the frequency of turns in a route (Sadalla and Magel 1980), the ease with which some information of this route can be recalled (Sadalla, Staplin. et al. 1979), or the number of intersections occurring to traversed streets (Sadalla and Staplin 1980). Further, it has been demonstrated that a person's attachment to certain places play a role in determining this person`s distance estimates (Smith 1984).

Perhaps the best way to understand the difficulties of assessing a person's spatial knowledge by asking him to estimate the distance between a pair of points is to describe an experiment realized in an university campus by Reginald Golledge (1995), one of the best known scientists in the field. Golledge asked thirty two students to draw eight routes between a series of distinctive locations in the setting. He discovered that most individuals traced different routes depending on the direction of travel, that is, that frequently the route they chose to go to from place X to place Y was different than the route selected when individuals had to go from place Y to place X. In the second part of the experiment, Golledge told individuals to physically navigate these routes, discovering that most individuals repeated the patterns observed in maps, that is, they took different routes between the same pair of points depending on the direction of travel. He then concluded that the most likely explanation for this result is that the routes were perceived differently in terms of length by participants depending on their direction of travel. This prompted the author to conclude that "*the real question is whether route selection criteria also change: from examining the actual paths taken and recording response times, and other variables, it seems that they often do"* (Golledge 1995:221).

The diversity of environmental and cognitive factors affecting the perception of distance has prompted some authors to dismiss distance estimation techniques as reliable indicators of a person's configurational knowledge (Cadwallader 1979). This is the case of Montello who contended that questions regarding distance estimation queries may be misleading, for distance itself can be measured in time, effort or length (Montello 1991). He argued that even an apparently simple question like asking an individual to mentally estimate the metric distance between two points demands to clarify what type of length (travel time, Euclidean, route distance) should be assessed.

As direct methods, indirect techniques also intend to reveal how spatial understanding is gained by people. However, they do not require individuals to physically navigate an environment, but to verbally or pictorially describe it. Indirect techniques are frequently combined with direct ones, although it is more common that two or three distinct indirect methods (e.g. a person is asked to draw an environment and to give a foreigner directions to reach a place), are combined in experiments. Four main families of techniques will be presented here: sketch mapping, verbal recall, slide and video presentation and map understanding.

Sketch mapping is one of the most popular techniques used to unveil individuals´ spatial understanding. Basically it consists in asking a person to draw a scheme of his environment in a piece of paper with as much detail as possible, and then to examine these depictions against the environment itself.

Apart from Lynch (1960), one of the earliest examples on the use of this technique in cognitive studies was made by Donald Appleyard in the city Guyana, Venezuela (Appleyard 1970). Appleyard asked people to draw two sketch maps: in the first of them individuals had to picture the whole city, whereas in the second each person had to draw their respective local areas. People were requested to place as many distinctive elements (or landmarks) as they could in the drawings, preserving at the same time the environment underlying structure.

Appleyard then examined these depictions in two ways: first, he studied whether maps were similar to each other, so to classify them in terms of their appearance, and second, he counted the number of landmarks, misplacements, omissions and distortions appearing on them. Appleyard found out that sketch maps could be divided into four main groups: fragmented, chain, branch and loop and netted maps, a sequence that, according to him, mirrored these maps passing from primitive to more complex representations. He also discovered that educated people drew more sequential and network-like maps whereas less-educated ones represented their environment in a more disorganized fashion, and that spatial errors (omission, mismatching and displacement of information) diminished as a product of formal education too.

Sketch mapping techniques have been defended because of their capacity to mirror wayfinding performance too. Proof of that is Rovine and Weisman`s experiment in which forty-five novice individuals were told to walk along a route of approximately ten blocks (Rovine and Weisman 1989). During the trip, individuals were required to observe some “imageable” and”non imageable” buildings in order to retain as much information of these buildings as they could. Low-imageable buildings, as defined by Rovine and Weisman, were basically simple store fronts with no distinctive outline, whilst high-imageable ones were physically distinct from their surroundings, either by their architectural style of proximity. Once subjects had completed the trip they were asked to draw the traversed route and its landmarks. Rovine and Weisman analyzed the drawings by counting the number of landmarks and path segments appearing on them, and by measuring the complexity of the maps, a procedure that was undertaken by employing a mechanism similar to Appleyard`s. Finally, they measured the wayfinding abilities of all participants, asking them to go to some previously visited places using the shortest possible route. After comparing all sources of data, Robinson and Weisman found that the number of landmarks appearing in sketch map was a good predictor of people wayfinding performance, meaning that the higher the number of landmarks, the better the spatial abilities of an individual.

Some authors have nonetheless questioned this result. Evans et al (Evans, Marrero et al. 1981), for example, asked forty French and American students living in America and France respectively to draw sketch maps of their campuses. Subjects were tested in two opportunities: immediately after arriving to their new countries and after a year of living on them. As per Appeyard`s approach, Evans told individuals to make maps as detailed and accurate as possible. He then examined these depictions by counting the number of landmarks, paths and nodes (paths intersections) existing on them, as well as the level of accuracy of these depictions. The main findings indicated that the number of landmarks in sketch maps remains relatively stable but what changes is how these landmarks are organized in the maps. *“Individuals initially comprehend the relative positions of items in space, but fine tune the exact location of items in space with increasing experience”* (Evans, Marrero et al. 1981:101).

In spite of its simplicity, relative economy and familiarity (Blades 1990), mapping techniques have been criticized by different authors. Gale et al (Gale, Golledge et al. 1990), for example, have suggested that *"recall and graphic representation of features is a relatively difficult task and may not be a good indicator of route learning activities"* (Gale, Golledge et al. 1990:14). Concordant with this opinion, some authors (Blaut, McClearly et al. 1970; Passini 1984) have argued that sketch mapping techniques under represent people's comprehension of environmental knowledge. In view of Penn (2003), subjects with good graphic abilities will tend to draw more comprehensible sketch maps than people who don't possess this capacity.

Here it will be argued that perhaps the main limitation of sketch mapping techniques is that they do not permit the researcher to observe some non discursive information about the environment existing in people`s minds, specifically the one concerned with relational information (in space syntax`s terminology, configurational information). As Appleyard suggested (1970), to ask a person to reproduce the scheme of the world and its components do not necessarily guarantee that all that he attended to of this environment's was what was depicted.

Another popular technique to reveal a person's allocentric spatial knowledge (frequently used in conjunction with mapping), is to ask him to give a verbal account of the environment. A classic exponent of this technique is Denis and Pazzaglia`s study in the city of Venice (Denis, Pazzaglia et al. 1999). Composed of four parts, Denis and Pazzaglia first asked twenty locals to write down three typical routes in the city of Venice with as much detail as possible. Next, the authors converted these directions in protocols, that is, in phrases with a predicate and one or two adjectives (e.g walk straight until you reach the bridge). They also listed all landmarks appearing in these descriptions, including in this category all monuments, streets, channels, distinctive places and squares. In the second experiment, Denis and Pazzaglia compiled all descriptions and constructed a major one, which they then passed to a new pool of individuals. They were told to shorten these descriptions as much as possible without loosing their clarity. In the meantime, the authors made a ranking of the most popular landmarks appearing in people`s descriptions in experiment one. Dennis and Pazzaglia then compared both sources of data, finding that a strong agreement between novice and more experienced individuals existed, and that that both groups were capable to define standard (or skeletal in Dennis and Pazzaglia's words) directions. In a third experiment, the authors distributed again all route directions obtained in experiment one, but this time they passed them to a select number of judges, half of whom were citizens of Venice, while the others were students coming from different parts of Italy. The authors asked them to rank these directions. They found that in most cases unfamiliar and more experienced judges coincided in their ratings, which seemed to reinforced the idea that there is a standard way to make route directions. Finally, in the fourth experiment, Denis and Pazzaglia gave another pool of individuals copies of route descriptions considered as good, bad and short by the judges of the previous experiment, asking a new pool of individuals to use these directions in their explorations of the city. They recorded theirdirectional errors, hesitations and requests for assistance. Perhaps unsurprisingly, they found out that good descriptions led people to few errors, while poor ones resulted in more mistakes. Dennis and Pazzaglia conclude that route directions are basically procedural statement in which landmarks play a crucial role, which prompted them to sustain that route instructions are mainly *"configurations of landmarks"* (Denis, Pazzaglia et al. 1999:170).

A similar but less landmark-centered stance has been taken by Tversky`s and colleagues. Tversky and Lee asked university students to give directions to a third party on seven well-known routes (Tversky and Lee 1999). Unlike Denis and Pazzaglia, Tversky and Lee gave subjects some toolkits consisting in procedural actions and landmarks to complete the task. Since toolkits were essentially basic, Tversky and Lee informed students that they could add further information to their descriptions. The main findings indicate that most subjects had enriched their directions with extra information, mentioning elements such streets signs and lights existing in routes. However, the authors commented, the commonest way to enrich directions was to place landmarks on them. The result is that route directions seemed to be a combination of landmarks and actions that ultimately formed a *procedural spatial statements* for people to follow.

Lovelace and colleagues (Lovelace, Hegarty et al. 1999) discovered that route directions are essentially sequences of landmarks and actions too. They asked individuals to give route directions of well-known route to a third party, and then assessed the quality of these instructions by counting the number of landmarks and paths segments existing on them. Next, they asked another group of subjects to rate these descriptions in terms of their quality to guide a foreigner to a destination. Lovelace et al found that highly rated routes were those that contained many landmarks, whereas poorly rated ones contained few ones.

In spite of their popularity, some authors have questioned the reliability of verbal descriptions of an environment as a mean to assess a person's spatial knowledge. Riesbeck, for example, contended that route directions do not necessarily reflect a person`s mental representation of the world but his capacity to memorize big objects (Riesbeck 1980). Vanetti and Allen (1988), on the other hand, argued that a person´s ability to define good route directions does not necessarily predict our ability to navigate successfully in the environment.

The third method aimed to disclose a person's spatial understanding in people to be commented here is to show him videos and slides of an environment. Basically it consists in showing a person a given path in a film or in slides, and then to ask him to identify the relative order of its elements. A classic example of this technique is that of Hirtle and Hudson`s (1991). Hirtle and Hudson asked three groups of sixteen persons to watch a film showing a short but broken route, and then to execute a series of spatial tasks. The first group had to see slides, the second a map and the third served as the control group. The slide group saw more than one hundred slides corresponding to a path of about twelve blocks that contained seven landmarks. As in Montello and Pick (1993), each time a landmark appeared in scene its respective name was loudly recalled and a red arrow was shown in screen and maps. In order to make sure individuals had memorized them, Hirtle and Hudson told individuals to recall five randomly selected landmarks in the exact order they were observed. Once these tasks were completed, individuals were asked to estimate distances between several pairs of points as means to disclose their understanding of the environment. The main results showed that, although all groups had developed some kind of configurational knowledge, the slide group was less precise in its spatial judgments than its counterparts.

Concordant with these results, Gale and others showed that seeing slides of an environment does not produce an spatial understanding of the same quality than real navigation (Gale, Golledge et al. 1990). Gale and others asked sixteen children aged nine to twelve to traverse two different but partially overlapped routes in a residential area of California, USA. Children were divided in two groups: one was ordered to physically navigate the environment, whereas the other was told to see slides of it. Both groups had to complete their tasks during ten consequent days. At the end of that period, the researcher asked them to make sketch maps of these routes.

Gale et al discovered that, although both groups could depict similar amount of features in their maps, the field group tended to be less diverse than the slide one in both the type and location of these elements. In practical terms, this meant that the field group tended to picture mailboxes and bus stops in their maps, whereas the slide group depicted other entities, like distinctive houses, trees and the like. However, such diversity did not mean that the slide group was more precise in its configurational understanding than its counterparts: as Gale et al reported, sketch maps of the former were far less precise and comprehensive than those realized by the walkers. The authors then conclude that attention to detail (but relative disregarding of more global information), seemed to be the price paid by those who had to watch slides, for this method did not result in a spatial knowledge as complete as real navigation.

With slight variations, similar results have been found by other researchers that have used slides and video as means to measure a person`s spatial knowledge (Evans, Skorpanich et al. 1984; Golledge, Smith et al. 1985; Cooper 1991), proving that although to watch videos or slides of a given route can somehow form comprehensive spatial knowledge, both the precision and stability of this understanding is poorer compared to the one gained by direct navigation.

The last indirect technique to be presented here regards the use of maps and aerial photographs. Broadly speaking, maps have been used in cognitive studies to respond to three main questions: if they produce a different type of spatial knowledge than the one resulting from real navigation, and if children can employ them as ways to represent space, and if people align them, or themselves, in the environment.

Example of the former is Thorndyke and Hayes-Roth’s work (1982), who compared the spatial abilities of people who apprehended the environment indirectly (that is, learning maps) versus the abilities of those who experienced the environment directly. Individuals were asked to execute pointing and distance tasks between different points. This time, however, distance assessments distinguished between time, route and Euclidean distances. Thorndyke and Hayes-Roth's found those who navigated in the environment directly outperformed map learners in all but Euclidean distance assessments, though the scale of these differences decayed in more experienced individuals. This prompted the authors to argue that *"map learners acquired a bird's eye view of the environment that encodes survey knowledge sufficient to support performance on a variety of estimation tasks"* (Thorndyke and Hayes-Roth 1982:585).

There is an interesting tradition of using maps in children too. A classical example of that is Stea and Kerkmann`s experiment in children aged between three to five years old (Stea, Kerkmann et al. 2004), in which a group of about thirty children were asked to search for a hidden toy (a monkey) in an open space. Children were divided in two groups: one had to read maps, whereas the other had navigated the setting physically. The map group were told to observe a bird's eye view of the environment, in which sixteen landmarks (a chair, some colored cupboards, several trees and a picnic table) were depicted. The navigation group was ordered to search for the same object without any help. Before proceeding with their searches, children were told to carefully observe each of the landmarks appearing in maps or existing in reality. Stea and Kermann found that most of those who received maps referred to them, though this trend was more accentuated in girls than in boys. Reading maps also resulted in a better performance, for mean times of completion were lower in the map group. Finally, it was revealed that age did not play a significant role in the experiment, prompting the authors to argue that map reading is a fundamental cultural ability that enables humans to carry on wayfinding tasks in macro-environments.

Concordant with these results, Freundschuch discovered that children were not only able to successfully use maps for wayfinding tasks, but also that they could perform successfully complex operations like aligning a map with respect to the environment (Freundschuh 1990). He asked children aged four to six to navigate in an environment in which some colored circles aimed to act as landmarks were painted on the floor. Children were then given maps showing these circles and told look for a hidden toy. Freundschuch discovered that most children could complete the task without problems, which lead him to conclude that an allocentric perspective of the environment is formed early in life.

Using a slightly different technique that employed aerial photographs instead of maps, Plester et al (2002) demonstrated that young children could match information coming from the environment with information appearing in maps. Plester et al asked thirty children aged to observe a map of their surroundings and to identify some of its features with those existing in the real world. They discovered that most children could identify places like their home or school in the map, despite the fact that none of them had previously observed these elements from the air.

The series of techniques presented here have shown that spatial knowledge can be assessed in different ways and that slight variations on these methods could produce rather contradictory outcomes. In other words, it seems that there is no neutral ways to measure a person`s spatial understanding, for all techniques have certain advantages and disadvantages. There is, however, a common aspect in all of them: so far they have put an exaggerated emphasis in employing landmarks as the ultimate pieces to asses a person’s spatial knowledge.

But what is a landmark?

The commonest definition of what constitutes a landmark is its visual distinctiveness. Lynch (1960), for example, contended that “*the key physical characteristic of landmarks is singularity, some aspect unique or memorable form the context”* (Lynch 1960:78), whereas Siegel and White argued that *“landmarks are unique patterns of perceptual events at a specific location, they are predominantly visual for human adults”* (Siegel and White 1975:23). But visual distinctiveness is per se a relatively ambiguous concept, for what is distinctive for one person might not be that interesting for another. Further, elements could de distinctive for several reasons, like their height, texture, color or material (Haken and Portugali 2003).

Perhaps aware of this limitation Sorrows and Hirtle have proposed that rather than being selected purely by their visual distinctiveness; landmarks could be defined by attending to some structural or cognitive characteristics (Sorrows and Hirtle 1999). Thus, some landmarks are defined because they are them “visually memorable' in their environments, whereas others (cognitive ones) are elements those whose meaning "stand out" in users` minds Finally, structural landmarks are those whose *"importance comes form its role or location in the structure of space"* (Sorrows and Hirtle 1999:46). But what ultimately defines a landmark is its capacity to serve in navigation tasks to users. *"Landmarks are prominent, identifying features in an environment which provide an observer or user of a space with a mean for locating oneself and establishing goals"* (Sorrows and Hirtle 1999:37),

Raubal and Werner, on the other hand, have attempted to clarify the matter, by distinguishing between physical, semantic and structural landmarks (Raubal and Winter 2002). Physical landmarks are those whose color, size, height, shape and visibility stand out from their contexts Semantic landmarks, on the other hand correspond to elements with great "historical or cultural" significance. Finally, structural landmarks are located at strategic points within a spatial system (e.g. major intersections). Unfortunately, Raubal and Winter's ultimate definition of landmarks: *"being a landmark is a relative property"* (Raubal and Winter 2002:245), does not seems to disambiguate the ultimate nature of landmarks.

As it can be seen, the main difficulty of cognitive theories is that so far no clear, unambiguous definition of what constitutes a landmark exists. Here it will be agued that such theoretical shortcoming ultimately has undermined most attempts to fully understand how spatial learning occurs in humans, for there is no clarity to what people attend or ignore, in order to gain a comprehensive understanding of their environments.

But why, if the idea of cognitive maps refers to the way in which things are related to each other, have most cognitive techniques employed landmarks as means to assess a person`s spatial understanding?

A moment's reflection indicates that what can be called the *landmarkization* of spatial theories (the utter reliance of landmarks as the ultimate pieces of spatial knowledge), can be explained by the fact that landmarks, unlike spatial relations, are easier to describe. This is because landmarks are physical elements that belong to the *real world*, meaning that persons can declare, for example, that "the ball is *behind the red shop*", or "keep going until you see a square with a *large fountain*". They serve to disambiguate speech.   Spatial relations, on the other hand, are exactly the opposite: they cannot be verbalized easily. How likely is, for example, that a person to say, keep going until you pass a intricate place, after that you will find a well- onnected space. I´ll be there waiting for you?

Various authors have recognized this problem. One of them is Appleyard himself (Appleyard 1970), who sustained that spatial relations are difficult to verbalize and that people use landmarks as distinctive information in order to disambiguate spatial information. In the same vein, Lakoff has contended that spatial relations are not physical entities as, say, a cat or a ball, they do not have real existence but they are mental representations of the world. *"When we perceive a cat in from of a car or behind a tree the spatial relations in front of or behind [ ] are not objectively there in the world. The spatial relation is not an entity in our visuals field"* (Lakoff and Johnson 1999:35). However, they exist "*at the heart of our conceptual system. They are what makes sense of space for us. They characterize spatial form and define spatial inference. But they do not exist as entities in the external world. We do not see spatial relations the way we see physical objects"* (Lakoff and Johnson 1999:30).

An additional problem to convey spatial relations is the fact that most languages are poor in terms to describe them (Lakoff and Johnson 1999; Hillier 2008). As Hillier has recently put it: "*Language has terms that deal precisely with spatial relations involving at most three entities, for example, the English prepositions such as between, inside, beyond, through are terms which all describe with some precision the relations of three things. Words like among describe more, but at a cost of less precision. In general, languages lack terms to describe complex patterns of spatial relations, and in fact complexes of relations of any kind"*(Hillier 2008:224).

In short, it seems that the landmarkization of most cognitive theories is caused by some methodological limitations rather than by theoretical assumptions. So rather than asking what is a landmark?, here another question will be posed: is it possible to employ *something other than landmarks* to reveal a person's spatial understanding?

2.3.- Is it possible to employ <u>something other than landmarks</u> to reveal a person's spatial understanding?

Unfortunately, this is not an easy question. Besides the fact that most languages lack precise terms to deal with spatial relations, there is another, perhaps more compelling difficulty; the absence of objectives methods to describe (and to measure) spatial relations. This is o say, even if a person can understand a relatively ambiguous term like "location X is rather inaccessible in city Y", few methods exists to evaluate such concept. This seems to explain why cognitive research has rather neglected the study of non discursive aspects of space, especially those concerned with relations among places.

Some exceptions to this rule exist, though. A particularly interesting one is Weisman`s work on plan configurations (Weisman 1981). Weisman asked one hundred independent judges to rate thirty plan configurations in terms of their complexity, preference, complexity, the ease with which each diagram could be described to another person, the ease with which each diagram could be memorized and finally the ease with which wayfinding tasks could be carried out in such buildings. In ten of these buildings, Weisman had previously distributed questionnaires to occupants in which he asked how difficult was to navigate on them. Results showed that a strong association existed between a plan configuration's judged simplicity and people self-reported navigational problems on it.

This is to say, plans configurations judged as simple by raters were at the same time plan configurations judged simple by occupants, whereas layouts considered as complex were layouts judged as difficult to navigate.

Weisman say little about why some buildings were considered easily navigable and why other didn´t, suggesting instead that the fact that people can somehow infer navigational problem by only attending to two-dimensional plans is per se, a noteworthy discovery.

Here it might be argued that space syntax could help to make Weisman`s findings even more interesting. After all, space syntax is not only a theory of space and society but also a set of techniques offering objective, measurable and comparable ways to represent space (Montello 2007). What is perhaps more important, space syntax is at the very end, a theory about spatial relations, precisely the most dismissed aspect of most cognitive theories of space.

But how space syntax`s techniques can be employed to study people`s understanding of spatial relations?

So far, the commonest form to respond to this question has been to compare movement patterns observed in real-world scenarios with configurational properties of these worlds. This is the case, for example, of Peponis et al (1990), Chang, Penn (1998), and Haq and Zimring (2003), who compared wayfinding behavior in a medical compound, a large multilevel and four hospitals respectively (for more information about these investigations, see the previous chapter). A less direct way to do so has been proposed by Young Ook and Penn (2003), who compared sketch maps made by people of an environment's against these maps` configurational properties.

Without question, these investigations have produced a valuable insight in showing how configurational information is captured in people`s minds. In fact, it can be argued that they are somehow responsible for the current interest in space syntax`s techniques coming from cognitive scientists, attention that has increased in the last five years. In spite of this promising scenario, two main shortcomings have so far limited the acceptance of these techniques to wider cognitive audiences.

The first of them refers to the circularity problem, recently posed by Montello and briefly discussed in chapter One (Montello 2007). To Montello, the fact that high associations might exist between a city`s configuration and its movement patterns is not necessarily an indicator that people think in configurational terms. This is due that there is no way to know if people go to configurationally salient places because of their configurational characteristics or simply because they learned (either consciously or unconsciously) to behave this way. This is to say: a person might have learned from past experiences (e.g. from infancy) that in central areas or in highly integrated streets an agglomeration of land uses exist, so he could repeat this behavior by going to these places in later stages in life. Thus, rather than thinking configurationally, this person would be merely repeating a habit.

The second criticism is subtler. To date, most syntactic studies on spatial cognition have neglected the role of metric aspects of the environment in shaping people's behavior. As Penn put it *"cognitive space is the space required to support the representation of this more global understanding of configuration based on some form of experience from learning, and this is the space that I believe may be not a metric space"* (Penn 2003:56). An example of such dismissal can be found in Peponis` work in hospitals (Peponis, Zimring et al. 1990), in which a series of correlations between configurational properties of space and movement patterns were undertaken. This was achieved by comparing the configurational properties of "choice nodes" (nodes resulting from the intersection of two axial lines) versus movement patterns observed in these nodes.. As a consequence, Peponis discovered that configurational properties of lines could robustly predict people's searches.

But what about these nodes' mean metric length?. Could be the case that individuals rather than attending to configurational properties of space, simply chose the longest line of sight to navigate?. Unfortunately, no mention to metric aspects is reported in this work, nor in the works of Haq and Zimring (2003) or Chang and Penn (1998)[1]. It seems logical therefore to study the role of metric aspects in people's understanding of space.

To summarize: until now cognitive theories have put an exaggerated emphasis on landmarks as means to disclose a person`s spatial knowledge, neglecting in the meantime the role of configurational information of space. Although space syntax appears to be a reasonable way to tackle this limitation, most research to date have either incurred in the circularity problem or have disregarded the role of metric factors. In order to present these arguments in a more comprehensible way, table 2.1 presents what should be done and what should not be done to enrich the promising dialogue between space syntax and spatial cognition.

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[1] A notable exception to this rule is the work of Tedjo, B. and K. Funahashi. *Strolling behavior around the neighborhood for leisure and spatial configuration*, presented in the Second International Space Syntax Symposium, that took place in 1999 in Brasilia. In this paper the authors discovered that metric factors were more important than configurational ones in predicting pedestrian movement flows.

Table 2.1: This thesis’ main aims

	SPATIAL COGNITION	SPACE SYNTAX
What to employ	Statistical analyses of groups	Objective spatial descriptions
	Follow-up experiments	Spatial models
	Emphasis on experimentation	
What to avoid	Use of landmarks	Montello´s circularity problem
		Omussion of metric factors

2.4.- Towards a cognitive syntax

In 2003 Hillier titled a paper with the suggestive statement *“is there a syntax of spatial cognition?”* (Hillier 2003:06:1). He responded himself affirmatively, suggesting that people make use of metric and visual properties of space as means to retrieve the structure of their environments. Following Hillier`s example, in this chapter a similar question will be posed: is there a manner to gain access to this cognitive syntax without falling in the circularity problem posed by Montello?

Here it will be argued that a promising way to respond to this question is to ask people to retrieve configurational information from spatial networks depicted in maps. As schematic representations of environments (that could be created on purpose), maps permit the researcher to evaluate how people encode configurational information. Further, since maps could be made highly abstract, they are potentially good mechanisms to evade the use of landmarks, one of the main limitations of most cognitive research- As Appleyard, sustained *“maps picture spatial relations difficult to verbalize”* (Appleyard 1970:116), permitting researchers to “*re-present the world by providing versions of truth for human minds to apprehend”* (Appleyard 1970:283).

The following section will explain how maps could be used to progress in the formulation of a syntactic theory of spatial cognition.

PART THREE

2.3.1.- Does the eye think?

If maps are to be used to observe a person's configurational understanding, it seems logical to first investigate how they work. This, in turn, demands to know how vision works, for maps are understand essentially by virtue of vision.

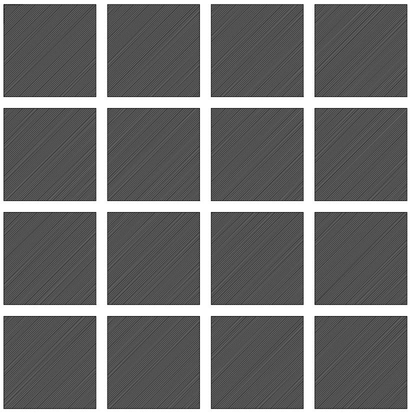
In a very simplistic manner, vision occurs at the eye by the activation of foreveal cells which detect the iridescence of surfaces. This information is then transmitted to the neurons that construct an image, which is then checked against the environment. It follows that persons can see by automatically activating a recursive process in which environmental information is transmitted by the eye and converted in images by the brain. Presented this way, vision seems to be a rather simple, automatic process.

The truth is nonetheless much more interesting and complex than that. Vision is not only a psychophysical process in which the brain receives electrochemical pulse of various frequencies from the eyes, but a cognitive process in which the brain selects, dismiss, and attend some information of the environment in order create plausible images. As Marr suggested *"vision is a process that produces from images of the external world, a description that is useful to the viewer and not cluttered with irrelevant information"* (Marr 1982:31). It is precisely this characteristic of vision (its capacity to provide the subject of relevant information) which permits persons to, for example, perceive stables images of the environment, in spite of the fact the world in inherently dynamic (1950; Gibson 1979). *"If the brain were not continually trying out organizations of data, for searching purposes, such as faces, the cartoonist would have a hard time. In fact all he of she does is to present a few well-chosen lines and we see a face, complete with an expression. This essential process can, however, go over the top and make us to see faces in the fire, galleons in the clouds or the Man in the Moon. Vision is certainly not infallible"* (Gregory 1998:6).

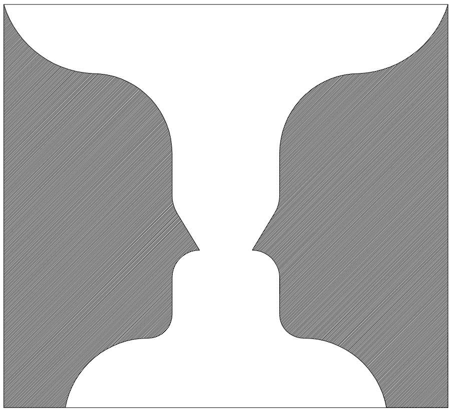
But how does the brain organize what it sees?

Marr sustains that order to extract "useful" information and discard "irrelevant" information, the brain first identifies the objects to be seen, and then it constructs a plausible description of these shapes in space. Since these operations would demand to orient the perceptive apparatus to certain type of information, he contends, vision could be considered *"an information-processing task"* (Marr 1982), that is, a mechanism in which information is manipulated and encoded, rather than merely transmitted, by the eye. Gregory (1998) has affirmed that or this process to occur, the eye should define some perceptual *hypotheses*, which are then examined by the brain and returned to the visual system to further inspection. It seems therefore that in order to see, a series of attentive and pre attentive processes have to be performed in a recursive manner (Kosslyn 1991).

As it names indicates, pre attentive processes are involuntary processes caused by the combination of psychophysical and cognitive mechanisms of great complexity. On the contrary, attentive processes require some conscious effort on the part of users. Two examples serve to clarify these ideas. On the first of them (figure 2.2a), a series of black squares have been disposed upon a white surface. Known as the "Hermann grid illusion", in this experiment subjects can perceive smaller grey squares at junctions, in spite of the fact that these squares do not exist in reality. They are, in synthesis, the resultant of pre attentive visual processes. Working in a opposite way, the Rubin´s vase-case figure (1915), shown in figure 2.2b, illustrates the operation of attentive visual processes, for to "see" any of the figures a person has to consciously segregate the other to the background. The next section will briefly present show such processes take form in map reading.



a)



b)

Figure 2.2a: The Hermann grid illusion: small dots are perceived at intersections

Figure 2.2b: The Rubin's vase-face ambiguous figure

2.3.4.- The role of Gestalt principles in vision

One of the earliest attempts to explain the puzzling nature of perception is that of the Gestalt (Koffka 1935; Kohler 1947). According to this view, human perception is driven by one principle, the principle of *pragnanz,* which organizes what exists in the world in order to make sense of it. *"Our reality is not a mere collocation of external facts, but consists of units in which no part exists for itself, where each parts points beyond itself and implies a larger wholes"* (Koffka 1935:176). This means that human perception does not merely "absorb" external information but that molds and shapes what comes from the environments in order to form plausible meanings. This is achieved by the operation of several perceptual laws:

- The law of closure, that assumes that regular figures will be "completed" by the mind
- The law of similarity, which states the mind groups similar elements (depending on some properties such as color, shape, size) forming aggregate units.
- The law of proximity: under which proximal objects will be treated as a one unity.

- The law of symmetry: that indicates that symmetric figures will be seen as joint entities.
- The law of common faith: visual entities moving in the same direction will be perceived as belonging to the same object.
- The law of good continuation: which states that visual entities organized along a smooth line or curved will be perceived as belonging to the same object.

By far the most relevant of these laws, at least in relation with map reading, is the law of Good Continuation. This is because the world is populated by sinuous flows of natural (e.g rivers, coastal borders) or artificial nature (e.g streets, highways), that are normally perceived as a continuous paths rather than as isolated entities (Thomson and Brooks 2002). Beck et al suggested that the principle of Good Continuation operates in the early stages of visual processing (Beck, Prazdny et al. 1983). To Beck, people would naturally form a this stage would result in a primal sketch of the world which would be then enriched by other properties such as brightness, color, size and the slopes of lines.

Marr also argued the principle of Good Continuation operates in the first stage of vision. According to Marr, the visual process can be divided in three sequential phases. In the first of them., persons would form a "primal sketch", in which "*explicit important information about the two dimensional image, primarily the intensity changes and their geometrical distribution and organization"* (Marr 1982:37) arrives to the brain. This would permit persons to perceive blobs, line discontinuities or groups of things in the environment, as well as the existence of boundaries, edge segments or curvilinear organizations. In the second phases, called by Marr as the "2,5 sketch", this image would be refined in terms of orientation and rough depth of visible surfaces. The resultant image would then gain resolution and applicability, though still with high degrees of "fuzziness". Lastly, the image would gain definition and organization, forming what is known as a 3d image.

The brief description of vision serves to understand how complex is to use maps as means to disclose a person's spatial understanding.

2.3.5.- How a maps are read

Since map reading is essentially a visual process, it is not surprising that cartographic theories have several points in common with visual ones. This is the case of one of the most comprehensive reviews on map reading realized to date; MachEachren`s *How maps work* book (1995) .

As Marr, MachEachren contended that maps reading involves the operation of pre attentive and attentive processes. However, he said, map reading also demands to encode semantic and lexical information, for people have to interpret the meaning of signs appearing in maps, as well as the series of cartographic conventions appearing on them. To MacEachren, signs could be of universal or specific nature, which in turn will depend on the map`s own purpose. For example, tourist maps will tend to employ unspecific signs (e.g. a plane representing an airport), whereas economic maps (e.g. a geological one) could employ signs of difficult comprehension, at least for untrained individuals. Similarly, a map`s scale is crucial to determine the appearance of some features (for instance, local lanes, distinctive sites). This phenomenon is known in cartographic jargon as the cartographic generalization, and states the information appearing in maps will be both simplified (Monmonier 1989; Mackaness and Beard 1993; Mackaness 1995), and generalized (Mc Master 1987; Boutoura 1989; Longley and Batty 1989).

The underlying complexity of map reading has prompted some authors to contend that prior to map understanding, a meta-knowledge (Barkowsky and Freksa 1997), that is, an ability to read symbols (and to ignore certain simplifications and omissions of them) in relation with the type of map to be read, is necessary. "*To interpret the contents of these media, knowledge about maps in general and knowledge about the specific type of map involved is necessary. Much of the knowledge applicable to a given level of representation can be meaningfully applied to other levels of representation as well, thus adding to the problem solving capabilities. However, the application of a given piece of knowledge may not be correct on all levels of representation. Certain kinds of cartographic misinterpretation can be explained by the application of inappropriate knowledge for a given level of generalization"* (Barkowsky and Freksa 1997:12) .

2.3.2- How maps work

In spite that maps have been used since ancient times (Raisz 1962; Elliot 1987), it is widely agreed that the origins of cartography as a scientific discipline can be traced back to the work of the American Arthur Robinson. To Robinson (Robinson 1952), maps were communication devices whose main objective was to transmit certain messages to users. In order to facilitate this task, cartographers had to learn how to manipulate the graphic and semantic information appearing in maps, in order to define the most adequate type of lettering, style, scale or colouring in a map. This means that cartographers had to know the type of cartographic conventions necessary for making maps understandable. *"From colors to boundary lines, and from lettering to projections, the field of cartography lens, or rather reclines, on its conventions"* (Robinson 1952:9).

Robinson was perhaps first cartographer that studied conventions in a scientific manner, and whose main objective was to improve the effectiveness of these mechanisms. In practice, this meant that Robison attempted to eliminate those conventions that did not facilitate map reading and instead, to preserve and improve those who did. Robinson`s stance quickly gained many adherents in the cognitive field. In fact, in the thirty years that followed the publication of *The look of maps* a series of cartographic techniques appeared in America, such as Keates` "Cartographic design and production" (1973) or Fisher's "Mapping information" (1982).

Another consequence of Robinson`s ideas is a new interest in observing people´s physical responses to map reading. One of the earliest of such studies is that ofYarbus` (1967), who undertook a series of experiments on eye-tracking in map reading. Several researchers followed Yarbus example during the seventies and eighties (Castner and Lywood 1978; Antes, Chang et al. 1985), progressively refining the scope and precision of this technique (Steinke 1987).

Some authors have nonetheless questioned the impact of these investigations, at least in relation with the discipline of cartography. Montello (2002), for example, maintained that despite the fact that eye-tracking studies were meant to help map designers and cartographers to make better maps, were rarely acknowledged outside academic spheres. Moreover, he contended, most of these experiments` findings were discrete, meaning that they did not help much to clarify how maps are read. *“Many cartographers had recognized the potential value of eye-movement studies but came to believe that it told the mapmaker nothing he or she did not already know. Conclusions such as “subjects look more at areas of the map that contain relevant information” or “different map designs produce different eye-scan paths” were not earthshaking revelations”* (Montello 2002:293).

The second criticism is perhaps more fundamental. It contended that, although the study of the practicalities of map usage might improve map design, it would scarcely contribute to a more comprehensive understanding of how maps work. This is to say, even if a cartographer has learned how to manipulate some cartographic conventions, thus making it possible for a map to be understood more easily, this says nothing about the cognitive mechanisms employed by people to arrive to such understanding. *“There is no reason that cartography should direct all its research energy to questions of map functionality. In the long run, a more complete understanding of how maps work would be an equally worthwhile goal”* (MacEachren 1995:22).

The precedents of this criticism can be found in the works of Olson (1979), and Salitchnev (1978), who during the seventies started questioning the assumptions posed by Robinson. Olson maintained that maps are representations aimed to initiate mental processes, rather than actions, in subjects. According to him, cartography should be more preoccupied with the mental processes triggered by map reading than by people’s responses to graphic stimuli. Salitchev suggested that maps should be considered information-processing systems, which involve a series of reflective processes of pre-attentive and attentive nature.

Concordantly with this view, Eastman (1985) argued that in order to understand maps, people have to perform bottom-up and top-down cognitive mechanisms. Furthermore, he argued that the mechanism by which these operations were assembled together in order to create a plausible meaning of a map, demanded subjects to define syntax, a set of principles aimed to organize the semantic and graphic information appearing in a map. *"Syntax embedded within the symbols themselves, and thus the order of reading may take any course to suit the* *individual. However, the relationships between symbols remain, regardless of the order to reading, and it is up to the perceiving individual to explore and make sense of those relationships within the context of his or her cognitive realm"* (Eastman 1985:99).

In his own extensive review of maps, MacEachren adhered to the view that maps are information-processing systems (MacEachren 1995). To MacEachren the communication paradigm failed in understanding the ultimate nature of map reading because wrongfully assumed two aspects: first, that a map's purposes are foreseeable, and second, that people will understand a map in a unequivocal way when adequate conventions are utilized.

Aiming at proposing an alternative model of map understanding, Pinker said that in order to comprehend a graphic image, people unconsciously activate a sequential process in which some of the already mentioned Gestalt principles will be complemented with other visual processes of pre attentive character (Pinker 1990). According to Pinker, this image would be then “interrogated” recursively by the brain, forming as a result the type of plausible visual descriptions that maps represent. Figure 2.3 exemplifies how this model works.

Complementing Pinker`s model, MacEachren and Ganter’s (1990) developed their own (see figure 2.4), which proposed that pre-attentive visual processes somehow *inquire* primitive visual schemes, thus triggering a series of visual inspections that give form to plausible representations of maps. The main difference of this model with respect to Pinker`s is its emphasis on the role of categorization as a guiding principle in human vision.

The emergence of information-processing theories can to some extent be equated with the emergence of contemporary approaches of spatial understanding. In fact, both views have challenged some existing assumptions of rather determinist nature, proposing instead that human reasoning is highly adaptable and dynamic. Likewise, both perspectives are now mainstream theories, meaning that they somehow set the agenda in the cognitive and cartographic fields respectively.

Seeing it this way, it is not far from the truth that information-processing theories of cartography have contributed to modernize an otherwise conservative discipline, introducing a whole set of new ideas aimed to understand the ultimate nature of vision. This, in turn, has enabled researchers all over the globe to start a series of compelling questions such as: *"What are the map maker's options for resolving conflicts between competing geographic features in the map making process?, Which map features can transmit multiple messages and in which ways may these messages conflict or harmonize, Which role plays the context of features in a map, What kind of general map knowledge is employed in a given interpretation task and to what extent does specific knowledge carry over from one given situation to another"* (Barkowsky and Freksa 1997:12)

This thesis should be read in this context. By studying how people retrieve non discursive spatial information from artificial spatial networks , this thesis hopes to avoid the causal shortcoming of many studies carried out by researchers belonging to the space syntax's sphere, so to see whether people can obtain qualitative information from space. As a consequence, this thesis aims to respond to questions such as: What are the cognitive processes employed by people to infer configurational information?, What would happen when configurational information does not coincide with metric information? How do people react in such circumstances?

2.3.3- Incoming chapters and topics

In order to respond to these questions, the next chapters will show a series of experiments with maps. The first of them, shown in chapter Three, will attempt to respond whether people could use geometrical information of space appearing in maps in order determine their direction of gaze. Consequence of a collaborative effort between UCL, The University of Huddersfield and the Ordnance Survey (Britain´s cartographic agency), will show that relational (or configurational) information of space could be employed by people to solve domestic spatial tasks.
The second experiment, shown in chapter Four, will use a different methodology. Rather than asking people to observe simplified maps of cities (as in the previous experiment), in this opportunity maps will be more abstract, resembling Nolli representations. Three scenarios will be tested in this experiment. In the first of them, the map will have streets of identical width. In the second, a short and poorly-connected street will be widened in order to make it to appear as more important. Finally, in the third scenario the widest street will correspond to a long

and well-connected road. People will be told to “walk” along one street until reaching the main street of the map. It is expected that the experiment will show the role of configurational and metric aspects of space in enabling people to retrieve hierarchical information from maps.

The third experiment, shown in chapter Five, will refine the technique sketched Before,, consisting in asking people to identity the “main street” of a map. The main difference is that all streets will have the same width and that people will be asked to outline, not only the main street of the map, but also the three main streets of it, as well as the three most important junctions. These questions attempted to observe whether people could grasp different scales of hierarchies appearing in maps, as well as to see if seemingly important streets are related with seemingly important junctions.

The fourth experiment, shown in chapter Six, will continue this line of enquire but employing maps that will look alike but whose configurational and metric properties are rather distinct. This means that individuals will be asked to outline the main street, the three main streets and the three most important junctions of three maps, in order to observe how flexible and adaptive are people´s cognitive apparatus when forced to retrieve spatial information from spatial networks.

The fifth experiment, shown in chapter Seven, will also demand people to outline the main street of a map, but this time each individual will be asked to assess only one map. Two different worlds, world H and world V, each depicting a long and well-connected street, will be built. Each of these worlds will be modified in three different ways, forming as a result eight slightly different scenarios. Unlike the previous experiment in which several changes were introduced in maps, in this experiment all maps will be identical except by one small misalignment occurring to streets H and V. This change was designed to alter the degree of synchrony between metric and configurational properties of these lines, which means that in some maps streets H and V will be the longest and configurationally most salient paths, but in others this won´t be the case.

Finally, the last chapter will summarize the results of all experiments, putting them in a more comprehensive context.

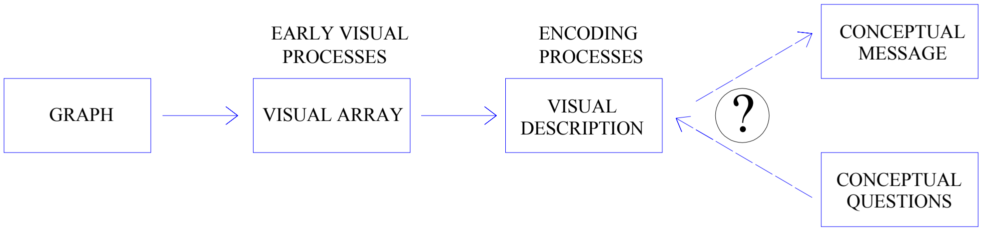


Figure 2.3: Pinker`s model of visual information associated with graph comprehension.

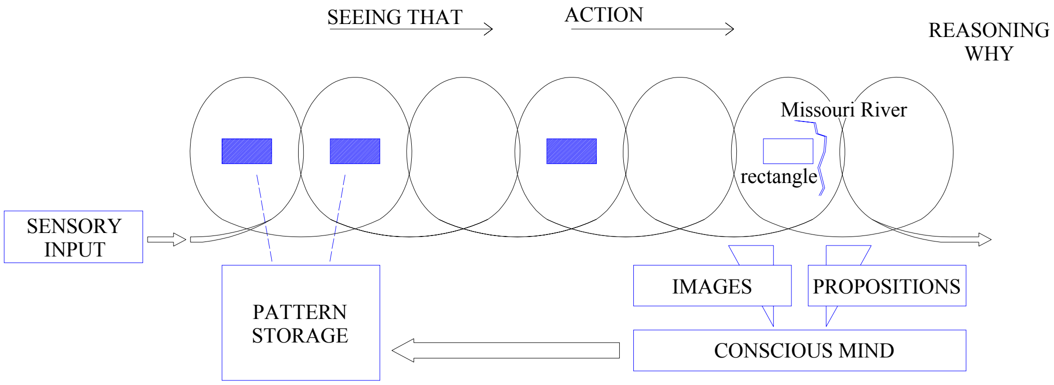


Figure 2.4: MacEahren and Ganter`s model of map understanding (1990)

chapter Three

The role of isovists in orientation

Abstract

This chapter presents a collaborative project between University College London, the Ordnance Survey (Britain's cartographic agency), and the University of Huddersfield on the role of isovists in map reading. The research employed isovist analysis in the context of a "drop off" directional task, in which participants had to match a city's scenes with their respective plans. A total of forty-nine subjects and sixteen locations were tested in this experiment, resulting in a total of twenty-nine scenes. Behavioural data (directional errors and time of completion) was then compared against the spatial geometry of all charts.

Two hypotheses were tested. The first assumed that people will infer and use the scenes´ isovist properties in order to solve the task. The other considered that people will attend to some environmental information regarding some of the scenes´ distinctive features, or landmarks, to define the initial match necessary to fulfil the problem.

The main findings show that isovist properties themselves are insufficient in explaining people's strategies to match plans and scenes. In fact, the analysis of people's responses revealed the existence of a "default" mechanism employed by most people, which consisted in attending, simultaneously, the spatial geometry of scenes and the presence of landmarks. Nonetheless, those who preferred to notice the scenes` geometry had more correct responses than those who preferred to be guided by the scenes´ landmarks.

These findings suggest that people can infer the geometric structures of space and that this information can be used to disguise some directional judgements of their position in space.

3.1.- Introduction

The previous chapter presented a summary of the methods and techniques that to date have been employed to assess people's allocentric spatial understanding. It was argued that most of these techniques fail in detecting configurational information of space and, conversely, tend to stress the role of landmarks in people´s spatial understanding. In order to overcome these limitations, it was argued, the assessment of spatial understanding in people should use mechanisms that purposefully evade any reference to landmarks and, instead, investigate how they internalize relational and structural information of space.

This is the first attempt in that direction. Using isovist analysis, this research aimed to see whether people can use geometrical information of space to solve a typical spatial dilemma: the "drop off" [1] orientation task.

The problem could be summarized as follows: imagine that subject X has been invited to celebrate subject Y`s birthday in a trendy and central restaurant. Imagine too that subject X has neither visited the restaurant before, nor its neighbourhood. All what person X knows is that he should arrive at tube station Z and then walk about five minutes until he reaches the place. Fortunately, he has a map.

The day of person Y's birthday, person X arrives punctually to station Z with the map at hand. Looking at it, he distinguishes some street names and salient places, like parks, roundabouts, squares and the like, and perhaps some functional entities (e.g. "a school" or a "police station"). He then tries to link some elements appearing in the map with some elements existing in the environment. How is this achieved?

The commonest way to do so it to pay attention to the map's most distinguishable features (e.g. a square, a monument, a rare building) and to look for them in the environment or vice versa. Once this initial match making is achieved, person X would probably define an action plan to reach his goal (Golledge and Stimson 1997).

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[1] This regard s the problem facing by an observer who has to use a map in an unfamiliar place. A good example of this situation can be found in London's tube stations, which display maps on their walls for users to read.

Ideally, person X should arrive at his friend's party without complications. However, different causes may turn this mission especially difficult. For example, in the dark some of the map's distinctive features may be indistinguishable, so the necessary match making between map and scene could be impossible. It also might occur that some buildings have been expanded or demolished, meaning that there is no longer a correspondence between what is shown in images and what it is observable in reality. Asking for directions or attending street names might not always be possible or advisable.

What should person X do?. What other sources of information might help him to solve the problem?

A moment's reflection indicates that there is another strategy that subject X might employ. This consists in attending the map's spatial geometry, or the way in which streets, buildings and distinctive places are distributed and organized, and to compare this information against the environment[2]. For example, subject X may have noted that he is facing an extended and uninterrupted street and that the short and sinuous street at his right ends abruptly two blocks away.

This is the topic of this research. Aiming to see whether people, in the absence of clearly recognisable landmarks (see previous chapter), can pay attention to configurational information of space in order to solve the problem.

3.2.- Theoretical preliminaries

The immediate precedent of this research can be found in the work of Conroy-Dalton and Bafna, who in 2003 analyzed the syntactic dimensions of Kevin Lynch's book *The image of the city* (1960). In their paper, Conroy-Dalton and Bafna analyzed whether the five elements that, according to Lynch, were responsible for forming "a city`s image" (landmarks, edges, districts, nodes and paths), had some syntactic correlates. In other words, they attempted to see if space syntax could also explain how the environment was mentally internalized by subjects.

Conroy-Dalton and Bafna proceeded by constructing the axial map of Boston, and then compared its structure with the one proposed by Lynch. In order to do so, the

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[2] The spatial geometry of space may change when buildings are constructed or demolished too

authors divided these elements into what they called spatial descriptors (paths, nodes and districts), and visual descriptors (landmarks and edges). They then compared these descriptors against the configurational properties of the city, employing, for such aim, one of the most traditional syntactic techniques; the axial map.

Conroy-Dalton and Bafna concluded that all Lynchian elements could somehow be understood syntactically, that is, that a city`s image (as defined by Lynch) was utterly dependant of its configurational structure. For example, they suggested that prominent paths corresponded to highly integrated axial lines, or that notable nodes are captured by the encounter of two or more configurationally salient streets.

The crucial argument posed by Conroy-Dalton and Bafna regarded, however, the ultimate nature of landmarks. As in other theories preoccupied with the ways humans perceive space, Lynch suggested that landmarks are attended by both their distinctiveness and their location. This is to say that for a landmark to be noticed, it might be placed at a hierarchical location in a city and, at the same time, it might posses singular characteristics in relation to its context. "*Our hypothesis in this paper is that, personal landmarks set aside the inhabitants' 'consensus landmarks' are those whose visual catchment regions can be accessed from spatially integrated lines of movement, and have a distinctive isovist shape"* (Conroy-Dalton and Bafna 2003:59.18).

Conroy-Dalton and Bafna's suggestive ideas prompted the Ordnance Survey (OS)[3], Britain`s cartographic agency, to initiate an investigation on the role of isovists in orientation. As an institution preoccupied with the design and confection of maps, OS wanted to generate a model that automatically could select the most appropriate landmarks in maps, so to facilitate the necessary map matching required in wayfinding tasks. Isovist analysis seemed to be a logic way to explore the subject.

Besides this practical dimension, the research also has theoretical implications, for it permitted to study how people can retrieve spatial information of non discursive character in order to perform what could be considered a simple, familiar spatial

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[3] The Ordnance Survey is the institution in charge of producing all kind of maps in Great Britain. Its origins can be traced back to 1746, when King George II commissioned a military survey of the Scottish highlands. Today, the OS`s maps are produced for a great variety of uses, from GIS systems to educational, economic or social data.

task. In that respect, this research seemed perfectly appropriate as a starting point of the fundamental question of this thesis, which attempted to see whether people could internalize configurational information, because what people could see in the charts (as it will be shown in the next section), were in fact *different spatial systems*. This means that people could see that chart X was a network in which all of streets converged to a point at the centre of the figure, whereas in chart Y there was no such a convergence, for its streets finished at three main locations. It was hypothesized that people could imagine the field of view of a person standing at a given location of these environments, and therefore to use this information to infer this person's direction of gaze. The next section will present the results of this investigation.

3.2.1.- About isovist theory

Although the term isovist was firstly mentioned in the work of Tandy (1967), the concept has more in common with the work of Gibson (1950; Gibson 1979) and his idea of "visual flows". Gibson, an American psychologist preoccupied with the way in which the environment is visually perceived by people, posed a fundamental question: how do individuals form a unified version of the world if they only see partial images of it?

Gibson responded to this question in an elegant way. He suggested that although individuals have a partial view of the environment (what he called the visual field of the area potentially observable by an individual's eyes), motion allows them to infer the stability of the external world. As humans move, Gibson said, the visual field constantly shrinks and expands, reflecting the fact that opaque barriers appear and disappear from a person's retinal image. In order to form a unified and plausible representation of the world, a subject has to make inferences and to imagine the surfaces and objects abruptly disappearing from view. This would permit a person to detect *"the invariant structure of the house, the town, or the whole habitat"* (Gibson 1979:198).

Gibson's ideas were highly influential on the work of Benedikt (1979), who simplified them in order to construct what he called an isovist. Defined as the *"set of all points visible from a given vantage point in space and with respect to an environment"* (Benedikt 1979:47), an isovist is in fact a planar description of

Gibson´s idea of field of view, without the inclusion of the vertical dimension. Figure 3.1 shows an example of an isovist.

Normally traced at eye-level, isovists were conceived as a way to depict, in an objective manner, how the world is visually perceived by humans. *"An observer's perception is thus circumscribe, if not determined, by the environment-as-presented at the point of observation. A cumulative understanding of the form of the environment is arrived at by perceiving variants and invariants in the transformation of the information available caused by the observer's movement "* (Benedikt 1979:48).

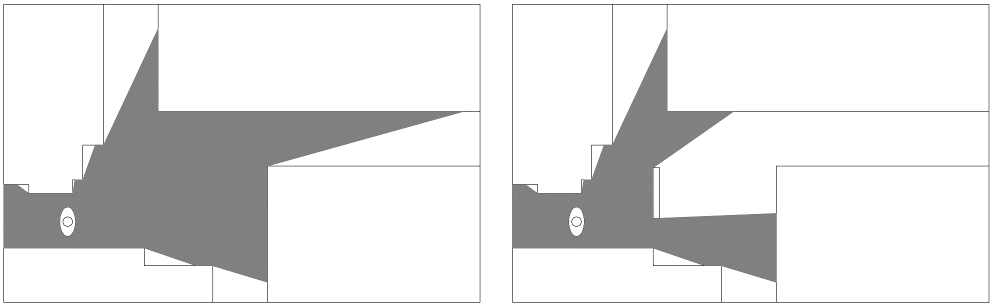

Figure 3.1: a person`s isovist in a invented environment in two situations. On the left no wall interrupts his field of view, on the right an occluding opaque barrier has been placed in front of him.

Benedikt saw in isovist analysis an objective method to analyse how humans perceive space. He exemplified this idea by showing the case of a hypothetical museum guard[4], in charge of a series of valuable items in an art gallery. In order to comply with his duty, Benedikt argued, the guard would probably define an economical path (a trajectory that enables him to visually inspect all elements in the setting), and a minimum set of locations to survey these items. Benedikt went on by suggesting that spatial layouts set the basis for a person`s visual experience of it. *"Thus a description of an environment by means of isovists allows one to study not only the environment but also something about the visual experience of it"* (Benedikt 1979:51).

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[4] This problem has became a well-known mathematical problem. A series of papers have been written in the last forty years aiming at solve it.

In 1985 Benedikt and Burnham proposed a series of isovist measures, most of which resulted from the relation between an isovist`s area and its perimeter (see next section). They then studied if any of these measurements could serve to predict people's idea of "spaciousness", by asking subjects to observe a highly irregular layout from different points of view, and to determine the place with the largest visible space. Results showed that the measure of Occlusivity could predict to a reasonable degree participants` impressions. *"We perceive an area as being more spacious when we see less wall surface, rather than more, and when we see less space around the corner rather than more"* (Benedikt and Burnham 1985:112).

During the last twenty years, a growing number of researchers (especially those belonging to the space syntax community), have utilized this technique to assess the visual properties of spatial schemes. Batty (2001), suggested that isovist analysis sheds light on two of the fundamental aspects of visual perception: *how much* and *how far* an individual can see in an environment. He employed isovist analysis to study these properties on three different scales of the built environment: a building, a neighbourhood and an entire village. Like Benedikt, he discovered that isovist analysis could not only picture the visual affordances of each of these environments, but also that isovist analysis could inform an external viewer about the visual experience of a person navigating in these worlds. Concordant with Batty, Conroy-Dalton (Conroy-Dalton 2001; 2007) has shown that people tend to intuitively navigate along well-connected routes of ample and extended isovists, and that pauses are likely to occur at places with large and "spiky" isovists.

In the same vein, Turner and Penn (2002), discovered that isovists analysis can, to some extent, predict people's movement's patterns in indoor environments. The authors used data from a previous study that followed more than one-hundred persons during ten minutes at the Tate Britain Gallery, in London, in which recorded people's trajectories and pauses. This data was then compared these results against the gallery's visual configuration, finding that people tended to circulate along highly visible spaces. In 2003 Turner employed isovist analysis in a popular area of London (Turner 2003), revealing that visual properties of space could also predict people's dynamic occupancy of streets.

Another interesting work on isovist analysis is that of Peponis' et al, (2004). In order to understand how people explored exhibition settings in open layouts, the authors followed several individuals in their visits to four exhibitions in USA. Peponis et al, measured how people interacted with what was being shown in the setting, distinguishing for that purpose, people's visual contact with a display, as well as their engagement with what was being shown. The former category was meant to happen when an individual could gain visual awareness of a given exhibition setting, whereas the latter category was meant to happen when an individual stopped at an exhibition setting in order to interact with it. They discovered that the artefacts more visually connected to other artefacts received more attention (and hence, more visits), than those with lower degrees of visibility.

Similar results have been found in squares, too. Campos de Arruda (Campos 1997), for example, observed static occupancy patterns in twelve squares in London. She then compared these results against what she called "overlapping isovist analysis", a method that combined axial and isovists analysis and reflected the degree of visual exposure of these spaces. Campos de Arruda discovered that stationary patterns of occupancy were inversely related to the degree of overlapping point isovists, meaning that highly exposed places were avoided for most people, who instead tended to choose more secluded locations. Thus, *"the user is in control of how far he wants to be visually exposed but without losing the ability to see. Only when the more secluded areas are taken, users gradually start to occupy the more exposed"* (Campos 1997:6).

Another interesting study is that of Chang and Penn`s (1998) in a multilevel setting in London. Puzzled by the poor association between configurational properties and movement patterns observed in the setting, Chang and Penn turned their attention to the visual properties of space, especially how much visual information individuals could obtain at decision points. They discovered that systematic disorientation problems in the precinct were due to the existence of short and local vistas, which deterred them from a comprehensive understanding of the entire layout.

In an attempt to explain the role of visual perception on human locomotion, Penn and Turner (2001), have moved one step forward, by developing virtual agents provided with a simple stochastic architecture whose unique input is to retrieve the visual properties of space. In order to do so, they built some virtual agents, and made them to navigate the environment purely guided by its visual properties. Penn and Turner discovered that the agents, despite lacking any intentionality, could robustly reflect how people moved in real-world scenarios. *"The agent can infer the affordances of the environment, or at least information on the global spatial relations visible from their current position in the environment"* (Penn and Turner 2001:105),

Before completing this section it is worth reviewing the work of two German psychologists (Wiener and Franz 2004; Wiener, Franz et al. 2007), who recently have undertaken a set of virtual experiments occupying isovist analysis as a mean to disclose people`s qualitative judgements of space.

In the first of these experiments, Wiener and Franz (2004) constructed sixteen virtual rooms whose appearance resembled art galleries. Next, they asked people to freely explore the environments at their own pace, so to get accustomed with them. After that, subjects were told to go to what they thought were the most exposed and concealed places of these rooms. Wiener and Franz then examined people's choices according to their visual characteristics. The authors discovered that individuals were highly effective in detecting both the most exposed and secluded locations of the different layouts. Further, they discovered that some isovist properties could predict these behaviours.

In another experiment Wiener and Franz (2007) asked subjects to navigate in virtual rooms of different shapes (and hence, of different isovist characteristics), and then to describe these rooms according to a protocol. They found that qualitative judgements of scenes were highly related to some isovist properties, specifically to what the authors called an isovist "complexity", resulting from an isovist's area and perimeter. *"Isovist analysis provides generic descriptions of architectural spaces that have predictive power for subjects' spatial experience and behavior"* (Wiener and Franz 2004:56).

Despite its effectiveness for mirroring people's visual experience in space, some methodological limitations have undermined the massive use of isovists analysis in the assessment of the built environment. One of them refers to the idea that isovists analysis, as originally defined by Benedikt, was a procedure dependant on a researcher's judgement, for point isovists were not arbitrary, but corresponded to the points where the person in charge of the analysis decided to trace isovists.

As a result, isovist analysis allowed the researcher to capture the visual experience of a subject at these points, but it fails in detecting the visual properties of layouts themselves.

Aimed to overcome this shortcoming, Turner proposed in 1999 a method called Visibility Graph Analysis or VGA, that consisted in placing a virtual grid upon the visible space of a given layout and then calculates the visual relationships among the resulting cells (Turner and Penn 1999, Turner, Doxa et al, 2001). Although VGA does not draw isovists in a strict sense because an oblique line is drawn as a set of vertical and horizontal lines, rather than as single entity, it enables the researcher to picture a person's visual experience of the environment in a similar way to Benedikt's.

Unlike vector-based isovists, graph-based approaches do not depend on the user's criteria for the location of vantage points, but they are defined automatically once the grid is set. Another difference between isovist and VGA analysis is that the latter depends to some degree on the resolution of the grid defined in the open space. If, for example, a large grid is imposed upon a layout that contains a system of occluded barriers (say, a row of columns), this technique may be inadequate to represent realistically how much one can see. It is therefore crucial to define at the beginning of the study both the kind of barriers to be considered as an opaque barrier, and the resolution of the analysis.

The second difference regards the type of isovist constructed. Due to its reliance on an underlying orthogonal grid, graph-based isovists draw oblique lines as sequences of vertical and horizontal lines, rather than as straight vectors, as in conventional isovist analysis (see figure 3.2). This is a major limitation (at least for this experiment), insofar as it distorts an isovists perimeter and area. For this reason, this experiment has only used vector-based isovists, as originally proposed by Benedikt.

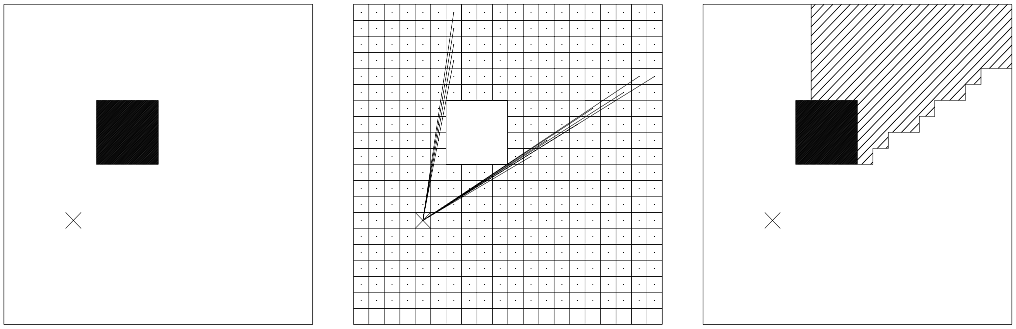

Figure 3.2: VGA`s way to construct isovists

3.3.-Method

Materials and Design

Behavioral data was collected and processed by Ordnance Survey and the University of Huddersfield [5]. All subjects responded to the experiment in a PC computer (17” display).

The representation occupied for this experiment belongs to Ordnance Survey and corresponded to a buildings-only 3D model overlaid on OS MasterMap _R Topography Layer and draped on an OS Land-Form PROFILE. The corresponding maps were circular sections of OS MasterMap_R Topography Layer at 1:1250 scale.

Scenarios

The scenario for this research was the English city of Southampton, where Ordnance Survey’s headquarters are located. As an institution concerned with the design of maps, Ordnance Survey had previously developed a virtual 3D model covering most of the city for research purposes, which was then utilized in this work. The model comprised most environmental information like streets, houses, parks and distinctive buildings. These elements were nonetheless unadorned, that

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[5] An extensive account of the psychological dimension of this work can be found in Peebles, D., C. Davies and R. Mora. (2007). Effects of landmarks, geometry and orientation strategies in the "drop-off" orientation task. Proceedings of the Conference in Information theory, COSIT 2007, Melbourne, Australia.

is, reduced to simplest forms, meaning that their environmental information such as fences, signage, windows and doors, vegetation or land uses was removed (see figure 3.4a).

A total of sixteen locations of the city were selected for the analysis, attempting to differentiate them as much as possible (see figure 3.3). For example, scenes were placed in the city's downtown, whereas others were located in post-war or traditional residential areas. In order to make a more efficient use of the 3D simplified model, some locations served for more than one scene (e. g. locations e10, e4 and p3), resulting as a consequence in twenty-nine charts. Figures 3.4a and 3.4b shows one of the charts presented to individuals.

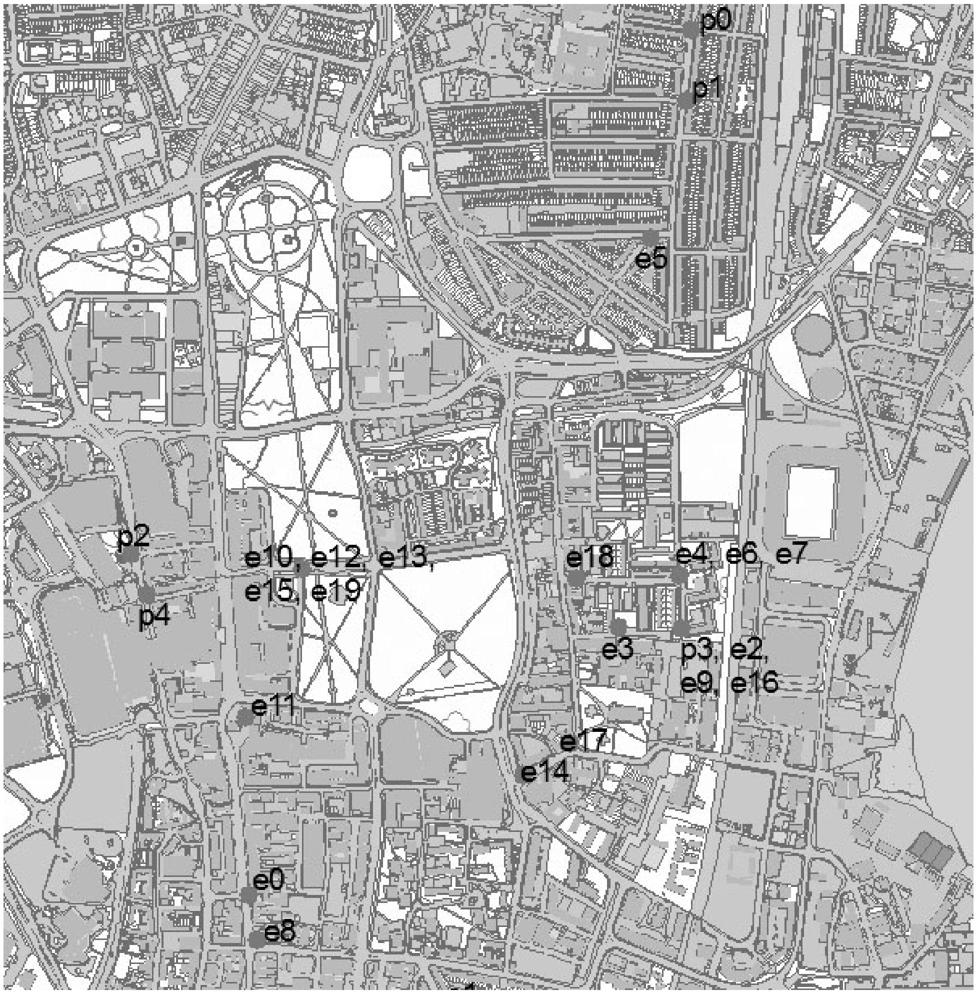
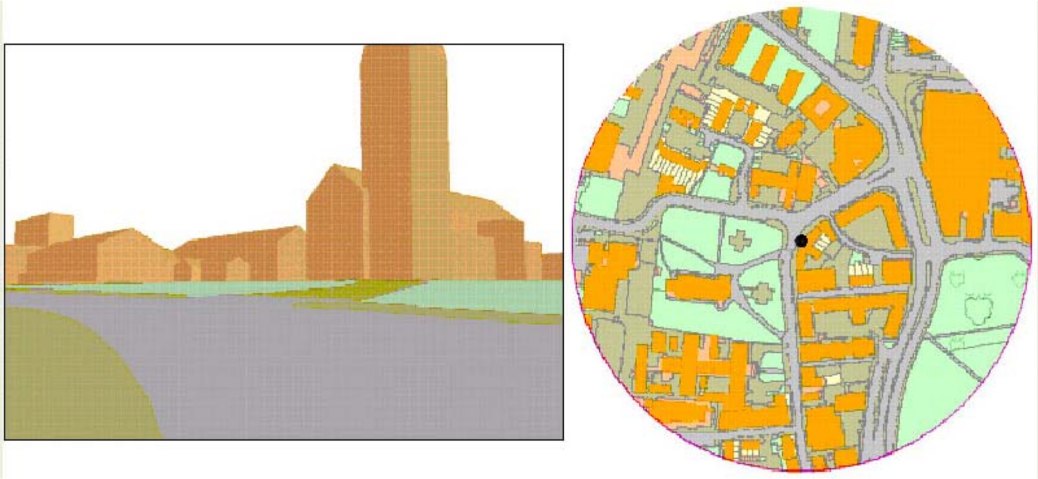


Figure 3.3: Map of Southampton with the locations of this experiment's scenes



a) b)

Figure 3.4: two sources of information of an urban space: a) 3d model of a scene (left) , and b) its corresponding map (right)

Participants and procedure

A total of forty-nine subjects took part in this study, most of them staff and students from the University of Huddersfield. They received the following instruction: *"Imagine that you are standing in a street in an unfamiliar town, holding a map. You know where on the map you are standing but you need to find out which way you are facing"*.

A circular map and a scene of the simplified model of Southampton accompanied the instruction (see figure 3.4). They were then told to indicate to which direction they should be facing on the map in order to see the scene depicted. Subjects had to click on the map once they thought they had aligned the scene and the map. A revolving cursor was provided for that purpose.

An initial learning phase, comprising a total of five charts, permitted individuals to familiarize with the experiment. After that, participants were instructed to proceed with the task. Participants were asked to respond as rapidly and as accurately as possible. It was also noted that all maps had the same scale, and that they should not assume that the 'upwards' direction on the map indicated 'forward' in the environment. All scenes were shown in a random order.

Each individual had to respond to a total of twenty scenes, and both their time of completion and directional errors were recorded. Correct responses were considered when angles fell within fifteen degrees from the real angle in either direction, leaving a 30º degrees angular area of "correctness".

Initial assumptions

Since vegetation was not included in the OS model, it was not considered in any of the analyses performed in this research[6]. The study was then carried out considering parks as open spaces. Each scene was initially restricted to an area of two-hundred meters radius, assuming that people could visually distinguish environmental information up to two blocks away.

Once the circles were drawn, an exhaustive revision of all scenes detected some interesting phenomena. First, since all charts were coloured, subjects were potentially able to distinguish between two types of built forms. One was orange and corresponded to what the model considered as "stable information", or opaque barriers like houses, buildings or walls. The other was pink and corresponded to some soft barriers representing mezzanines or bus shelters which, unlike the former, are less stable.

Since subjects were unaware of these differences and might consider pink and orange information as being impermeable boundaries, in this research two types of models were defined. The first of them considered that only walls, buildings and houses worked as opaque barriers. It was, therefore, called the *walls* model. The second assumed that and *soft* barriers like mezzanines, bus shelters and roof also acted as impermeable limits. The latter was called the *roofs* model.

The second assumption defined at this stage referred to the amount of environmental information potentially retrievable by subjects. A moment's reflection indicates that a radius of two-hundred meters might be considered as too extensive to recognize things or persons in the environment. Gehl (1971), for example, suggested that the *social field of vision*, or the distance at which figures becomes personas, terminates at about one- hundred meters, and that beyond that point persons can only distinguish silhouettes, not faces. In order to introduce a metric dimension in the analysis, this research distinguished between short-isovist scenarios, and long-isovist scenarios. The first category assumed that people did

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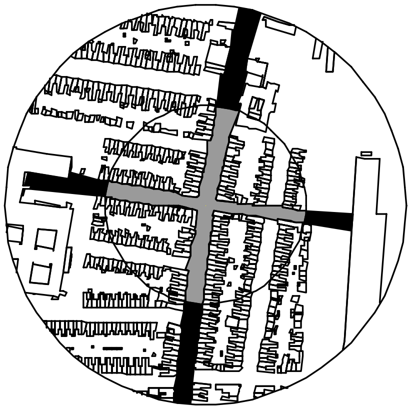
[6] Vegetation is a complex problem for Isovist analysis, because there is not way to know, unambiguously, how much a person can see through foliage.

not inspect the entire area of maps, but that they only paid attention to what occurred in the vicinity of the starting points. For the sake of simplicity, proximal information comprised environmental information existing up to a radius of one-hundred meters from the plans` centres.

By comparison, the second category assumed that subjects assessed the entire area of maps, in order to solve the task demanded in this experiment. This meant that isovist were set up to a radius of two-hundred meters from the starting locations. Figure 3.5 shows an example of both categories, by illustrating the area covered by an one-hundred meters isovist, and a two-hundred meters isovist.

The combination of perceptual and environmental variables resulted in four different scenarios: short-isovists/walls model; short-isovists/roofs model; long-isovists/walls model and finally long-isovists/roofs model, as table 3.1 illustrates.



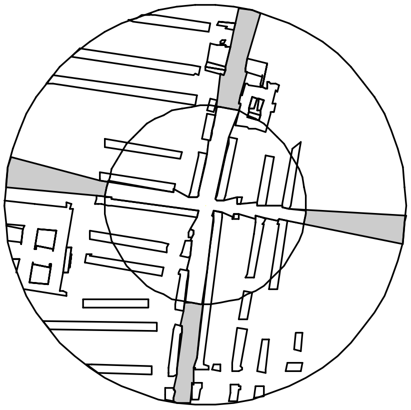


Figure 3.5a (left): the *walls model,* isovists at r=100 and r=200 meters

Figure 3.5b (right): the *roofs model,* isovists in r=100 and r=200 meters

Table 3.1: the kind of models studied in this research

		Environmental Variables	
		Walls Model	Roofs Model
Perceptual Variables	Short Isovist (r=100)		
	Long Isovist (r=200)		

Descriptive account of isovist shapes

Figure 3.6 presents the sixteen locations in which isovist were traced. For the sake of brevity, in this occasion short and long isovists are shown simultaneously, meaning that inner red circles depict “short” isovists (r=100m), whereas outer blue circles depict “long” isovists (r=200m).

At a first glance it seems that no common pattern exists among these shapes, since some isovists are rather small (e.g. location e11), whereas others are enormous (e.g. location e10). Likewise, some isovists have well-defined shapes (e.g location p1), whilst others have no conventional forms (e.g locations e3 and e17).

Aimed to investigate these shapes in a more objective manner, the next phase used the computational software Depthmap[7] to trace isovists. Along with the shapes, Depthmap delivered a series of isovist measurements resulting from a combination of those proposed by Benedikt (Benedikt 1979; Benedikt and

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[7] The author is very grateful of Alistair Turner for his assistance. He was fundamental for the completion of this project.

Burnham 1985), Conroy-Dalton (Conroy-Dalton and Dalton 2001) and Wiener and Franz (Wiener and Franz 2004; Wiener, Franz et al. 2007). These are: Area, Perimeter, Occlusivity, Compactness and Jaggedness[8]. The data regarding these measurements is shown in Tables 3.2 and table 3.3 (*walls* and *roofs* model respectively).

But what do these measurements represent? How do they relate to each other?

To respond to these questions, the next phase compared to what extent these measurements were associated to each other, so to dismiss the isovists variables that were expressing similar visual properties, and which ultimately might affect the construction of a predictive model, the main objective of this investigation. Results of this operation are shown in tables 3.4 and 3.5.

A rapid inspection of these tables reveals some interesting phenomena. First, poor associations between the measurements of Area and Perimeter were found. For example, the highest association between these values reached r = 0.25, whereas the lowest was r = 0.19. This is at odds with most research in the area (Benedikt and Burnham 1985; Conroy-Dalton 2001; Stamps III 2005), and demanded a more conscious examination of the results. Second, relatively high associations were found between the measurements of Area/Compactness, Jaggedness/Occlusivity and Compactness/Jaggedness. This seems to be of little surprise, since Occlusivity, Compactness and Jaggedness are all measures derived from the combination of Area and Perimeter. Finally, it was detected that associations among variables were slightly higher when long isovists (radius 200) were analyzed.

In order to explain these results, especially the puzzling result obtained when the measurements of Area and Perimeter where compared, all isovist shapes were inspected again in order to detect any possible unusual element that might be affecting these correlations. It was immediately clear that this element was isovist **e10**, whose shape was, unlike all others, nearly circular. Since a circle is by definition the most efficient way to cover an area with the minimum perimeter possible, it was evident that all measurements depending on the relationship

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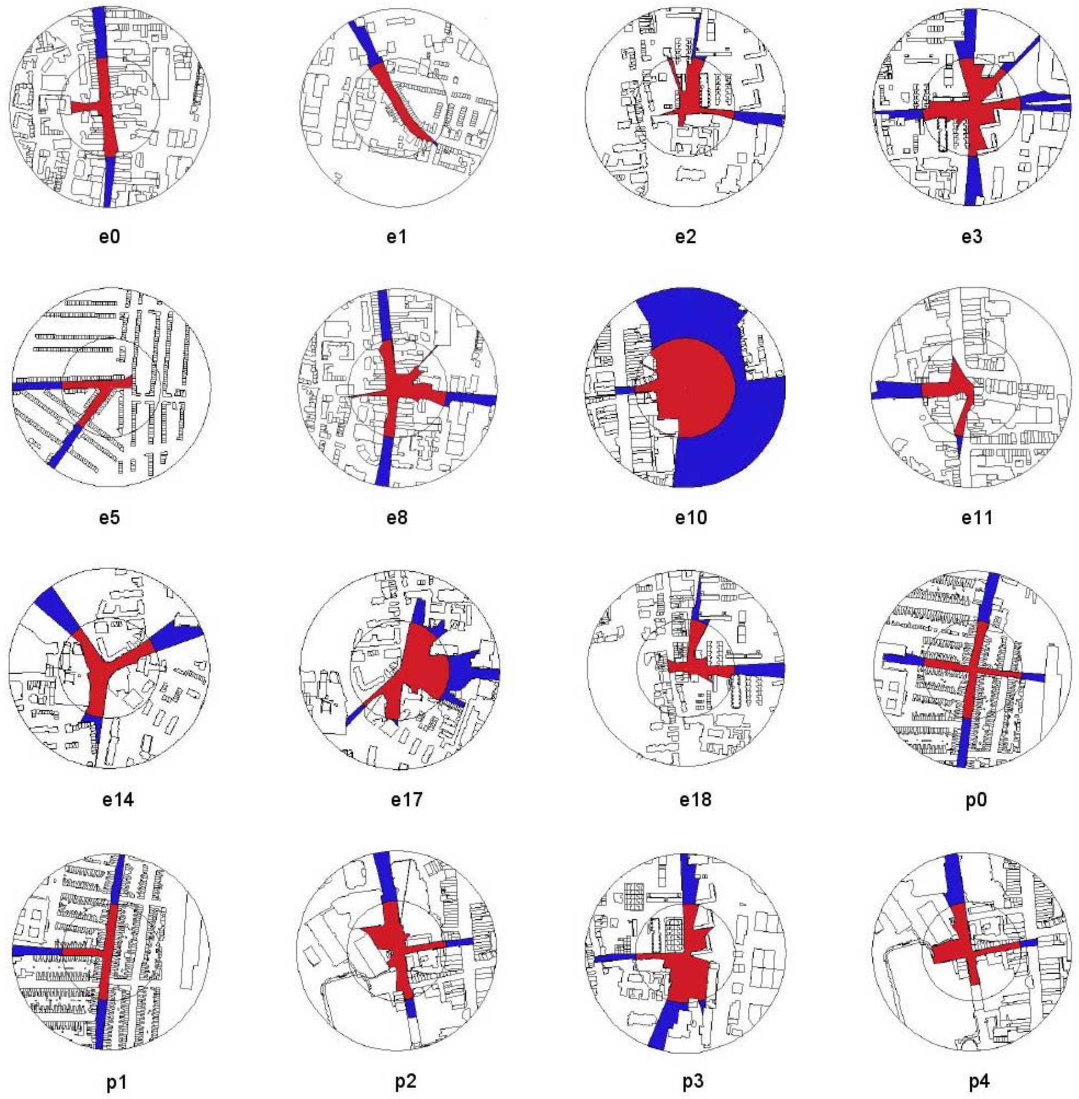
[8] Jaggedness: Although not defined by Benedikt, the measurement of Jaggedness was proposed by Wiener and Franz (2004) to describe "*the complexity of an isovist polygon"* It is calculated as the squared isovist polygon divided by its area.

between an isovist`s Area and its Perimeter were affected in this isovist. This, in turn, might have distorted all other correlations.

As a consequence, Location 10 was then excluded from the sample and the series of correlations were repeated. The results, shown in tables 3.7 and 3.8, resulted in an improvement of these associations, which was particularly substantial in the case of long isovists. For example, Area and Perimeter improved their association from $r = 0.21$ to $r = 0.76$ (Long Isovist/ Walls Model), and from $r=0.25$ to $r=0.81$ (Long Isovist/Roofs Model).



e0 e1 e2 e3

e5 e8 e10 e11

e14 e17 e18 p0

p1 p2 p3 p4

Figure 3.6: isovist shapes at different locations (the Roofs Model)

Table 3.2: vector-based isovist values for the Walls Model [9]

location	radius	Area	Perimeter	Comp (1)	Drift (2)	Occ (3)	Jagg (4)
e0	100	5573.03	577.02	0.21	15.25	160.67	59.74
e1	100	3940.48	460.72	0.23	13.00	175.24	53.87
e3	100	5545.86	756.77	0.12	30.04	423.02	103.27
e4e6e7	100	12891.19	1082.86	0.14	6.35	534.96	90.96
e5	100	4058.63	510.17	0.20	30.34	137.27	64.13
e8	100	8580.86	946.30	0.12	8.70	438.20	104.36
e10	100	25935.09	779.21	0.54	13.80	137.46	23.41
e11	100	4795.39	541.77	0.21	38.39	234.07	61.21
e14	100	7995.49	650.75	0.24	6.85	306.37	52.96
e17	100	13312.39	844.15	0.23	32.28	416.04	53.53
e18	100	7401.15	962.20	0.10	18.91	611.79	125.09
p0	100	6728.38	878.60	0.11	1.70	267.25	114.73
p1	100	5226.23	739.98	0.12	22.45	241.40	104.77
p2	100	10357.29	792.85	0.21	2.17	185.82	60.69
p3	100	12484.34	945.93	0.18	15.91	429.20	71.67
p4	100	8634.44	770.58	0.18	27.79	181.57	68.77
e0	200	9390.54	981.16	0.12	16.44	383.97	102.52
e1	200	6105.01	688.14	0.16	57.35	373.61	77.56
e3	200	8320.87	1207.47	0.07	54.40	819.01	175.22
e4e6e7	200	23558.75	2309.14	0.06	15.19	1548.93	226.33
e5	200	7088.71	918.47	0.11	74.57	406.52	119.00
e8	200	14895.15	1617.52	0.07	19.53	844.93	175.65
e10	200	75590.26	1697.11	0.33	44.73	622.71	38.10
e11	200	7953.77	838.07	0.14	76.94	417.36	88.30
e14	200	15862.70	1324.02	0.11	32.29	868.86	110.51
e17	400	20807.63	1624.52	0.10	55.94	968.84	126.83
e18	400	13312.78	1606.30	0.06	11.73	1176.52	193.81
p0	400	13985.76	1651.17	0.06	12.93	759.83	194.94
p1	400	10646.25	1461.77	0.06	41.68	701.63	200.71
p2	400	14514.05	1199.95	0.13	24.13	392.21	99.21
p3	400	20152.46	1822.22	0.08	17.82	1110.07	164.77
p4	400	13331.37	1095.56	0.14	58.82	371.28	90.03

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[9] 1) Compactness, 2) Drift Magnitude, 3) Occlusivity, 4) Jaggedness

Table 3.3: vector-based isovist values for the Roofs model[10]

location	Radius	Area	Perimeter	Comp (1)	Drift (2)	Occ (3)	Jagg (4)
e0	100	5565.87	576.58	0.21	15.45	160.80	59.73
e1	100	3874.38	449.21	0.24	13.97	157.99	52.08
e3	100	4329.97	586.71	0.16	35.76	298.13	79.50
e4e6e7	100	12173.79	1087.37	0.13	9.26	523.11	97.12
e5	100	4001.04	533.80	0.18	30.57	164.99	71.22
e8	100	8557.55	945.98	0.12	8.49	423.37	104.57
e10	100	25899.08	755.60	0.57	14.16	123.10	22.04
e11	100	4363.32	652.74	0.13	35.88	365.99	97.65
e14	100	8023.61	650.88	0.24	6.90	303.92	52.80
e17	100	11575.54	763.67	0.25	39.41	392.70	50.38
e18	100	5412.22	626.60	0.17	34.31	353.40	72.54
p0	100	6170.66	819.64	0.12	2.28	151.94	108.87
p1	100	4838.20	614.98	0.16	19.66	106.21	78.17
p2	100	8561.83	857.45	0.15	10.28	292.04	85.87
p3	100	11261.91	808.54	0.22	17.75	294.78	58.05
p4	100	7108.34	758.45	0.16	18.56	200.27	80.93
e0	200	9385.60	980.31	0.12	16.48	378.36	102.39
e1	200	6043.82	676.62	0.17	58.43	356.41	75.75
e3	200	5950.97	820.59	0.11	60.09	495.85	113.15
e4e6e7	200	21730.31	2302.19	0.05	23.45	1524.37	243.90
e5	200	6890.90	939.03	0.10	73.88	420.77	127.96
e8	200	14805.53	1636.93	0.07	19.47	860.66	180.98
e10	200	75541.80	1673.34	0.34	44.97	609.27	37.07
e11	200	6545.87	945.24	0.09	65.19	568.72	136.50
e14	200	16087.83	1306.64	0.12	32.08	847.53	106.12
e17	200	20697.83	1455.02	0.12	72.50	907.62	102.29
e18	200	8900.41	1051.67	0.10	68.02	701.92	124.27
p0	200	12101.37	1503.09	0.07	8.67	556.38	186.70
p1	200	9786.65	1225.72	0.08	38.95	469.71	153.51
p2	200	12812.39	1424.02	0.08	36.04	661.42	158.27
p3	200	18457.29	1484.42	0.11	20.40	768.49	119.38
p4	200	10782.51	1068.84	0.12	53.26	414.66	105.95

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[10] 1) Compactness, 2) Drift Magnitude, 3) Occlusivity, 4) Jaggedness

Table 3.4: correlations amongst isovist values in the Walls model (p>.01))

		radius = 200						
		Area	Perimeter	Occlussivity	Drift Angle	Drift Magnitude	Compactness	Jaggedness
radius = 100m	Area		0.21	0.02	0.12	0.01	**0.57**	0.12
	Perimeter	0.19		0.37	0.05	0.39	0.05	0.37
	Occlusivity	0	**0.56**		0.05	0.39	0.21	**0.53**
	Drift Angle	0.12	0	0.02		0	0.05	0.01
	Drift Magnitude	0.05	0.14	0	0.03		0.11	0.27
	Compactness	**0.55**	0.07	0.25	0.02	0		**0.71**
	Jaggedness	0.20	0.26	0.38	0.02	0.01	**0.70**	

Table 3.5: correlations amongst isovist values in the Roofs Model (p>.01)

		radius = 200						
		Area	Perimeter	Occlussivity	Drift Angle	Drift Magnitude	Compactness	Jaggedness
radius = 100	Area		0.25	0.04	0.11	0.01	**0.67**	0.14
	Perimeter	0.21		**0.71**	0.01	0.29	0	0.30
	Occlusivity	0	0.36		0.03	0.07	0.07	0.34
	Drift Angle	0.12	0.10	0.13		0.12	0.14	0.07
	Drift Magnitude	0.05	0.18	0.03	0		0.04	0.19
	Compactness	**0.66**	0.02	0.13	0.04	0		**0.64**
	Jaggedness	0.27	0.17	0.14	0	0.02	**0.74**	

Table 3.6: correlations amongst isovist values in the Walls model without location **e10** (p>.01)

		radius = 200						
		Area	Perimeter	Occlussivity	Drift Angle	Drift Magnitude	Compactness	Jaggedness
radius = 100	Area		**0.76**	**0.58**	0.04	0.28	0.22	0.19
	Perimeter	**0.56**		0.83	0.03	0.43	**0.67**	**0.68**
	Occlusivity	0.28	0.63		0.07	0.29	**0.59**	**0.62**
	Drift Angle	0.13	0	0		0	0.01	0.02
	Drift Magnitude	0.07	0.14	0.01	0		0.3	0.31
	Compactness	0	0.38	0.28	0.15	0.02		**0.94**
	Jaggedness	0.01	0.36	0.32	0.17	0.03	**0.96**	

Table 3.7: correlations among isovist values in the Roofs Model without location **e10** (p>.01)

		radius = 200m						
		Area	Perimeter	Occlussivity	Drift Angle	Drift Magnitude	Compactness	Jaggedness
radius = 100m	Area		**0.81**	**0.70**	0	0.22	0.14	0.20
	Perimeter	0.20		**0.83**	0	0.31	**0.51**	**0.72**
	Occlusivity	0.	0.44		0	0.1	0.33	0.44
	Drift Angle	0	0.11	0.25		0.1	0	0
	Drift Magnitude	0	0.2	0.11	0		0.22	0.21
	Compactness	**0.65**	0	0.13	0	0		**0.92**
	Jaggedness	0.23	0.25	0.12	0	0.11	**0.73**	

Comparing behavioral data against isovist values

In order to compare behavioral data against spatial data, in the first phase of this research a multiple regression analysis compared participants` answers with all isovists measures. This aimed to see if any isovist measure could predict the directional guesses made by participants when responding to this experiment. The findings suggested that Jaggedness, a measure depicting the complexity of an isovist` shape, was a fairly good predictor of a people's choices. These results seem concordant with those obtained by Wiener and Franz (2004), who discovered that Jaggedness was a robust predictor of people`s navigational performances [11].

Attempting to find a more satisfactory explanatory model of participants' choices, the second part of this research then explored whether people used other strategies to solve the problem. Particularly, it was hypothesized that people used all the information contained in charts (even if this included landmarks or any other type of distinctive features), in order to produce the necessary match making between scenes and maps. This idea considered that scenes, although stripped in part of contextual information, still possessed some valuable elements that were be quickly noticed by subjects.

Could be the case that persons were paying attention to environmental information appearing in charts to solve the task?

Another exercise was carried out in order to respond this question. This consisted in calculating the amount of environmental information contained in each isovist. In other words, the idea was to asses how "rich" was an isovist in terms of the amount of environmental information it possessed, and then to see if this measure could predict people`s answers. An interesting precedent of this idea can be found in the work of Desyllas et al (2003), who dissected the open space outside two large buildings to disclose the area that was visually controlled by subjects.

In the context of this work, environmental input was divided into ground level and vertical information. Ground-level information measured the area of the four

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[11] The correlation coefficient of Jaggedness in this experiment reached r=-.62 (p >.01)

different surfaces appearing in maps: sidewalk, pavement, green areas and front yards (see figure 3.7b). Vertical information, on the other hand, examined the type of boundary of an isovist. The idea was to see which proportion of an isovist`s shape was formed by opaque or a non opaque boundaries (or optical rays linking opaque borders), as figure 3.7 shows.

Table 3.8 illustrates the results of both operations, by showing the proportion of each isovist`s area that corresponded to sidewalk area, pavement area, green space and front yards, as well as the proportion of each isovist`s perimeter limited by opaque boundaries, or by non-opaque boundaries.

3.4.- Results

Initial findings showed that the existence of distinctive information (either 2D or 3D), slowed participants down, rather than improve response times. What is perhaps more surprising is the fact that the presence of landmarks did not improve people's performance but increased the likeliness of directional errors in persons. This is at odds with most of cognitive literature, which has stressed the role of landmarks as mechanisms that facilitate human navigation (Siegel and White 1975; Golledge, Smith et al. 1985).

The analysis also detected important differences in the ways in which people solved the task. Some individuals used a landmark-centered strategy, consisting in searching for landmarks in charts or in scenes, and then searching for these landmarks in the corresponding chart or scene. This enabled the person to match the two sources of informaiton up. In most cases, this strategy enabled subjects to solve the task in a rapid and efficient manner. Instead, others decided to pay attention to the spatial geometry of plans in order to infer the direction they were looking. To further study these differences, a cluster analysis of people's answers was undertaken.

The analysis revealed that individuals` strategies to solve the duty could be divided in four main groups. The most popular of them consisted of ignoring the spatial structure of layouts and instead, in searching for the distinctive features (or landmarks) appearing in maps and scenes in order to produce the match making necessary to solve the problem. Used by about 40% of subjects, this strategy resulted in a 63% of correct answers. The least popular strategy worked in the opposite way. Rather than attending to landmarks, individuals preferred to infer the spatial geometry of charts in order to guess the directional judgment that solved the problem. This strategy was the most efficient of all, reaching a 72% of correct answers. The remaining two strategies were a combination of these two methods and were less successful (49% and 24% respectively). No differences amongst groups were detected in terms of response times.

3.5.-Discussion

From a theoretical point of view, the results obtained in this experiment have two main implications. One is concerned with the design of more customized and user-friendly maps in cities and buildings, which could facilitate wayfinding tasks for people. Based on the findings presented here, it is possible to suggest that, if more effective maps are to be created, they should attempt to coordinate the location of distinctive features or landmarks with some distinctive geometries of space. This might capitalize a “default” strategy employed by most subjects in these tasks while, at the same time, would improve people’s performances on the matter.

The second implication seems to point in the direction of this thesis` ultimate aim. It was demonstrated that people are not only capable, but that they naturally pay attention to geometrical (and to some extent configurational) aspects of space, in order to solve spatial problems. Here it will be argued that this suggests that humans can retrieve information from space beyond the existence of landmarks. In other words, results indicate that it is possible “to employ something other than landmarks” (as posed in the previous chapter), to gain a sense of orientation.

The obvious question is therefore: what other type of non discursive spatial information could be inferred by people?

The next section will continue with this line of enquiry, aiming to see whether configurational information can be used by people when retrieving hierarchical information from maps.

Table 3.8: *Isovist Richness* in the Roofs Model

		Horizontal Dimension				Vertical Dimension	
location	radius	street area (%)	sidewalk area (%)	green spaces area (%)	Entran area (%)	building perimeter (%)	non building perimeter (%)
e0	100	71.04	28.96	-	-	75.44	24.56
e1	100	63.62	36.38	-	-	46.46	53.54
e3	100	26.5	40.61	32.89	-	45,4	54.6
e4e6e7	100	42.69	47.88	9.43	-	49.49	50.51
e5	100	56.95	33.92	-	13.81	87.22	12,78
e8	100	52.89	47.11	-	-	57.5	42.5
e10	100	19.65	16.36	63,99	-	65.69	34.31
e11	100	33.21	65.26	1,53	-	49	51
e14	100	57	41.9	1,1	-	53.69	46.31
e17	100	19.95	30.72	49.33	-	45.51	54.49
e18	100	33.28	51.96	12.86	5.4	38.97	61.03
p0	100	53.1	35.62	-	13.96	82.43	17.57
p1	100	50.54	34.95	14.51	-	74.6	25.4
p2	100	34.04	52.98	12.98	-	75.55	24.45
p3	100	11.22	66.69	22.09	-	54.3	45.7
p4	100	32.83	65.79	1.38	-	83.03	16.97
e0	200	67.46	32.54	-	-	67.27	32.73
e1	200	47.92	38.23	13.85	-	71.35	28.65
e3	200	25.74	39.18	35.08	-	36.43	63.57
e4e6e7	200	34.97	59.09	5,94	-	28.83	71.17
e5	200	57.1	31.97	2.94	7.98	68.07	31.93
e8	200	56.87	43.13	-	-	49.9	50.1
e10	200	14.85	9.13	76.02	-	54.02	45.98
e11	200	43.71	56.29	-	-	42.42	57.58
e14	200	28.15	26.97	44.88	-	34.02	65.98
e17	200	18.39	44.54	37.08	-	42.69	57.31
e18	200	34.55	55.31	10.15	-	32.49	67.51
p0	200	48.25	41.4	0.62	9.72	61.91	38.09
p1	200	56.92	29.71	13.37	-	59.21	40.79
p2	200	48.02	43.15	8.83	-	70.47	29.53
p3	200	15.74	62.31	21.95	-	45.17	54.83
p4	200	38.8	58.36	2.84	-	79.51	20.49

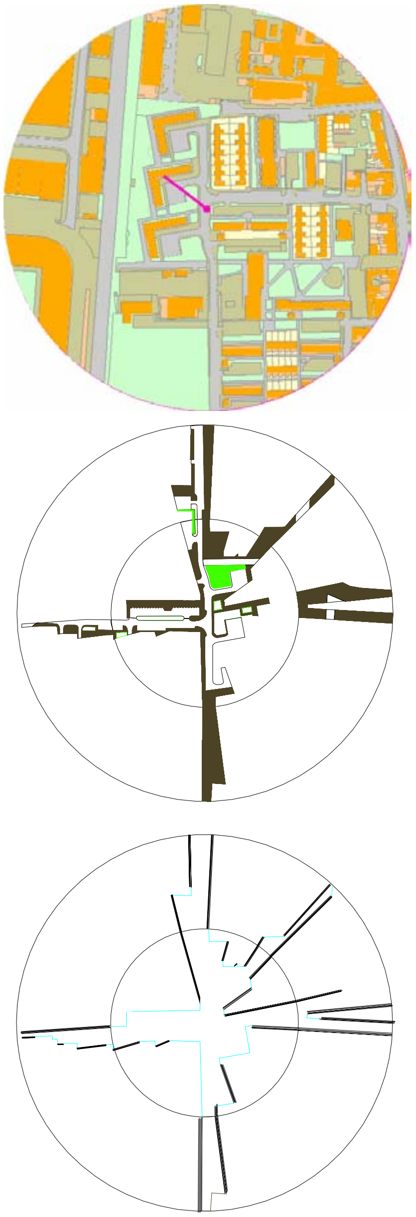

Figure 3.7a (top): map at location e17. Figure 3.7b (centre): vertical environmental "information" of isovist at location e17. Thicker lines represent building facades, while lighter lines depict isovist's rays. Figure 3,7c (bottom): horizontal information of isovist at location e17, where black represents street area, light grey means green areas and white are the sidewalks

chapter Four

Where is the main street?

Abstract

This chapter explores the role of a cartographic convention –line thickness- in shaping people's qualitative assessments of street maps. The main problem consisted of identifying "the main street" of three different layouts whose paths were sometimes widened in order to make them stand out from their counterparts. Three groups of approximately fifty subjects each were assigned to these scenarios. The main findings show that spatial hierarchies in maps are defined by a combination of spatial and cartographic factors. While the congruence of them may improve the understanding of maps, its incongruity might cause confusion and render map reading a rather complex task.

4.1. Introduction

The previous chapter showed an initial attempt to disclose how configurational information of space shapes map reading. By asking people to infer their direction of gaze of a given scene, it was demonstrated that most individuals used a default strategy consisting of paying attention to landmarks, in order to produce the necessary matching of maps and scenes that solved the problem. It was demonstrated, however, that some subjects were paid more attention to the geometrical characteristics of space in maps in order to solve the question, thus proving that relational (and to some degree, configurational) properties of space plays a crucial role in permitting humans to read maps.

This chapter further investigates this issue. However, rather than looking at how people retrieve spatial information from isovists` shapes, this chapter will focus on the ways in which people retrieve spatial information from spatial networks.

4.2.- Theoretical preliminaries

In chapter Two it was argued that maps have been historically understood under two main perspectives: the communication and the information-processing paradigms. The former assumes that the ultimate nature of maps is to carry a message, whereas the latter, the information-processing paradigm, contends that maps are graphic devices whose purpose is not only to transmit certain meanings, but to trigger visual processes of attentive and pre attentive nature [1].

In was also argued that the communication paradigm was epitomized by the work of Arthur Robinson, an American cartographer who in 1952 wrote a book called *The look of maps*. In *The look of maps* Robinson called for a new, more scientific approach to cartography, whose focus was to improve the efficency with which a map’s message would be delivered to subjects. For that process to occur, Robinson argued, cartographers should also pay attention to aspects such as colouring, lettering, style, and map design and structure. To Robinson, however, no other cartographic technique is as effective as contrast, and no mechanism of contrast was as affective as the manipulation of size of map`s elements.

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[1] Attentive and pre attentive visual processes were briefly described in chapter Two.

Robinson’s work[2] was highly influential for cartography in the post-war period (Raisz 1962; Keates 1973; Fisher 1982; Shirrefs 1985). Proof of that is Fisher`s quote that *"a map is a spatial analogue: its purpose is the understanding, portrayal and communication of information that varies in space"* (Fisher 1982:3). Aimed to translate these principles in practice, several books focused on the manipulation of cartographic conventions were published during this period (Keates 1973; Keates 1982; Shirrefs 1985), which addressed issues as diverse as what type of lettering or colour should be used in maps, as well as placing guidelines in terms of their size or style.

The communication paradigm of cartography started to be questioned from several fronts since the eighties. Harvey, for example, criticised what he considered the ideological dimension of map guidelines, posing the necessity to “deconstruct the map” in order to *"read between the lines of the map -in the margins of the text-, and through its tropes to discover the silences and contradictions that challenge the apparent honesty of the image”* (Harley 1989:3). Other authors (Salichtnev 1978; MacEachren 1982) started questioning one of the fundamental assumptions of the communication paradigm: that map convey unique messages to people. According to this view, there is not one, but many messages in maps and this depends on their users` existing knowledge[3]. It was affirmed that although maps may intend to convey some information, there is no guarantee that subjects would interpret their message as planned, since they are judged according to their appearance and the users’ intellectual background. It was then contended that a new paradigm had to be created to explain how maps are understood, one aimed to observe the cognitive process of the mind during map reading, rather than merely to define the graphic techniques that might facilitate this process. This new perspective was called the information-processing paradigm (Salichtnev 1978).

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[2] Montello (2003) has argued that the German school of cartography, specifically the work of Eckert was fundamental in the work of Robinson. However, the popularization of the role of cartography research for map design in the English-speaking world is normally attributed to the American author.

[3] Although there are cases in which people’s visual capacities may play a role,. This is the case, for example, of subjects with a restricted or an inexistent capacity to distinguish colors.

The theoretical shift from conceiving maps as communication devices to information-processing systems has been enormous. Because the ultimate objective was no longer the improvement of the map itself but the understanding of people´s cognitive processes when interacting with it, research has been less focused on the analysis of results and more preoccupied with the study of processes executed by people when attending these representations. *"Cartographic research based on an understanding of these cognitive processes is potentially more relevant to geographers and how they use maps, than is perceptual research dealing with symbol detection, discrimination and interpretation".* (MacEachren 1991:161)

Nonetheless, most research on the subject to date has revolved around the visual processes responsible for organizing visual information coming from maps, rather than on understanding the role of top-down cognitive process aimed to assess this information. This is the case, for example, of Hirtle and Jonides (1985), who asked individuals to memorize a series of landmarks disposed in a map, and then to assess the distance between some of them. Hirtle and Jonides discovered that landmarks were perceived as belonging to certain high-order clusters, and that relative distances between them was affected by this assumption.

Another relevant experiment on the matter was that of Holahan and Sorenson`s (1995), who studied how the principle of Good Continuation [4] affected map understanding. Holanan and Sorenson asked forty-five subjects to observe one network of sinuous pathways in which some minor changes were realized. Individuals were allocated into three different groups. Group One saw a map with no emphasis in its pathways. Group Two was given a map in which some of its paths were slightly darkened in order to make them more salient. Salient paths were defined according to the principle of Good Continuation, meaning that they defined a set of curvilinear pathways that seemed to capture the network's structure. Unlike group Two, in group Three no clear organization could be perceived from salient paths. Holahan and Sorenson discovered scenario two was more efficiently memorized by subjects, and that scenario three was the most difficult to recall.

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[4] As mentioned in Chapter Two, the principle of Good Continuation states that entities organized along a smooth line or curve will be perceived as continuous paths

To some extent, this experiment could be read as a continuation of Holahan and Sorenson`s ideas, with the sole (and major) difference that, rather than focusing on studying how the principle of Good Continuation affects the recalling of networks, here the emphasis is to understand how configurational information of space shapes human reasoning. .

4.3.-Method

Scenarios

A modified map of the area of Camden Town, in north London, was employed as scenario for this experiment. The map (shown in figure 4.1) portrayed no information regarding land uses or street names, and all blocks were shaded in grey in order to highlight its irregular character. As a result, the map appeared as a "Nolli" map [5].

A small dot located at the left hand side of the map showed location 5. A fictitious PUB was placed in front of it in order to anchor individuals, whereas an invented SHOP was located along one of the streets as a way to assure individuals on their paths.

Three scenarios and three different groups of individuals were tested in this experiment:

- Control (scenario One). In this condition no cartographic convention was applied and therefore all streets had the same width. Hence, choices had to be made purely based on spatial information.
- Cartographic convention misplaced (scenario Two). In this condition, a relatively minor (short and scarcely connected) street was highlighted, doubling its width in order to increase its importance. This scenario represents a dissonance in cartographic conventions.
- Cartographic convention correctly placed (scenario Three). In this condition, one of the longest and better connected streets of the system

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[5] This technique, developed by Giabattista Nolli (1701-1756) for the map of Rome, is widely popular in urban studies.

was widened, doubling its width in order to appear more important. It was assumed that this scenario managed to correctly apply a cartographic convention.

Participants and procedure

A total of 152 subjects (75 women, 77 men) participated voluntarily in the experiment. Most individuals were students at University College London or University of London. They were approached in the vicinity of UCL`s main campus and asked to participate in an experiment about map reading.

In order to avoid any bias in the responses participants belonging to the Departments of Geography or Architecture at UCL were excluded from taking part of this experiment. Most subjects were at their twenties (M=24.97, SD= 7.86) and all were native English speakers. Table 4.1 shows in detail some descriptive data about the participants of this experiment.

Subjects were divided into three different groups, each of whom corresponded to the scenarios defined in this experiment. Participants were asked to look at the map and to read the following instruction: *"You are at point 5, facing the PUB. Please take your left and walk along the road until you reach the SHOP. Keep walking until you reach the MAIN street. I'll be waiting for you there".* They were then asked to outline the corresponding path. No extra information was given during this process.

The task demanded several cognitive operations. First, participants had to rotate the map in order to obey instructions for point 5, since the starting location was in front, not behind, them. Most individuals therefore rotated the map straight at the beginning of the exercise. The second cognitive process demanded individuals to mentally navigate the maps until reaching the "main street". In order to facilitate this task, a fictitious SHOP was placed along the path..

For the purpose of this paper the concept "main street" was considered as the most important avenue of a local system in the Anglo-Saxon tradition. Most subjects seemed to implicitly agree with this definition but when clarifications were requested, the experimenter told them to outline the street they considered the most important. Despite subjects could employ as much time as necessary, most of them completed the task in just few minutes.

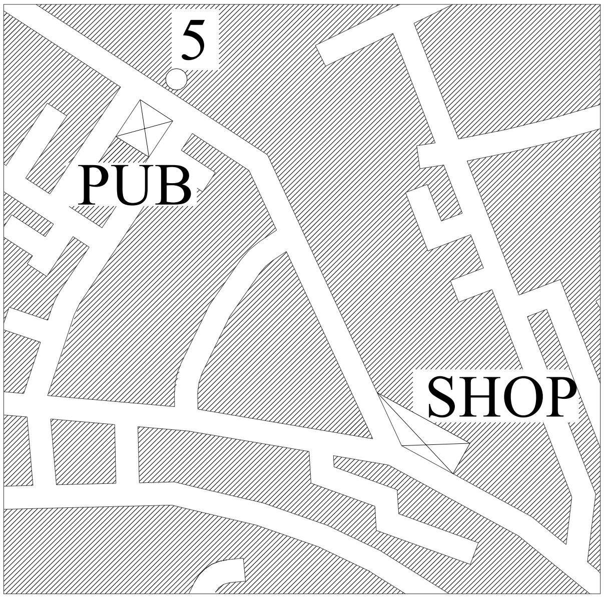


Figure 4.1a the Control map

Figure 4.1b: detail of the starting location

CONTROL MAP
(No cartographic convention)

DISSONANT SCENARIO
(Cartographic convention misplaced)

CONCORDANT SCENARIO
(Cartographic convention correctly placed)

Figure 4.2: the scenarios tested in this experiment

Both age and gender of participants were recorded. Once they have selected the "main street" of each system, they were asked to assess both their performance in the task (how confident are you about your answer?), and the degree of difficulty of the experiment itself. Both questions had to be rated from 1(minimum) to 10 (maximum).

Table 4.1:Descriptive data

			Sex		
			Women	Men	Total
Scenarios	One Control	cases	27	22	49
		%	55.1%	44.9%	100.0%
	Two (Dissonant, convention misplaced)	cases	29	25	54
		%	53.7%	46.3%	100.0%
	Three (Concordant, convention correctly placed)	cases	77	75	152
		%	50.7%	49.3%	100.0%
	Total	Cases	77	75	152
		%	50.7%	49.3%	100.0%

4.3.- Results

First, it was investigated if people´s answers were influenced by their sex or age. A non-parametric test (chi-square), showed no statistical association (X^2:1,238; p>.05) in the matter. This means that participants' qualitative judgements regarding maps were independent of their sex. The same seemed to occur in relation to participants self-confidence (t: .46; p>.05), and assessment of test's difficulty (t:-,91; p>.05). Next, it was investigated whether age influenced participants' self confidence. A Spearman correlation showed that no association existed between individuals` ages and their self-assessments (r_s: .13; p>.05). Likewise, subjects´ assessments of the degree of difficulty of the task was not related to their ages (r_s: .-.15; p>.05).

Once these tasks were terminated, answers made by participants were comprehensively studied. Figures 4.3, 4.4 and 4.5 show participants' paths and stops in scenarios One, Two and Three. As it can be noted, nearly all participants correctly interpreted the instructions and started walking along a diagonal street in which the SHOP was located. People's final stops (where they thought the main street was), were nevertheless deeply affected by the cartographic convention used, as it will be demonstrated.

In scenario One (Control), all individuals except one correctly selected the road at the right of the PUB and continued (virtually) walking until stopping at the location they considered as the "main street". Few exceptions deviated from this pattern: some individuals turned left at some point and reached a star-like intersection at the centre of the map, while others stopped randomly at places not involving junctions. In both cases, these responses were considered as mistakes, since the instruction explicitly told participants to finish their paths at a "corner" and to keep walking past the shop.

Unlike scenario One, in scenario Two (cartographic convention misplaced), few incorrect answers were made. Here most participants walked along the curvy path defined in the instruction and stopped at different junctions. Three main stopping points were chosen in this scenario: an extended sinuous path coming from the left to the right of the map, a diagonal street in the opposite direction and the widest street of the system, a small and not very well connected street at the centre of the map.

Finally, in scenario Three (cartographic convention correctly placed) all individuals except three chose the same path, quickly walking in the right direction until reaching the SHOP, passing it and stopping at the encounter with one of the longest and better connected street of the system. But was there any logic in participants` answers?

A visual inspection of paths made by respondents (figures 4.3, 4.4 and 4.5) shows that the vast majority of them stopped at intersections of well-connected, extended and sinuous streets, thus making evident that the perception of the network was deeply affected by the Gestalt`s principle of Good Continuation. Aimed to study this phenomenon in a more objective way, figure 4.6 has renamed the most traversed paths as streets 1, 2, 3 and 4. These correspond respectively to three sinuous and extended lines crisscrossing the map (streets 1,2 and 3), and to a short and not very well-connected lines placed at the centre of it (street 4).

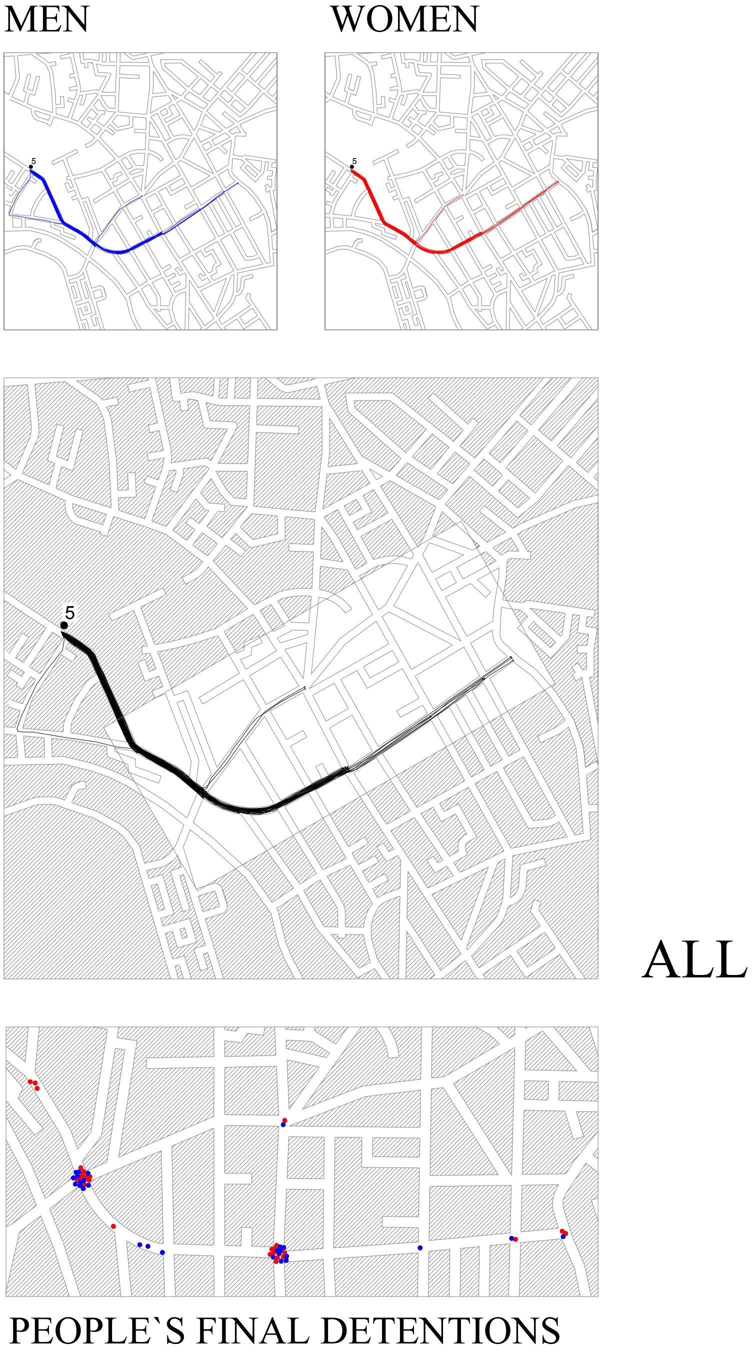


Figure 4.3: Participants´ answers in scenario One (Control)

Figure 4.4: Participants´ answers in scenario Two (cartographic convention misplaced)

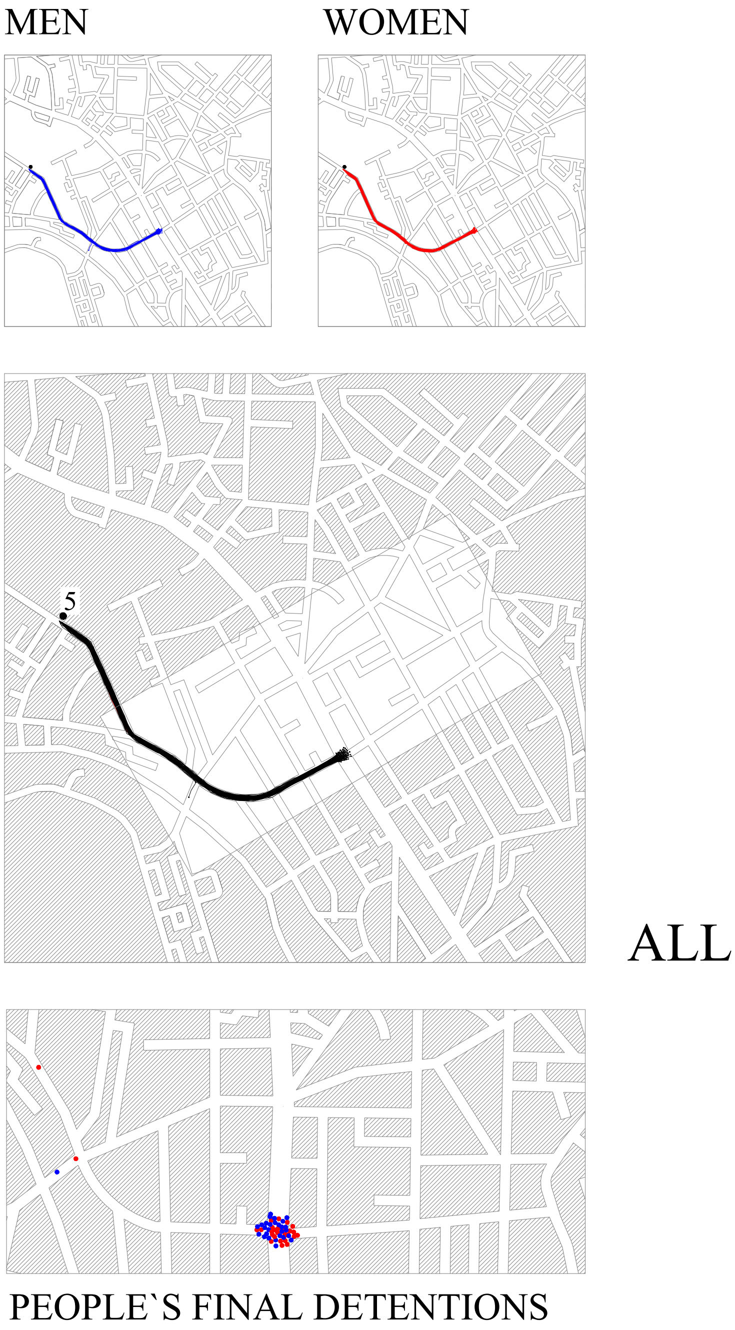


Figure 4.5: Participants´ answers in scenario Three (cartographic convention correctly placed)

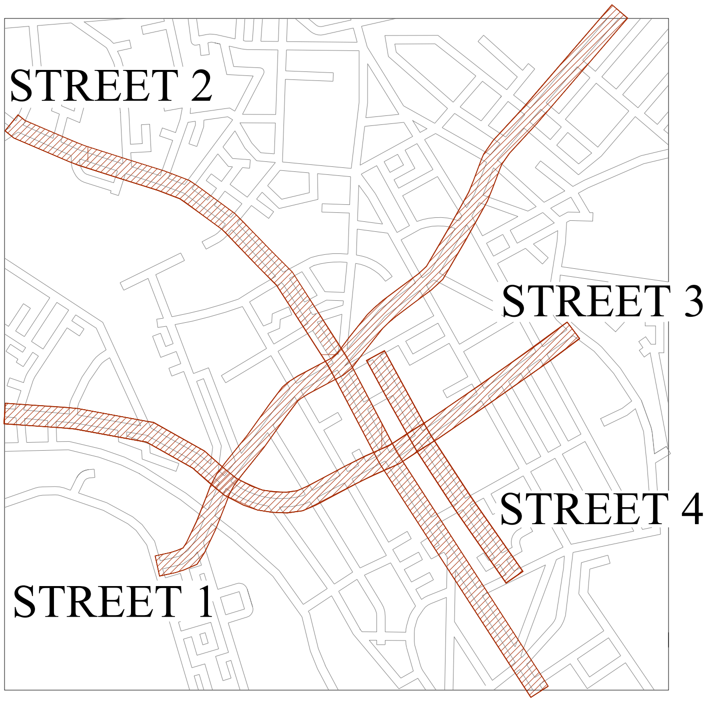


Figure 4.6: the streets were most subjects terminated their searches

Figure 4.7 shows participants` preferences for these streets in each of the scenarios tested. In scenario One (Control), no subject stopped at street 4. Instead, most subjects (about 70% of them) stopped at the crossing of streets 1 or 2, two of the longest roads on the system. A considerable number of subjects (about 30%) misinterpreted the instructions, pausing along street 3, as if they had already arrived to the system's main street.

Scenario Two tells a different story. In this case most people (59% of respondents) obeyed the cartographic convention applied to street 4 and stopped once they reached this junction, implicitly assuming this was the main street of the system. However, a large number of people (39% of respondents) did not choose street 4 as the main street and, instead, stopped at streets 1 and 2 (the streets favoured by individuals in the Control condition), or street 3. Finally, in the scenario where the cartographic convention was correctly applied (scenario 3), nearly all participants (95%) selected street 2 as the "main street" of the system.

But are these differences statistically significant?

In order to respond this question, a chi-square test was realized. This showed that a significant association (X^2:139,783; p<.001) existed between subjects´ choices and cartographic manipulation. In other words, this means that misusing or correctly placing a cartographic convention in the map profoundly affected participants´ choices.

Misplacing a cartographic convention also affected people’s self-confidence. As table 4.2 shows, mean confidence ratings in the two first conditions, was rather similar (6.57 and 6.27 respectively), with relative high values of standard deviation (2.33 for both). However, in scenario 3, people’s mean confidence increased to 8.07, whilst standard deviation decreased to 1.81. It seems therefore that when a cartographic convention was correctly placed (as it occurred in scenario 3) participants had a higher level of confidence and their judgments were more unanimous.

Participants´ judgments regarding the difficulty of the task showed the same pattern but in an inverse way (see table 4.3). Subjects considered that scenarios One and Two scenarios were more difficult than scenario Three, for mean values in the former scenario were 4.35 and 4.29 respectively, whereas the mean value in the latter scenario was 2.65.

In order to test if these differences were statistically meaningful, an one-way analysis of variance (ANOVA) was conducted to test if subjects` self confidence varied depending on the scenario employed in this experiment. This detected differences between some groups (F:10,503, p<,001), although no information was provided in relation to where these differences occurred. A post-hoc (Tukey) test was then performed to clarify this result detected that these differences occurred amongst groups 1 and 2 as well as between groups 2 and 3 of the sample. This is to say that the mean self-confidence rating of scenario One was significantly lower than the mean self confidence rating of scenario Three, and that the mean confidence rating observed in scenario Two was significantly lower than the mean confidence rating observed in scenario Three. Similar results were found with respect to this experiment’s degree of difficulty (F: 8,216; p<,001).

In short, statistical analyses showed that neither sex nor age determined any of the variables (type of street selected, self-confidence or degree of difficulty of the test) tested in this experiment. Instead, these variables seemed to be highly dependant on the scenario being tested or, in other words, of the location of a single cartographic convention like street width on a poorly connected and short street (scenario Two), or a highly linked road traversing the map (scenario Three).

Figure 4.7: Participants' choices in scenarios One, Two and Three

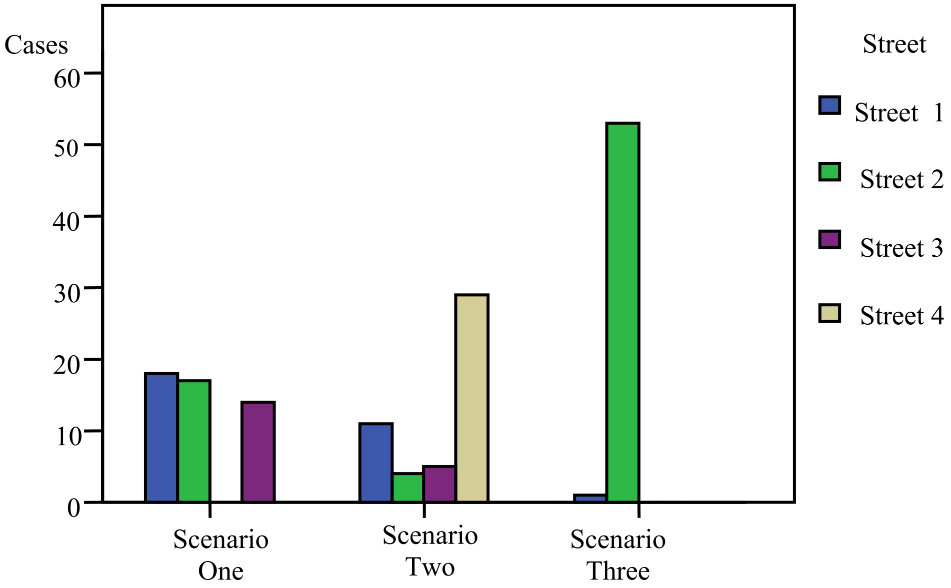


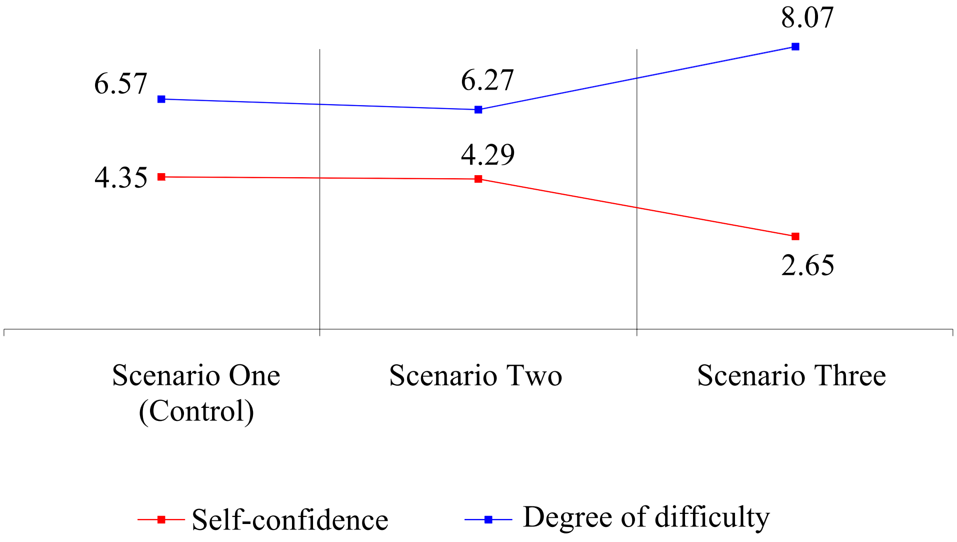
Table 4.2: degree of confidence in scenarios One, Two and Three

	Scenario One (Control)	Scenario Two	Scenario Three	Total
Mean	6.57	6.27	8.07	7.01
SD	2.33	2.33	1.81	2.29
Minimum	2	1	2	1
Maximum	10	10	10	10

Table 4.3: degree of difficulty in scenarios One, Two and Three

	Scenario One (Control)	Scenario Two	Scenario Three	Total
Mean	4.35	4.29	2.65	3.72
SD	2.6	2.62	2.057	2.54
Minimum	1	1	1	1
Maximum	10	10	8	10

Figure 4.8: Participants' confidence in scenarios One, Two and Three



4.4.- Discussion

In 1952 Robinson argued that streets in maps should employ principles of contrast in order to be more easily understood by people. According to Robinson, making things different would call peoples` attention to these items in a rapid, straightforward manner, making them to appear as more important. *"No visual technique is more important in cartography than that of contrast"* (Robinson 1952:57).

Results shown in this chapter experiment seem to be partially at odds with these ideas. In fact, despite the fact that in scenarios Two and Three one street was widened in order to make it more salient, subjects did not respond equally to this technique. While in scenario Two about 70% of individuals selected the widest street of the map, in scenario Three almost all individuals chose this alternative. Further, it was demonstrated that confidence varied significantly in these scenarios, too. This reflects that map contrast itself cannot fully explain a person's qualitative judgments of spatial networks.

The attentive reader might be wondering whether the reason why people responded differently in scenarios Two and Three is because the widest street in the former world was much shorter than the widest street on the latter world. A moment's reflection indicates that if this was to be the case, not only streets 1, 2 and 3, but also other sinuous paths in the map should have been marked by subjects.

Did that happen?

Figure 4.9 presents a sinuous path existing in the map (namely, path 5) that was rarely chosen as a main street. This is despite the fact that path 5 is, with its 13.64 cm, longer than that street 1 (13.02 cm), one of the popular stopping places in this experiment. Further, street 5 is nearly as long as the map's most popular street, path 2 (13.88 cm). Hence, it is clear that length itself does not fully explain a street's hierarchy.

But what kind of information could these networks provide to subjects to help them to find their main streets apart from the aforementioned cartographic conventions and metric aspects?.

Here it will be argued that, as per in the previous chapter, the answer to this question might be found in the existence of configurational information existing in maps. This is to say that, since maps were outstripped of any contextual information like landmarks, streets names or land uses (apart from the fictitious pub and shop employed to help the participants in their task), subjects could only retrieve information from the network itself to solve the problem.

In order to test this idea, an exercise was carried out. Figure 4.10 shows a manual axial break-up of scenarios One, Two and Three formed by 237 lines[6]. Figure 4.11 shows the syntactic measures of Global Integration (r=n), Local Integration, Connectivity and Betweenness Centrality (or Choice) of this system[7]. As it can be appreciated, one of the segments forming street 2 is one of the most globally and locally integrated lines in the map, as well as one of highest Choice on it. The same cannot be said of the series of paths forming street 1, whose sinuous structure seems to be severely diminished by axial analysis.

However, if instead of purely observing the axial components of these paths, they are analyzed in terms of the number of lines they intersect, a different picture is obtained. Figure 4.12 shows a series of exercises in which street 1, 2 and path Y are examined in terms of the catchment areas they involve. Two slightly different methods have been employed for that purpose: the first consisted in selecting only those axial lines intersecting lines 1, 2 and path Y, whereas the second expands this criterion to incorporate a two-step analysis of such paths. Results of this exercise are shown in table 4.5, which shows the number of axial lines directly intersected by streets 1, 2 and path Y, as well as the mean value and the total line length value of these paths.

As it can be seen, path Y covers considerably fewer lines than street 1 or street 2 regardless of the type of analysis selected to measure these path`s catchment areas. This means that, while streets 1 and 2 are intersected directly by 31 axial lines each, path Y is intersected by only 24 axial lines. Moreover, if instead of merely counting the number of axial lines that intersect paths 1, 2 and Y, these lines are analyzed in terms of the length they cover, the situation remains similar, for the total length in paths 1 and 2 reached 249.8 and 183.4 respectively, versus

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[6] An automatic axial map was constructed in parallel way, in order to avoid any criticisms regarding the arbitrariness of the procedure. Both the manual and the automatic map seemed at first sight very similar, but the automatic version contained almost 40 fewer lines (193). The extra lines of the manual map lines corresponded to those situated at the periphery of the map.

[7] These measures were briefly explained in the second chapter.

164.1 of path Y. This tendency remains relatively stable when a two-steps is analyzed (last columns of table 4.5).

Attempting to put these results in a more readable manner, columns five and nine of table 4.4 show the percentage or total length that street 2 and path Y represent of street 1`s length or, in other words, how effective are these paths compared with the most effective street of the sample (street 1). Results of this exercise show that path Y is far less efficient in terms of catchment area than streets 1 or 2, either when one or two step analyses are considered.

Seeing it this way, people`s willingness to choose streets 1 and 2 instead of path Y as a main street of the map seem perfectly reasonable; after all, by choosing these roads, subjects were implicitly selecting well-connected and longest roads as main streets.

Conclusions

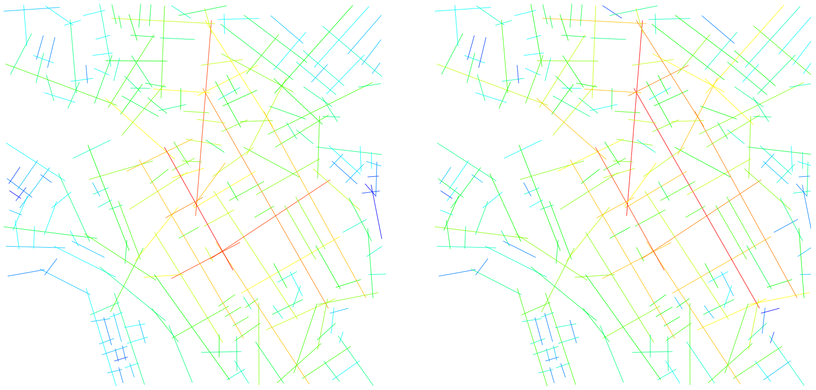
An immediate application of these findings is cartographic theory and map design, as this experiment showed that, for conventions to operate efficiently, they should be coordinated with configurational properties of space.

An equally important result of this exercise is that it permitted to define a methodology capable of unveiling a pervasive but silent part of human reasoning: its capacity to infer configurational properties of spatial networks. Moreover, this methodology can successfully evade the circularity problem as defined by Montello (2007).

The following chapters will show how this methodology could be adapted to disclose the role of configurational information in shaping people`s spatial reasoning.

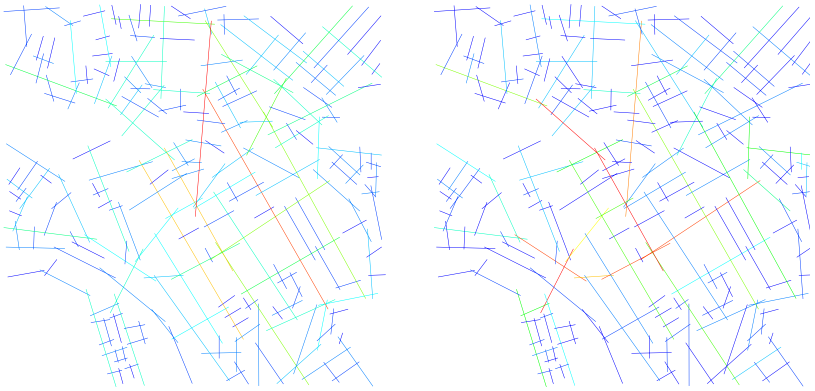
Figure 4.9: a rarely selected main street

Figure 4.10: a manually drawn axial map



Global Integration

Local Integration



Connectivity

Choice

Figure 4.11: Axial analysis of scenario One

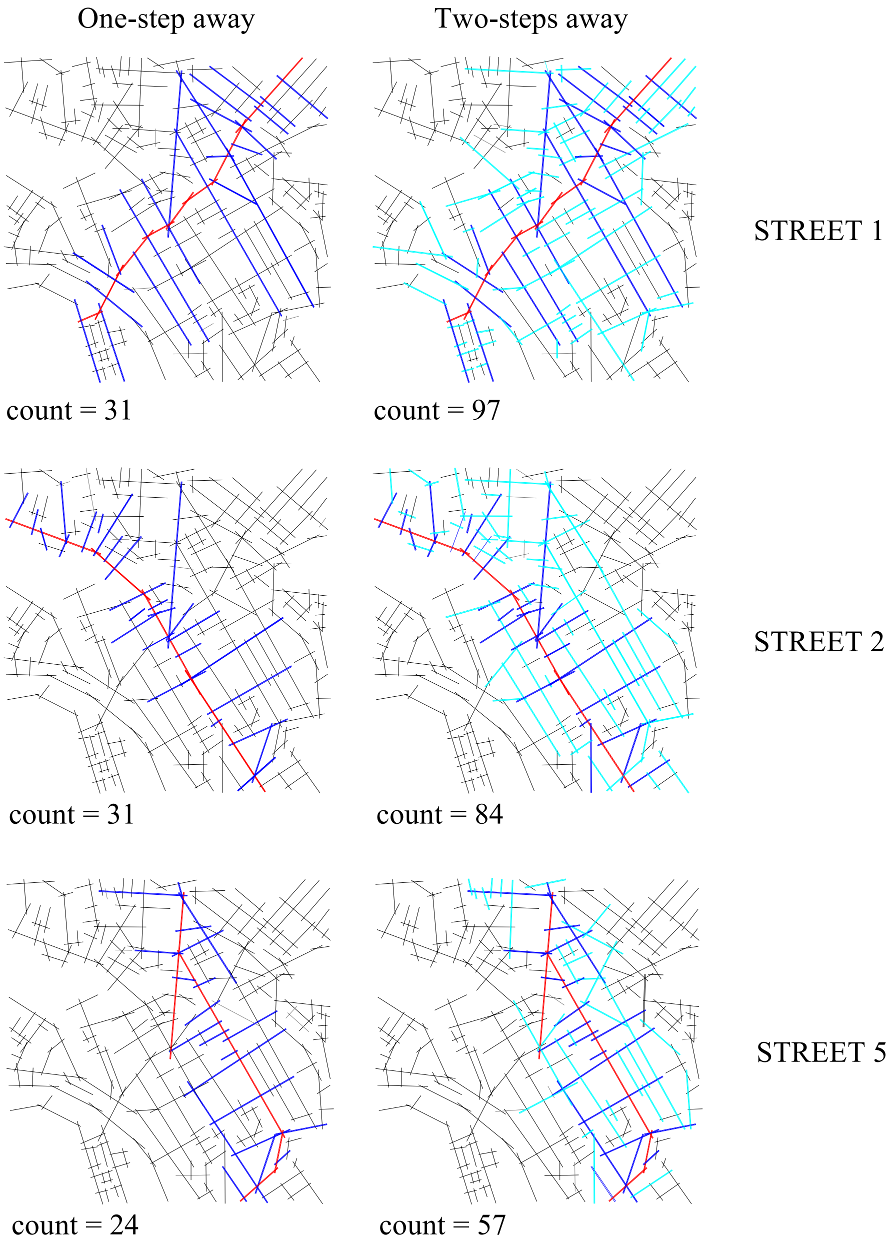


Figure 4.12: the catchment areas of street 1, street 2 and street 5

Table 4.4: one and two-step analysis of street 1, street 2, and street 5

One-step Analysis	Number of lines	Mean Line Length	Total length	%
STREET 1	31	8.06	249.86	100
STREET 2	31	5.98	185.38	74.2
STREET 5	24	6.87	164.88	65.9
Two-steps Analysis				
STREET 1	97	5.37	975.37	100
STREET 2	84	5.31	446.04	45.7
STREET 5	57	5.84	332.88	34.1

Chapter Five (a)

Unpacking people's spatial reasoning

Abstract

This chapter continues the line of enquiry proposed in Chapter Four, in which participants were asked to retrieve hierarchical information from maps. This was achieved by asking them to outline the "main street" and an invented map.

A total of thirty-six persons took part in the experiment. They were asked to outline the three main streets, the three most important junctions and the main street of a map. These responses were then analyzed using two methods: by counting the number of axial (Hillier and Hanson 1984), segment (Turner 2006) or Mindwalk`s continuity lines (Figueiredo and Amorim 2005; Figueiredo and Amorim 2007) involved (what was called line analysis), or by counting the number of choice nodes considered (what was called node analysis). As a result, a series of correlations between behavioral and spatial data were obtained.

The main findings suggested that judgments regarding hierarchical streets are more robustly predicted by configurational rather than metric properties of space, but that none of these variables could reasonably predict people´s judgments regarding hierarchical junctions.

5.1.- Introduction

The previous chapter showed that in order to retrieve hierarchical information from networks, subjects made use metric and configurational factors. It was also shown that when a cartographic convention like line thickness is utilized in opposition to configurational knowledge, subjects get confused, their confidence lessens and their answers become more subjective and less predictable. On the contrary, when a cartographic convention like line thickness is placed on a well-connected and extended street, participants are more homogeneous in their responses and confidence improves.

Another important finding of this chapter was methodological, for it was shown that, in order to avoid the causal problem posed by Montello (2007), maps could be successfully employed to unveil how people retrieve configurational properties of space. Aimed to further explore this methodology, this chapter will ask participants to outline, in a clear and straightforward manner, hierarchical paths and nodes in maps.

5.2.- Method

Scenario

As in chapter Four, this experiment used a map which lacked all environmental information such as streets names, land uses or landmarks and where all streets were shaded in grey to make the network appear more relevant (see figure 5.1). Like in the previous experiment too, this network was highly irregular and might be part of the urban fabric of any European city.

Participants and procedure

A total of 36 subjects (18 women, 18 men) participated voluntarily in the experiment. None of them had participated in the previous experiment. Most individuals were students at University College London or University of London.

They were approached in the vicinity of UCL`s main campus and asked to participate in an experiment about map reading. All respondents were native English speakers.

In order to avoid any bias in the responses participants from the Departments of Geography or Architecture were excluded from the experiment. Most subjects were at their twenties (M=24.97, SD= 7.86). Table 5.1 shows in detail the number and gender of all participants.

Participants were given a set of three charts, all of which contained the same map but demanded a different task. All charts were presented in the same order [1]. The first chart asked subjects to read carefully the map and to read the following instruction: "*Please look carefully at the map and outline what you think are the MAIN streets (3) of the system".* Once subjects completed the task, they were asked to encircle the three MOST IMPORTANT junctions of the map (chart 2), and the MAIN street of it (chart 3). They were not allowed to see their previous answers.

For the sake of simplicity, these questions will be named as:

Question A: please outline the three main streets

Question B: please highlight the three most important junctions

Question C: please outline the main street of the system

Most people could easily complete the task in few minutes. As in the previous experiment, few subjects asked for a clarification of the term "main street' and, like in the past, the experimenter responded suggesting to outline what they considered was the most important road of the map. The last part of the experiment required individuals to rate their self confidence on their answers in a 1-10 scale, being 1 the minimum and 10 the maximum.

A new experiment is planned to present charts randomly

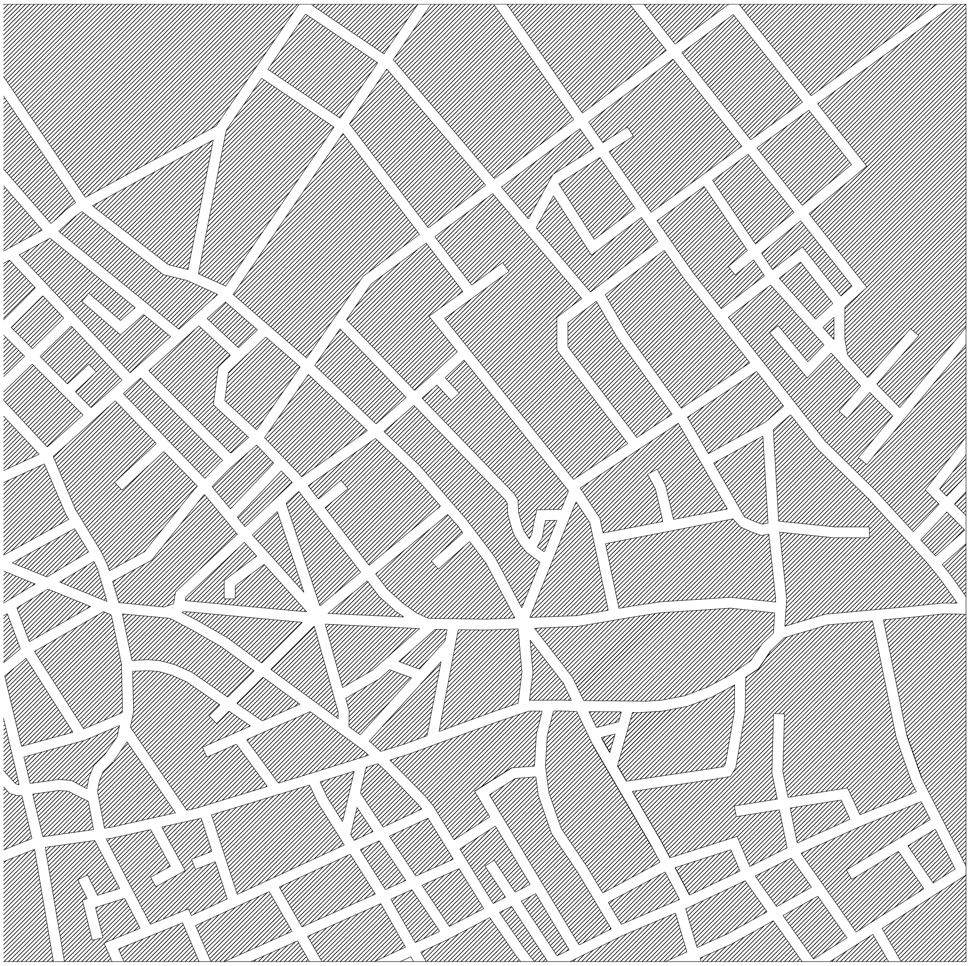


Figure 5.1: the map tested in this experiment

Methodological preliminaries

If participants` paths and marks are to be analyzed and compared against spatial data, the first question is to decide how. This in turn demands the definition of two aspects: which spatial model will be employed to analyze the network used in this experiment, and how participants` choices will de dissected in order to compare them against spatial data. Both aspects will be explained now.

Selecting spatial models

The most obvious way to analyze spatial data is to use the best known syntactic representation: the axial map. This is due to the fact that most cognitive studies undertaken by researchers belonging to the space syntax community have, so far, employed axial maps as means to represent and analyze space in buildings and cities. As a result, the findings encountered in this experiment will be potentially comparable with those coming from other studies in the field. However, as the previous chapter demonstrated, axial analysis sometimes falls short in capturing a network's profound spatial structure, especially when such network is of irregular character, like the one employed here. This is due to the fact that axial analysis imposes an exaggerated cost to slight deviations occurring in streets (Stonor 1991; Dalton 2001; Ratti 2004), forming what it has been named the "Manhattan problem"(Stonor 1991) of axial representations.

The Manhattan problem alludes to the fact that Broadway, New York`s most important commercial axis, in axial analysis is not the most integrated street of the city but merely a relatively well-connected one. This is because Broadway is not a straight but a sinuous line. The Manhattan problem is particularly important in this experiment, for most extended streets are not straight but curvy roads.

In the last ten years a new series of computational packages have tried to overcome the Manhattan problem. One of the earliest of such attempts is Dalton`s "fractional analysis" (Dalton 2001), a procedure that assesses a network topologically according to the angle of incidence of its axial lines. A similar procedure has been recently proposed by Turner (Turner 2001; 2005) under the name "Segment analysis" which, rather than assessing the topological "cost" between two axial lines according to their angle of incidence, it decomposes each axial lines into multiple segments. These segments are then analyzed in terms of their topological depth with respect to all other segments in the network, using a procedure similar to Dalton`s.. Hillier and Iida (2005), have recently shown that Segment Angular analysis can robustly predict people's movement patterns in a large area of London. Turner (2005), on the other hand, found that segment analysis could better capture movement patterns in a large section of London than axial analysis. It seems therefore that segment analysis might be a good method to analyze maps.

The last method to be described here is Figueiredo`s Contuinuity Lines (or Mindwalk) analysis (2005; Figueiredo and Amorim 2007). Unlike Segment analysis, this perspective maintains one of the main assumptions of axial analysis; that space can be decomposed into a discrete number of straight lines. However, the continuity lines analysis "merges" axial lines according to certain angles of aggregation that have to be defined by the user. This is because Mindwalk assumes that minor deviations occurring to streets are ignored by subjects, which instead perceived these paths as continuous entities *"When axial maps are gradually aggregated, continuity lines emerge from their grids revealing long curved and sinuous paths, which seem to assume similar positions in the configuration as the pre-existing long axial lines. As a result, a clearer hierarchy based on line length becomes apparent, mainly within organic grids, but also within regular grids"* (Figueiredo and Amorim 2005:116).

Analyzing people's choices

But, how can people's answers be analysed?. It is fairly obvious that this depends on the type of question asked to the subjects. For example, questions C and A asked persons to outline, respectively, the main street of the map, and the three main streets of the map. These questions, therefore, resulted in a series of different paths. By comparison, Question B told persons to mark the three main junctions of the spatial network used in this experiment, resulting in a series of marks. Now the question could be reformulated as: How could these paths and points be compared against the configurational or metric properties of the map?

Here it will be argued that a possible solution is that of Peponis` et al (1990), who used a interesting method to compare, in an objective way, people's spatial behaviour with configurational properties of space. The method consisted in dissecting a spatial layout's internal structure into a series of *choice nodes*. Defined as places that permit individuals to amend their trajectories, choice nodes are in fact spaces that demand individuals to make spatial decisions like going straight or turn right. From a configurational point of view, choices nodes also correspond to the intersection of axial lines. It follows then that for any choice node, a set of mean configurational values (e.g, Global Integration, Local

Integration, Choice, and Connectivity) can be calculated by summing up all axial lines that encounter at each node and then dividing this value by the number of lines.

The resulting series of techniques to be employed in this experiment can be summarized as follows: spatial networks will be analyzed by using Axial analysis, Segment analysis and Mindwalk analysis, whereas behavioural data will be studied by examining how many choices nodes involved. Table 5.1 clarifies the point.

Table 5.1: type of analyses carried out in this chapter

		SPATIAL MODELS			
		Axial Analysis	Segment Analysis	Continuity Lines Analysis	
				15º [2]	30º
SPATIAL ANALYSIS	Nodes	Axial Node Analysis	Segment Node Analysis	Mindwalk Node Analysis (15º)	Mindwalk Node Analysis (30º)
	Lines	Axial Line Analysis	Segment Line Analysis		

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[2] A detailed explanation of the reasons behind the selections of these angles will be given in the second part of this chapter (chapter 5b)

5. 3.- Results

Descriptive analysis of data

Figure 5.2 shows participants' answers regarding the three main streets of the map. As it can be seen, paths made by respondents were concentrated in five avenues: three of them move obliquely, whereas the remaining ones move in a horizontal manner, thus dividing the map in an upper and a lower part[3]. All paths were slightly sinuous, reflecting the fact that the grid itself was irregular.

Figure 5.4 shows participants' answers regarding the three most important junctions of the map. Here it is possible to see that a triad of junctions running horizontally concentrated the vast majority of marks, whereas a pool of secondary junctions (three of them placed along a extended diagonal path), concentrated far fewer choices.

Finally, figure 5.3 illustrates participants' choices concerning the main street of the system. The pattern strongly resembled the one observed in figure 5.2, but limited to only three avenues, two of which move in a rather horizontal manner, whereas the last one moves diagonally.

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[3] A couple of additional paths were also marked by two persons

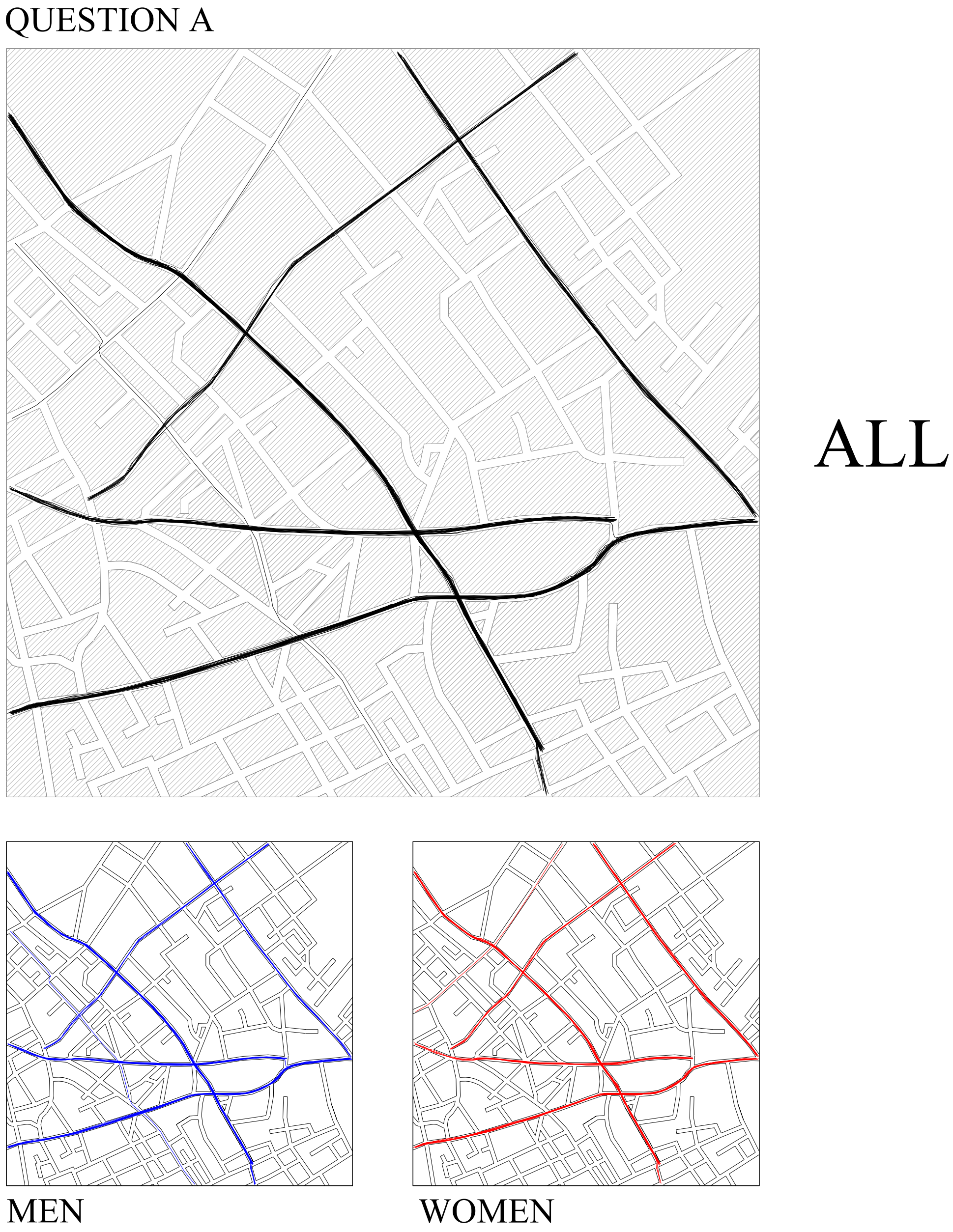

Figure 5.2: Subjects’ answers regarding the three main streets

Figure 5.3: Subjects’ answers regarding the main street

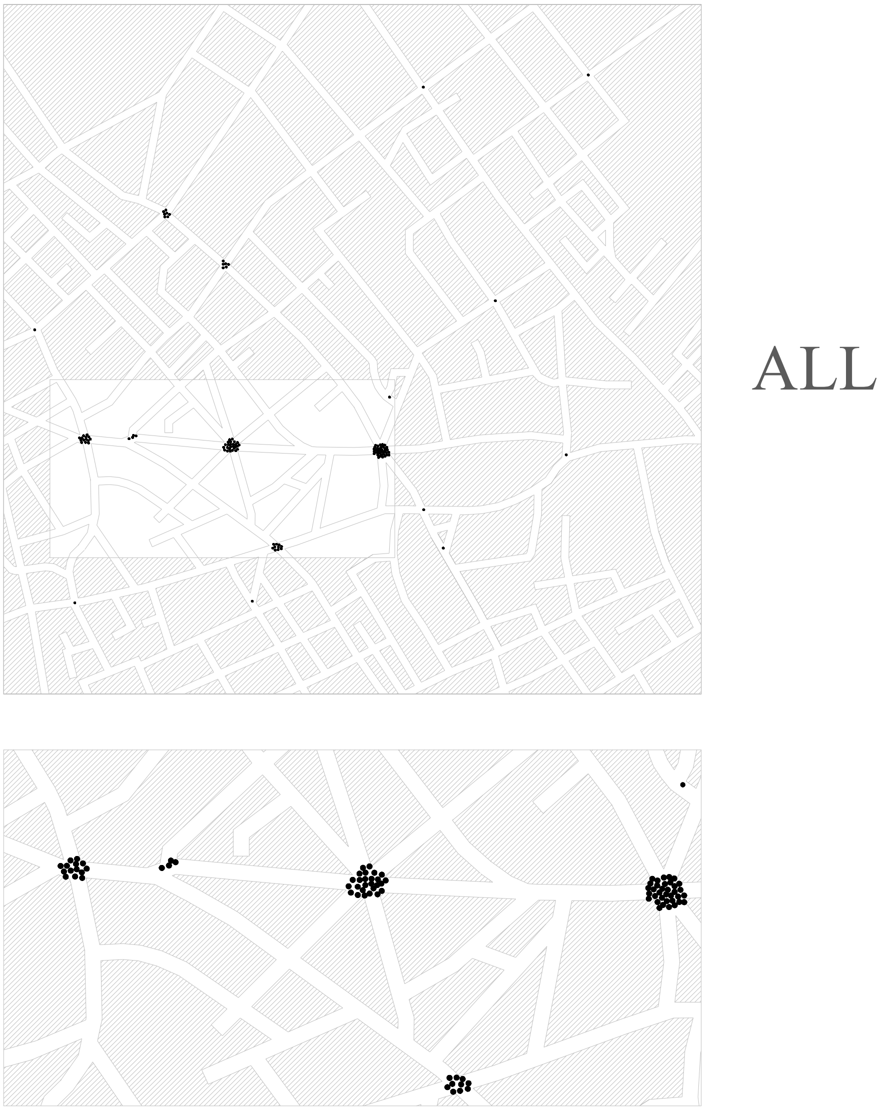

Figure 5.4: Subjects’ answers regarding the three most important junctions

5.4.- *Axial analysis*

As mentioned before, Axial Analysis comprised two parts: the first examined the choices nodes selected by individuals when responding to questions A and C, and the second part examined the axial lines selected by them. For the sake of brevity, these analyses will be called Axial Node Analysis and Axial Line Analysis respectively.

Figure 5.5 shows a manual axial map of the scenario tested in this experiment, which was built according to the principle of making the fewest possible straight lines that fill the public space of the network. The number of axial of lines that resulted from this exercise was 159. Figures 5.6 a and 5.6 b show the ID number of each line, as delivered by Depthmap [4]. Figures 5.6c and 5.6c show the series of choices nodes existing in this network. For the purposes of this study, choices nodes were considered as nodes that demanded subjects to define alternative paths to pursue their trajectories. This means that intersections leading to cul de sacs were not considered as choice nodes. The amount of choice nodes that resulted from this exercise was 186.

Following Conroy-Dalton`s procedure for examining participants' traces (Conroy-Dalton 2001), in this experiment data was analyzed as follows: first, each person's answer was analyzed as a protocol of choices nodes or lines. For example, if person X passed through nodes 1, 2 3 and 4, his trajectory was be defined as the sequence of nodes 1-2-3-4. Likewise, if the same person traversed axial lines 5-6 and 7, his path was described as the chain 5-6-7. An example of this procedure will be presented by analyzing a path made by one of the participants that took part in this experiment. Figure 5.7 shows person 5`s answer when selecting the main street of the system. Analyzed from the point of view of line analysis, this path involved the axial lines axial lines 73-77-78-70-83-109-125, as figure 5.8a shows. However, from the point of view of the choice nodes this path involved,

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[4] Since this number was delivered automatically by Depthmap, the task consisted in translating this information into a more workable format.

this path can be summarized as the sequence, 6-1-12-186-23-31-32-33-49-82-85-86-87-88-89-90, as figure 5.8b illustrates.

Since subjects had to respond to three questions, all answers made by participants involved the selection of a different set of nodes and axial lines. For example, subject X might have chosen axial lines 1,2 3, 4 and nodes 9,8 and 7 when selecting the main street of the map, whilst subject Y could have selected axial lines 3, 4 and 5 and nodes 9, 11 and 12 when responding to the same question. It follows that taken together, axial lines 3 and 4, as well as node 11 were chosen twice, while all other remaining axial lines and nodes were selected just once. The sum of all participants` choices resulted in what was called Node Total Occupancy Index (NTOI), and a Line Total Occupancy Index (LTOI). These measures were then compared to each line or node's configurational and metric values[5], which showed to what extent configurational and/or metric properties of networks predicted participants' answers.

5.4.1.- Analyzing axial maps

Figures 5.9a to 5.9e show a series of maps depicting the configurational measures of Global Integration, Local Integration, Connectivity and Choice, as well as the metric measure of Line Length. A rapid inspection of these charts reveals that highly globally integrated lines are located at the center of the map (see figure 5.9a), whereas less integrated lines tend to be located at the map`s borders. Although this is typical pattern of convex or semi convex spatial structures, what is nonetheless distinctive in this case is the fact that highly integrated lines seem to concur to just one point. As a result, a highly salient junction is distinguishable in the map. Local Integration (figure 5.9b) seems to be less concentrated in just one street and, instead, comprises a rather diverse set of lines, some of which are distant of the map` core.

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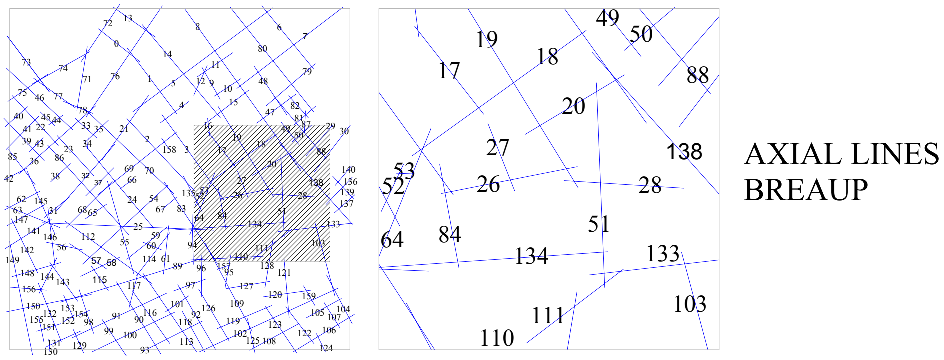
[5] A Spearman technique was chosen due to the asymmetric distribution of some variables. While Choice, Line Length and Connectivity were did not follow a normal distribution, the distribution of values of Global and Local Integration was normal. A detailed study of all distribution is displayed in Appendix 2

Figure 5.5: axial breakup of the map used in this experiment



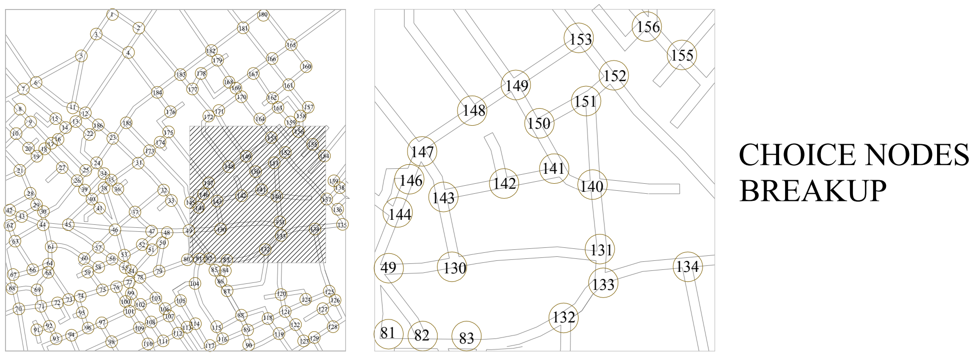
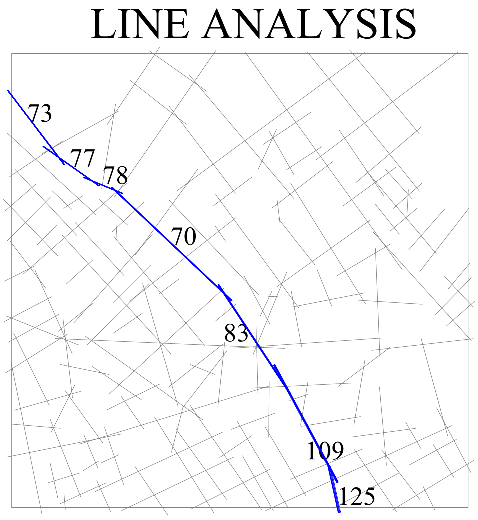
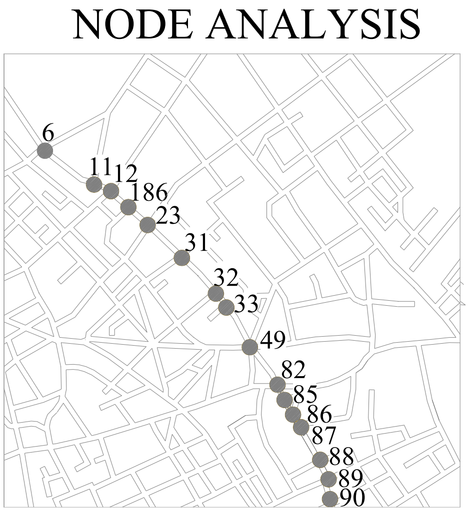


Figure 5.6a and 5.6b (top left): axial breakup of the map

Figure 5.6c and 5.6d (bottom left): choice node breakup of the map

Figure 5.7: subject 5`s path when responding to question C





Figures 5.8a (left): axial lines involved in person 5`s answer to question C

Figure 5.8b (right): choice nodes involved in person 5`s answer to question C

Connectivity (figure 5.9c) tells a different story. Here the line with the highest number of connections is rather short and stands at the core of the network, while other well-connected lines are evenly distributed on it. Choice (figure 5.9d), on the other hand, works in the same fashion as Connectivity, although in a more hierarchical way. Lines of high Choice value are encountered at the core of the map, forming a salient junction that resembles the star-like pattern shown by Global Integration. Finally, the measure of Line Length (figure 5.9e), highlights some lines located at the uppermost corner of the map.

Table 5.2 shows some descriptive information concerning these measures. For the sake of brevity, only the minimum, the maximum, the mean and the standard deviation values of these measures are presented in this table. Here it can be observed that mean Global and Local Integration of lines reached 1.53 and 1.82 respectively, while average values of Connectivity, Choice and Line Length were 3.85, 29.21 and 5.5. But which of these measures could better predict people`s choices?

A moment's reflection indicates that before responding to this question, it is necessary to know to what degree these measures are associated to each other. In other words, it is necessary to check if some of these measures are collinear[6] before comparing them to behavioral data. Aiming at investigate this problem, Table 5.3 shows a series of correlations (Spearman) between all configurational and metric measures of this axial map. Results indicate that, although not strictly collinear, high associations exist between configurational and metric measures of lines. For example, the lowest association between them is that of Global Integration and Line Length at r_s =0.508, whereas the highest is that of Choice and Connectivity at r_s =0.856. In practical terms this means that there is a high chance that a highly integrated line would be, at the same time, a highly connected and extended one. The following section will study if any of these measures can explain how persons perceived hierarchies in maps.

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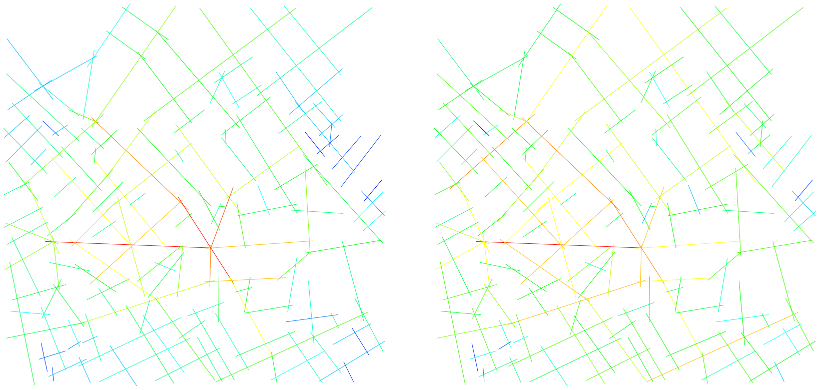
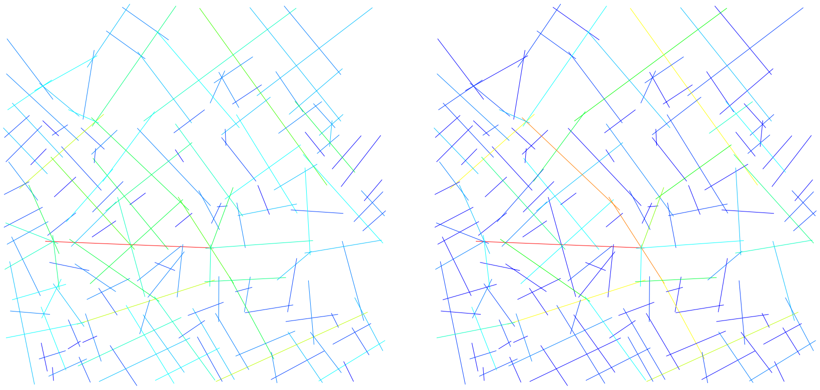
[6] Since colinearity is defined as being more than $p>0.95$.



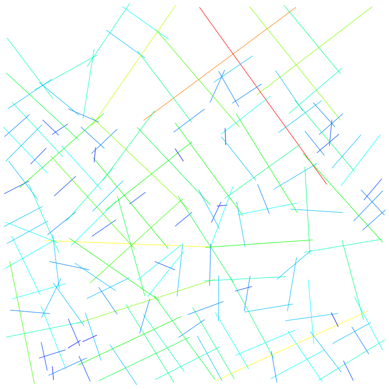
Global Integration

Local Integration



Connectivity

Choice



Line Length

Figure 5.9a to 5.9e: Axial Analysis

Table 5.2: Axial Line Analysis: descriptive data of configurational and metric measures

	Choice	Conn	Global Integration	Local Integration	Line Length
N	159	159	159	159	159
Minimum	.00	1.00	0.70	0.42	1.17
Maximum	2276.00	16.00	2.13	3.15	18.62
Mean	29.21	3.85	1.53	1.82	5.50
SD	471.11	2.45	0.28	0.49	3.27

Table 5.3: Axial Line Analysis: correlations between configurational and metric variables

	Choice	Conn.	Global Integration	Local Integration	Line Length
Choice	▨				
Connectivity	0.856	▨			
Global Int.	0.603	0.613	▨		
Local Int.	0.809	0.866	0.841	▨	
Line Length	0.70	0.807	0.508	0.710	▨

Mean 0.73.

5.4.2.- Axial Line Analysis

Axial Line[7] Analysis began by observing how many lines each subject selected when contesting questions A and C. Table 5.4 shows that the number of axial lines chosen by subjects when contesting question A (the three main streets) was more than two times the number of lines selected when participants had to respond to question C (the main street).

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[7] All descsiptive data concerning each line configurational and metric values is displayed in Table 1 of Appendix 2

A Mann-Whitney U test was carried out[8] to test if males and females chose, on average, a different number of lines. This did not show any statistical difference between sexes for neither one “main street” (U: 138,0; p>0,05), nor the three main streets (U: 128,5; p>0.5). Next, it was investigated if a person’s willingness to select few (or several) lines in one test (e.g question A) might predict his/her inclination to do the same in the following test (question C). A correlation [9] (Spearman) detected no significant association between these two variables (r_s: -.24; p>0.05).

The second part of the analysis examined which axial lines were, and were not, selected by people when responding to questions A and C. A visual inspection of figures 5.2 and 5.3, permits to see that in both cases paths made by participants were far from being random but reduced to a discrete set of sinuous lines. Further, it seems that a consistency existed in people between questions A and question C, meaning that few extra paths appear when subjects had to select three “main streets” than when they were asked to select just one “main street”.

Table 5.5 tested this idea, showing the degree of coincidence between a person´s answer to question A and C. For example, when one line had to be marked, more than half of participants (55% in fact) selected the same line, whereas when three streets had to be marked, one sole line was chosen by 86% of respondents. In order to test statistically these coincidences, another correlation (Spearman) was realized. This detected a high association (r_s: .744; p<0.01) between these two variables. In other words, when a line is selected in question A (to select 3 main streets), it is highly likely that it will appear in question C (to select the main street).

But consistency does not explain why street X but not street Y was chosen as a main street. In other words, it does not explain the phenomenon, it merely characterizes it. Aimed to find an explanation to this dilemma, as series of correlations between metric and configurational aspects of lines and these Lines` Total Occupancy Index (LTOI) were realized. Table 5.6 shows the results of this exercise.

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[8] This test was selected due to the abnormality of this distribution, as mentioned later in this text.

There are several aspects of interest in this table. First, correlations moved upwards when more streets were selected. For example, mean correlation value when one street was selected reached 0.356 (SD =0.043), whereas mean correlation value when three streets were chosen was 0.441 (SD =0.024). From a statistical point of view, these results seem reasonable, since allowing subjects to select more than one option as main street equals giving them more chances to "diminish the risk" of making wrong selections.

Second, either when subjects had to respond to question A or C, configurational properties of the map, rather than metric aspects of it, could better explain the likeliness of a line of being chosen as a "main street". Proof of that is the fact that when one street was chosen, Global Integration and Connectivity were the variables that most efficiently predicted people's judgments (r_s: .389; $p<.01$ y r_s: .382; $p<.01$ respectively), whereas line length was the least effective variable in doing the same. A similar result was obtained when three main streets were marked, with the sole difference that this time Connectivity and Local Integration (r_s: .470; $p<.01$ y r_s: .461; $p<.01$ respectively), were the configurational variables more highly associated to participants` choices.

Table 5.4: Number of axial lines selected by participants

	One main street	Three main streets
Minimum	2	7
Maximum	7	18
Mean	5.11	12.4
SD	1.62	2.66

Table 5.5: Level of agreement among participants

	One main street	Three main streets
Participants	35	36
Minimum	0	0
Most used line (N)	20	31
Most used line (%)	55.55	86.10

Table 5.6: Axial Line Analysis: predictive power of configurational and metric measures

	One main street	Three main streets
Choice	0.362	0.440
Connectivity	0.382	0.470
Global Integration	0.389	0.419
Local Integration	0.380	0.461
Line Length	0.284	0.416
Mean	0.359	0.441
SD	0.043	0.024

5.4.3.-Axial Node Analysis

The first step of axial node analysis was rather similar to the one employed in Axial Line Analysis. It demanded first to see aggregate information about the measures of Global Integration, Local Integration, Connectivity, Choice and Line Length of the 186 choice nodes existing in the map. Table 5.7 shows some information about the mean, the maximum the minimum, and the Standard Deviation of these measures.

Once this was terminated, it was calculated how many nodes each participants selected when contesting to question A (to select the three main street), and when contesting to question C (to select the main street). Table 5.8 shows the result of this exercise here it is possible to appreciate that when three main streets had to be selected (table 5.7), the average of nodes selected was 39.75 (SD 5.21), while when participants had to mark just one main street, the average of nodes chosen was 4.17 (SD 2.96).

Concordant with what was observed in Axial Line Analysis, no difference in the amount of nodes selected by males and females was detected (U: 141,5; p>0,05 y U: 142,0; p>0,05), nor does association exist between the amount of nodes selected by people in questions A and C (r_s: -.127; p>0.05).

Some nodes received more choices than others, though. For example, when subjects selected the main street of the system, node Nº 49 captured 82% of preferences, meaning that four out of five people selected this node as being part of a path (any path) that corresponded to the main street. Similarly, when individuals had to select the three main streets of the system, node Nº 82 was chosen by 77% of individuals. This trend was even more evident when individuals had to select the map`s three most important junctions, for all but one contestant chose a given node (node Nº 49) as one of three most salient nodes.

Unlike Axial Line analysis, the process of assessing each node`s configurational or metric value was far more complicated and time-consuming. It started by observing the axial lines that concurred to each of the 186 nodes existing in the network. Then, all configurational and metric values of these lines were summed up, and divided by the total number of incoming lines of each node. For example, if node Nº 100 received the axial lines 10, 11 and 12, the configurational measures of Global Integration, Local Integration, Connectivity, Choice as well and the metric measure of Line Length belonging to lines 10, 11 and 12 were summed up independently, so to obtain the aggregate value of lines 10, 11 and 12's Global Integration, Local Integration, Connectivity, Choice and Line Length measures. Finally, these values were divided by three (since only three lines reached node Nº 100), which resulted in five mean values: four of them were of configurational nature (Global Integration, Local Integration, Connectivity and Choice), whilst the last one was of metric nature (Line length). Table 2 (see Appendix 1) shows in this exercise.

Once mean values were calculated for all nodes, the first phase of the analysis investigated if collinearly effects existed in the sample, that is, if mean configurational values of nodes were highly associated to each other, or if any of these values was associated to metric ones. A new series of correlations (Spearman) were carried out for this purpose.

Table 5.10 presents the results of this exercise, showing that in most cases the association between configurational and metric measures of lines have moved slightly upwards when a node analysis is employed (mean r_s =0.75 compared with r_s =0.73 of line analysis). For example, a high level of association existed between Local Integration and Connectivity (r_s = .933), and between Local Integration and Global Integration (r_s = .870). It seems, therefore, that the node technique has increased the convergence between the map`s configurational and metric properties.

But can node analysis predict people's answers regarding hierarchies more efficiently than line analysis?

Table 5.11 attempts to respond this question. Here another set of correlations (Spearman) between mean metric and configurational values nodes and each node's NTOI rate was undertaken. An initial inspection of these figures reveals some intriguing results. First, it seems that dissecting people's choices using a node technique, improves the predictive power of configurational or metric properties for questions A and C (those involving paths), but not for question B (the three most important junctions of the system). Likewise, it was found that higher associations were detected between metric and configurational aspects of maps and behavioral data when three, rather than one, streets had to be selected.

As per Axial Line analysis, the employment of a node technique revealed that configurational aspects of the network were more effective in predicting people`s choices than metric aspects. However, the type of configurational variable that most highly predicted people`s judgments about the main and the three main streets in the map varied in node analysis with respect with line analysis, for was Choice, rather than any other syntactic or metric measure, the measure that most robustly predicted paths made by participants. Equally interesting is the fact that Line Length had the lowest value of the sample (r_s: 0.447).

As mentioned, node analysis did not mean a substantial improvement in detecting whether any configurational or metric variable could predict participants` choices, concerning the three most important junctions. Although the highest association is, again, Choice, a discrete r_s: .246 was obtained.

Table 5.7: descriptive information of nodes

As mentioned, node analysis did not mean a substantial improvement in detecting

	Choice	Connectivity	Global Integration	Local Integration	Line Length
N	186	186	186	186	186
Minimum	1.00	1.50	0.81	0.76	2,43
Maximum	1685.00	12.00	2.02	2.85	17,42
Mean	483.54	5.04	1.37	2.02	7,15
SD	409.45	1.89	0.26	.37	2,68

Table 5.8: node's frequency of use for questions C, A and B [10]

	1 main street	3 main streets	3 most important junctions
N	186	186	186
Minimum	0	0	0
Maximum	29	56	35
Mean	2.62	7.81	0.80
SD	5.84	12.22	3.472

Table 5.9: correlations between configurational and metric variables

	Choice	Conn	Global Integration	Local Integration	Line Length
Choice					
Connectivity	0.837				
Global Integration	0.679	0.711			
Local Integration	0.806	0.933	0.870		
Line Length	0.691	0.746	0.523	0.710	

Conn: Connectivity

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[10] A clarification is necessary. When two different paths belonging to a given individual have one node in common, this node was counted twice, not one.

Table 5.10. Axial Node Analysis: predictive power of configurational and metric measures

	One main street	Three main streets	Three most important junctions
Choice	0.444	0.636	0.246
Connectivity	0.378	0.523	0.220
Global Integration	0.488	0.555	0.243
Local Integration	0.419	0.554	0.236
Line Length	0.270	0.447	0.176
Mean	0.399	0.543	0.224
SD	0.082	0.068	0.028

5.5.- Segment Analysis

5.5.1.- Segment Line analysis

In a similar manner to Axial Line Analysis, the first step of Segment Line Analysis consisted of placing an ID number for all segments. This was carried out by translating the information delivered by Depthmap into a CAD platform, and then using this program to study people's paths. Nonetheless, prior to this procedure, it was necessary to eliminate a large number of very short segments resulting from what Dalton (2001) called as *trivial rings*, or rings resulting when two or more than two axial lines intersect at a given point in space. The irregular character of the map employed in this experiment meant that trivial rings were abundant when the network was analyzed using Segment Analysis. In fact, a total of 491 segments resulted from decomposing the axial map into segments, although only 369 of them could be considered as relevant for the analysis, meaning that they were not part of any trivial ring[11]. This equaled to approximately 25% of lines.

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[11] The criteria for discarding trivial rings consisted of measuring the shortest block in the map and then to eliminate all segments whose length was shorter than this value. About a 25% of all original segment lines were discarded as a result of this process.

Figures 510a to 510e show a series of segment maps depicting various configurational and metric measures. In order to make results comparable, Mean Depth and Mean Depth R3 have been equated to Global and Local Integration respectively. Mean Depth (figure 5.10a) seems to encompass a vast zone at the center of the map, capturing some well-connected and long lines crossing the system both horizontal and diagonally. Mean Depth R3 (figure 5.10b) follows a different pattern for it picks up highly salient junctions in the map. Connectivity (figure 5.10c), perhaps the least interesting measure of segment analysis, just highlights a star-like junction at the left hand side of the figure. Choice (figure 5.10d) shows a rather complex distribution, one that produces a super grid network covering the entire area of the map and at the same time, it emphasized a horizontal street in the map Finally, the map's longest segments (shown in figure 5.10e) are evenly distributed on the network and none of them is placed along on of the map's longest axes.

Unlike Axial Line Analysis, Segment Line Analysis shows a lower degree of association among configurational and metric variables. Most of them seem to move in a $r_{s:}$ 0.4-0.6 range, although some of them (especially those related to segment length), do not surpass the $r_{s:}$ 0.3 limit. The highest value of the sample correspond to the relation between Mean Depth and Choice (r_s:-.74; $p<0.01$). For the sake of brevity, all descriptive data is presented in Appendix 2.

The first dimension of analysis explored whether sex differences existed for questions A and C. Since what changed was the way data is analyzed (not the information itself), one should not expect any substantial change with respect to axial line analysis. All results show that this is the case: no differences were found in the number of segment chosen by males and females for questions and A or C (U: 141,5; $p>0,05$ y U: 142,0; $p>0,05$ respectively). Likewise, a poor association exists between the number of segments chosen by subjects when responding to question A and C (r_s: -.19; $p>0.05$), meaning that the number of nodes selected by person X regarding the main street of the system was not a good predictor of the number of segments when the same subject marked the three streets of the system.

Table 5.11 shows what is probably the most important part of this analysis, which consisted in comparing behavioral data against configurational and metric values of networks. Concordant with the pattern observed so far, lower correlations were found when just one main street had to be marked than when three streets were outlined by participants. Another aspect of importance regards the preeminence of configurational over metric aspects of space in predicting people's choices. For example, the configurational measure that most efficiently predicted people´s paths when three main streets were marked, was Mean Depth[12] (r_s: -0.580), followed by Choice (r_s:0.473), while the highest correlations when just one street was marked were Choice and Mean Depth (r_s: -0.589 and $r_{s:}$ 0.547 respectively). Two other effects deserve study. The first regards the null effect of Connectivity, a measure that in previous experiments was highly associated to participants' selections. In segment analysis Connectivity merely shows the number of lines a given segment intersects. Since these intersections can be produced at the end of segments, values are usually between one (a dead end street) and six (a multiple junction), it is of little surprise that Connectivity was poor capturing behavioral data. The same seemed to occur with Line Length. As Connectivity, line length in segment analysis is a controversial measure, for it does not show how extended is a path. but merely a block's dimension.

5.5.2.- Segment Node analysis

Since all data concerning gender or individual differences was the same for all kind of analyses involving nodes (after all, both paths and nodes are identical) this section will omit a detailed description of those topics. In both cases, results are exactly the same as those presented in point 5.2. Instead, this section will focus on the study of nodes, so to see if there was any relation between a node´s frequency of use and its configurational or metric properties [13].

Table 5.12 presents these associations. A rapid inspection of this table reveals several facts. The first effect shows that node analysis seems to better encapsulate configurational information of networks, and therefore to better reflect participants` choices.

The second effect has been also commented before and regards the fact that higher associations were obtained when three, rather than just one line, had to be

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[12] Negative correlations are explained by the nature of this measure. Unlike Global or Local Integration in Axial Analysis, a low depth value of Mean Depth indicates a highly accessible line in topological terms.

[13] All descriptive data concerning segment node analysis is exposed in Appendix 2.

selected. The third effect seems to stress the predominance of configurational variables over metric variables in predicting of people's choices for either questions A and C. For example, while Mean Depth and Choice were reasonably associated to node use in question C (r_S: 0.588 and r_S: -0.658), Line Length cannot predict to any degree how often a node was selected.

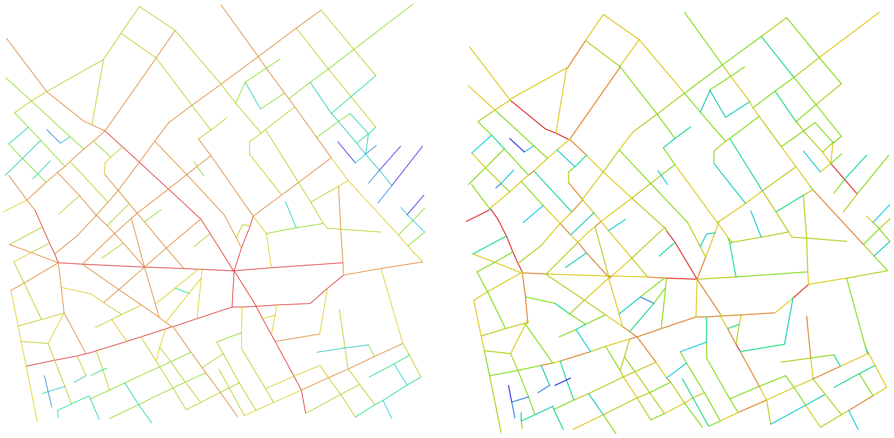
The fourth phenomenon refers to the poor results obtained in the case of question 2 (three most important junction of the system). As in Axial Node Analysis, contestants' choices have been not captured by either configurational or metric properties of nodes, thus leaving correlations in a in r_S: 0.2-0.3 range.

Table 5.11. Segment Line Analysis: correlations between behavioral and spatial data

	Choice	Conn	Mean Depth r =n	Mean Depth r = 3	Segment Length
One main street	0.473	n/s	-0.580	-0.343	n/s
Three main streets	0.547	n/s	-0.589	-0.432	n/s

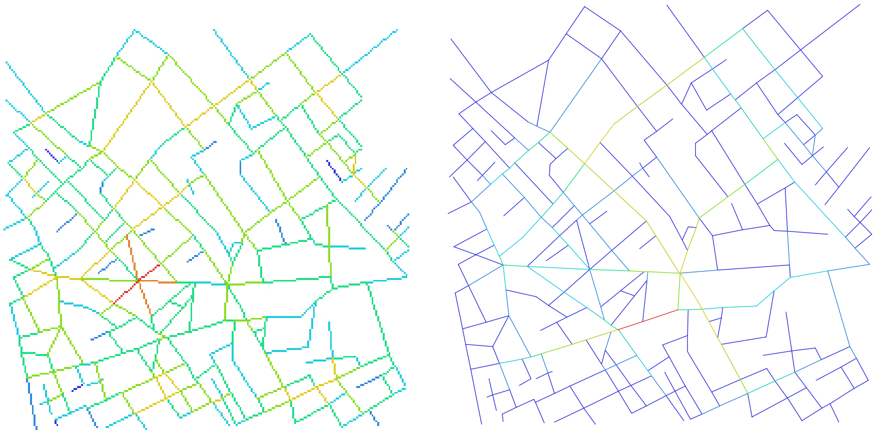
Table 5.12. Segment Node Analysis: correlations between behavioral and spatial data

	Choice	Conn	Mean Depth	Mean Depth r=3	Segment Length
One main street	0.461	n/s	-.642	-.325	.234
Three main streets	0.588	n/s	-.658	-.433	n/s
Three most important junctions	.189	.178	-.282	-.209	n/s



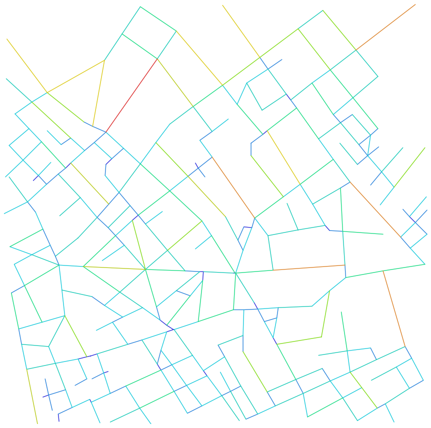
Mean Depth

Mean Depth r =3



Connectivity

Choice



Segment Length

Figure 5.10a to e: Segment Analysis

5.6.- Discussion

The series of analyses realized so far have shown that configurational, rather than metric, properties of space could better predict participants' choices about hierarchical information in the map employed in this experiment. This occurred regardless changes realized in the type of analysis being employed, the type of technique with which people's answers were studied (segment of axial analysis), or the amount of lines individuals were asked to select (one or three main streets).

It was also demonstrated that comparing people's answers against choices nodes resulted in higher associations than comparing their judgments against axial or segments lines. Another interesting result is that higher correlations were detected when three main streets, rather than when just one main street, had to be selected. As mentioned earlier, this might be explained statistically, for it means that subjects *spread the risk* of making some mistakes when more lines were taken into account then when fewer lines had to be chosen.

There are of course several questions that need further investigation. One refers to the type of configurational measure that better predicts participants` choices. Results shown here that there is no unique answer to this query, for the configurational measure that most efficiently predicted participants' choices depended on the type of spatial model being used (axial or segment), the way in which configurational or metric measures are measured (nodes of lines), or the type of question being answered question being answered (one or three main streets). In seems, therefore, that no single spatial variable can fully predict how persons retrieve hierarchical information from networks.

Here it will be argued that this could be explained by the strong association between metric and configurational measures of network. It might therefore of no surprise that under certain conditions one configurational measure was the best predictor behavioral data, whereas in other circumstances a different configurational measure took this role.

The second unresolved question refers to the role of configurational or metric aspects in shaping participants` judgments about the three most important junctions of the map. As it was presented, no configurational or metric property could give a reasonable account about why a given point, and no other, was considered as important by respondents.

Although preliminary, the outcomes of this experiment have made several steps towards a better understanding of the role of configurational information in permitting people to retrieve hierarchical information in maps. The next section will make further advances in that direction.

chapter Five (b)

Continuity Lines Analysis

Abstract

This section continues the analysis which started in the previous chapter, where people were asked to retrieve spatial hierarchies in a map, with the sole difference that a new spatial model, the Continuity Lines analysis (or Mindwalk), will be employed to analyze people´s answers.

The model "merges" the axial lines existing in a system according to a certain angle of aggregation, and then calculates configurational and metric relationships amongst the continuous paths of this new system. Two threshold angles were employed in this analysis: 15º and 30º.

The main findings suggests that the Continuity Lines analysis is more efficient in predicting people's choices about the main and the three main streets of the map, than either the Axial or Segment analyses, although no improvement was detected when the map's three most important junctions had to be marked.

5.7.- Continuity lines analysis

The Continuity Lines Analysis (or Mindwalk) model is a close relative of Axial analysis. Recently created by Lucas Figueiredo[1] as part of his MSc thesis, the model employs two of the fundamental assumptions of syntactic analysis: that urban space can be represented as a set of axial lines, and that these lines can be examined in terms of their configurational properties. The main difference of this technique with respect to axial analysis is Mindwalk`s capacity to merge lines[2]. This means that Mindwalk does not decompose urban space into a series of straight lines, but assumes that slight deviations occurring to these lines are ignored by individuals, which leads to the model to represent urban space as a series of continuous lines (hence its name), which are then assessed configurationally.

In order to run Mindwalk, users have to first determine the aggregation angle to be employed. For example, if the aggregation angle is set at 10º, all lines whose encounter is up to 10º will be merged and converted into continuous entities. This in turn will affect both the number of lines existing in the spatial system, and the distribution of configurational and metric properties of these elements.

Seeing it this way, it seems reasonable to suggest that Mindwalk is a creative solution to the "Manhattan problem", posed by Stonor in 1991, and outlined in chapter Five.

The main cost of employing Mindwalk is that users have the responsibility of defining the angle of aggregation with which all lines of a given spatial system will be merged. This means that the first question that any user of the software is called to respond is: What aggregation angle should be employed?

There are various ways to answer this question. One of these could be to examine the impact that different aggregation angles produce in the spatial system subject of study. This would allow to those in charge of the analysis to see which angles have more consequences in terms of line aggregation, and then to select the most decisive angular thresholds for subsequent analyses. For example, in a fully

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[1] Figueiredo currently realizes a PhD in UCL. The author is especially grateful to him for his advice and support during this chapter.

[2] Mindwalk prioritizes longer lines, over shorted ones, to aggregate streets. This means that if two lines of different length fall within a given threshold angle (e.g. 30º), the software will automatically choose the longest line for the merging.

orthogonal grid, any angle below 10º will not aggregate a single line, but in a more irregular structure like those found in Europe, a low angle of aggregation will merge an important proportion of lines.

Another way to deal with the problem is to see if there are precedents in the literature of the subject that indicate the existence of mental thresholds employed by people to encode angular information. For example, it might be the case that up to 15º, people do not consider that a line bends, but that any angle sharper than that will be considered as a turn.

For the purpose of this study, both perspectives were employed, meaning that the map was firstly studied by observing the consequences of applying a threshold angle of 5º, and then, by reviewing existing literature on the issue.

Results of the first part of this exercise are shown in Table 5.14., which shows the number of lines resulting from applying a 5º aggregation angle in the original axial map[3]. As it can be seen, the number of lines existing in the map decreased significantly as a product of line aggregation, moving from a total of 159 when no angle was applied, to 120 when a 40º angle was utilized. However, while in the 25º-30º interval only one line was merged, in the 30º- 35º interval five lines were aggregated.

Figure 5.11 clarifies the point, by showing that in the first phase of line aggregation (between 0º and 15º), a large number of lines were merged, whereas during an intermediate phase (15º to 30º) few lines were aggregated. Finally, during the final phase (30º to 40º) the velocity of line merging resumed its pace.

The aggregation of lines affected the system's configurational properties too. As table 5.13 illustrates, mean Global Integration jumped from 1.24, when no angle was employed, to 1.61 when a 40º angle was utilized.

Aimed to further explore this fact, another exercise was undertaken. This consisted in examining the mean configurational and metric values resulting from the employment of a 15º, a 30º and a 40º angle. These angles were chosen because they seemed to encompass three phases in the aggregation process of this map: one in which line merging occurred at a rapid pace (0º to 15º), another in which this process comes to a halt (15º to 30º), and a final one in which line aggregation seemed to gain momentum again (40º).

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[3] For the sake of brevity, the analysis stopped at 40º .

Results of this exercise are shown in table 5.14. Here it can be appreciated that Global Integration's mean value moved from 1.26 in Mindwalk 15º analysis, to 1.63 in Mindwalk 40º analysis, while Line Length mean value moved from 5.5 to 6.65 in the same interval. But as mean values increased, so did the values of Standard Deviation (SD). For example, the SD of Line Length passed from 3.38 in Mindwalk 15º analysis to 6.49 in Mindwalk 40º analysis, whereas the Global Integration's SD moved from 0.28 to 0.41. It seems therefore that merging lines did not only alter the number of lines existing in each system, but also the way in which these systems configurational and metric values were distributed.

Table 5.13: Consequences of employing a 5º aggregation angle

Angle of aggregation	Number of lines	%	Mean Global Integration value	%
0 º	159	100	1.25	100
5 º	157	98.7	1.32	105.57
10 º	151	94.7	1.37	109.18
15 º	141	88.6	1.48	118.23
20 º	133	83.6	1.53	122.16
25 º	130	81.7	1.52	121.14
30 º	129	81.1	1.52	121.32
35 º	124	78	1.56	124.59
40 º	120	75.4	1.61	128.92

Table 5.14: mean configurational and metric values of lines

	Axial analysis	Mindwalk 15º	Mindwalk 30º	Mindwalk 40º
Number of lines	159	141	129	121
Global Int.	1.53 (SD 0.28)	1.26 (SD 0.28)	1.54 (SD 0.37)	1.63 (SD 0.41)
Local Int.	1.82 (SD 0.49)	1.87 (SD 0.55)	1.87 (SD 0.57)	1.91 (SD 0.60)
Connectivity	3.85 (SD 2.45)	3.74 (SD 2.83)	3.66 (SD 2.88)	3.68 (SD 3.11)
Choice	295 (SD 471)	0.02 (SD 0.04)	0.02 (SD 0.05)	0.02 (SD 0.05)
Line Length	5.50 (SD 3.27)	5.36 (SD 3.38)	5.84 (SD 4.90)	6.65 (SD 6.49)

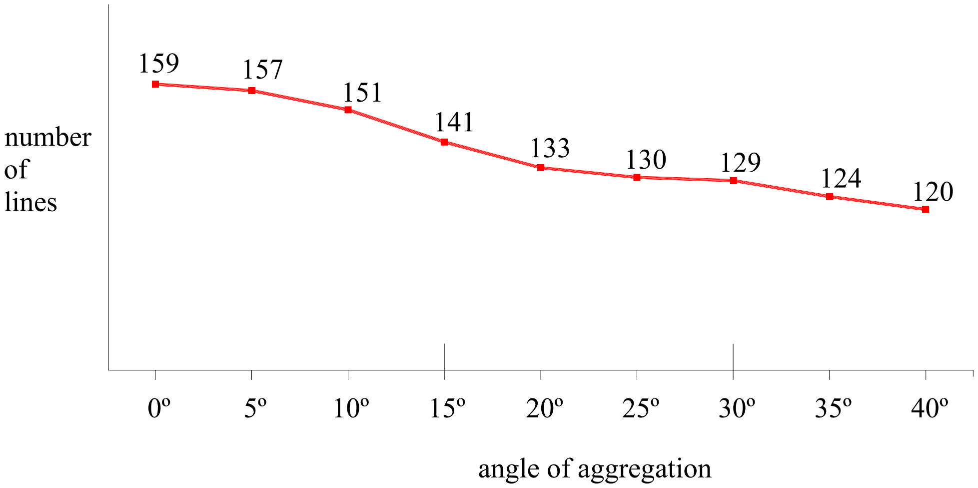


Figure 5.11: Number of lines resulting from employing a 5º angle

The analysis of literature seems to support these findings. In fact, there is evidence supporting the fact that slight deviations occurring to lines are either ignored by humans (who consider these paths as continuous), or are mentally stored in a categorical way. Apart from the already mentioned series of Gestalt laws (Wertheimer 1933; Koffka 1935; Kohler 1947), various scientists have studied the mechanisms by which people encode information regarding turns. Griffin (1948) for example, sustained that slight turns occurring to lines are often ignored by people, who instead perceive them as sinuous paths. Similarly, Tversky (2003) demonstrated that angles are usually judged closer to the 0º and 90º axes than to any other intermediate location. Sadalla and Montello (1989) have shown that these axes shape people`s ability to memorize angular information, for angles closer to the 0º and 90º are more easily and efficiently recalled than those belonging to intermediate intervals.

Especially relevant in this context is the work of Alexander Klippel. After asking people to group different turns into a discrete number of linguistic categories (Klippel and Montello 2004; Klippel and Montello 2007), Klippel found out that turns are mentally stored in an asymmetrical way, meaning that they form a cone of which the linguistic terms of right (R), left (L), half-right (HR), half-left (HL), steer right (SR), steer left (SL) and straight, are not identical in size. Figure 5.12 illustrates this idea. Here it can be appreciated that, while the term “straight” was reserved for a vertical line, an ample meaning was given to the concepts of (R), (L), (HR), (HL), (SR) and (SL). Moreover, these categories were not identical in size, meaning that the area of a circle covered by the HR category was larger than the area of a circle covered by HL, and that both categories summed up covered less space than the sum of SR and SL. This shows that the mechanisms used by people to encode information about turns are much more sophisticated than it might be initially thought.

Although Klippel`s work has undoubtedly contributed to the debate of how people encode angular information of the environment, the strict meaning he gave to the category “straight” is nonetheless questionable, for there is evidence that this term is to some degree dependant on contextual information. An interesting point in that regard is that of Tversky`s (1999), who suggested that route directions are governed by the rule of forward progression, according to which people would ignore slight reorientations occurring to paths when the destination is clearly identifiable. This means that when persons are told to go straight along street X until getting to landmark Y (e.g. a church), they are likely to ignore the presence of slight turns occurring to this street (hence, interpreting the term straight in a rather ambiguous manner), in order to be able to reach the destination. Clearly aware of this limitation, Klippel sustained that *"when performing the linguistic task of giving route instructions, therefore, this decision-point focus leads to the more classical characterization—in terms of qualitative directions—in which the linguistic concepts of LEFT and RIGHT serve as sectors centered around the orthogonal axes of 90° and 270°".*(Klippel and Montello 2007:16-17)

For the purpose of this study and considering that the ultimate nature of the statement "please outline the main street" demanded people to assess contextual information coming from the entire network, the idea of straightness will be interpreted in a flexible way, so to mirror people`s spatial reasoning as much as possible. Two aggregation angles will be employed to do so: 15º and 30º, as figure 5.13 exemplifies.

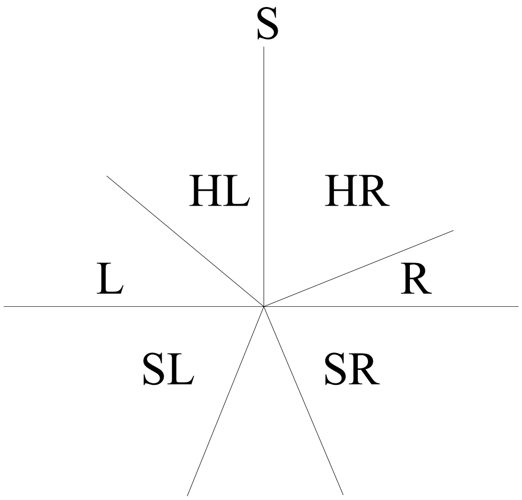


Figure 5.12: Klippel`s spatial model of angular categorization. HR and HL correspond to half-right and half-left respectively, whereas SR and SL mean steer right and steer left respectively.

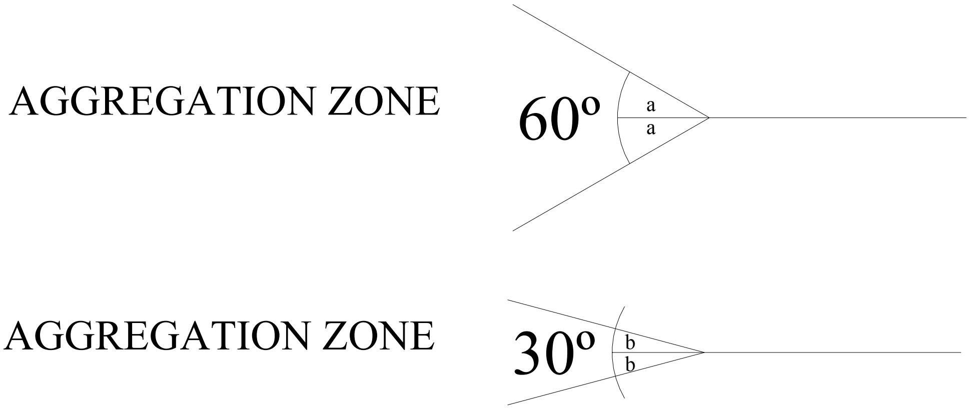


Figure 5.13: angles of aggregation used in this experiment

5.7.1- Mindwalk (15º) Line Analysis

As in Axial Line Analysis, Mindwalk 15º Line Analysis started by assessing if gender differences existed in the number of (continuous) lines chosen by participants. A Mann-Whitney test detected no differences in that regard (U: 148,5; p>0,05 and U: 117,5; p>0,05 for questions A and C respectively). Similarly, no association was found between the number of lines that each individual chose in these tests (r_s: -.195; p>0.05). Finally, it was investigated whether the fact that a line was named as a main street could mean that it would appear as being part of the three main streets. A high association was found between these two variables (r_s: .743; p<0.01), proving that individuals were fairly consistent in their answers.

Table 5.16 shows that the level of association between configurational and metric values in Mindwalk 15º Line Analysis was higher than in Axial Line Analysis or Segment Line Analysis, which seems to support the idea that line aggregation produced a reorganization of configurational and metric variables.

Figure 5.14 (a to d) shows graphically this idea. Here a series of maps containing the configurational measures of Global Integration, Local Integration, Connectivity, Choice as well as the metric measure of Line Length are presented. At a first glance it is evident that, unlike Axial or Segment Line analyses, in Mindwalk 15ºanalysis there was a higher degree of coincidence between metric and configurational values. Proof of that is the fact that a diagonal path is at the same time the longest, the most connected; the most globally and locally integrated street and the line of highest Choice of the system.

In order to see if this degree of synchrony can be observed in other salient lines, an exercise was undertaken. This consisted in highlighting in different maps the five lines with the highest value of Global Integration, Local Integration, Connectivity, Choice and Line Length. Figure 5.15 (a to e) shows the results of this exercise. As it can be appreciated the group of the five most connected, globally and locally integrated, of highest choice and longest lines, comprised only seven different lines. It can therefore be said that line aggregation not only resulted in a synchronization of the metric and configurational aspects of line at a aggregate level (as the convergence of mean values of lines showed), but also meant a synchronization of the network's salient lines.

The obvious question is: did this phenomenon help or deter people in retrieving hierarchical information?

In order to respond to this question, a series of correlations between spatial variables and behavioral data were carried out. Following the procedure employed in Axial Line analysis and Segment Line analysis, people's choices concerning the main, and the three main streets, were examined by observing which continuous lines they involved. The sum of all paths produced a Line Total Occupancy index (LTO), which was then compared to the configurational and metric value of each of the continuous lines existing in the system, as table 5.17 shows.

The first thing to note is that, like in previous calculations, configurational variables were more efficient in predicting people's choices than metric ones. For example, Global Integration was the variable that most efficiently predicted people's paths when one street had to be selected (r_S: .416) , as well as when three main streets had to be chosen (r_S: .479). By comparison, the metric measure of Line Length was less efficient in predicting people`s answers when one or three main streets had to be marked.

Table 5.16. Mindwalk 15º Line Analysis: correlations

	Choice	Conn	Global Integration	Local Integration	Line Length
Choice					
Connectivity	0.806				
Global Integration	0.572	0.480			
Local Integration	0.684	0.790	0.935		
Line Length	0.649	0.813	0.575	0.677	

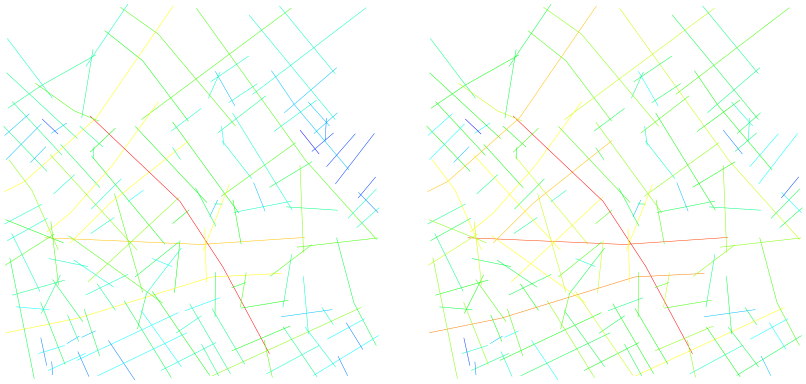
Table 5.17. Mindwalk 15º Line Analysis: predictive power of configurational and metric variables

	1 main street	3 main streets
Choice	0.349	0.408
Connectivity	0.339	0.440
Global Integration	0.416	0.479
Local Integration	0.381	0.471
Line Length	0.304	0.421
Mean	0.358	0.444
SD	0.042	0.030

5.7.2- Mindwalk 15º Node Analysis

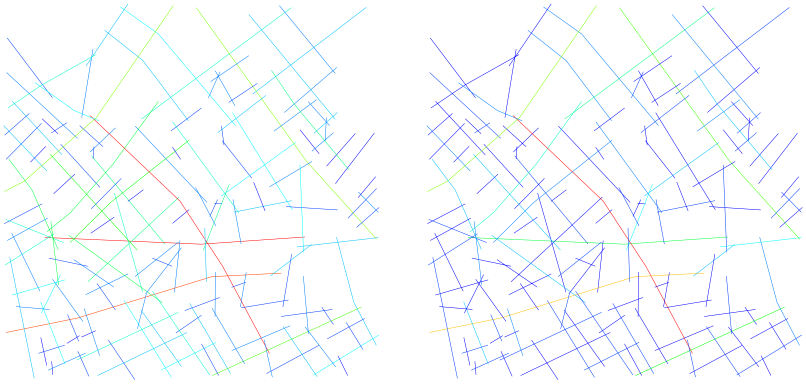
In order to shorten the analysis, and considering that people's choices in relation with the selection of nodes is identical to Axial Node Analysis and to Segment Node Analysis, this section will not examine gender differences on the number of nodes selected by participants. Instead, this analysis will focus upon the study of the role of configurational and metric properties of space in shaping people's answers.

Table 5.17 shows some descriptive data of nodes when a 15º angle was employed. A brief study of these figures shows that some of the trends previously observed in Axial Line Analysis emerge. For example, the mean values of configurational and metric measure are higher than in Axial Node Analysis and Segment Node Analysis. Similarly, the Standard Deviation of these values is larger in all configurational and metric measures, which seems to reinforce the idea that line aggregation has resulted in an "oligarchy of routes", as proposed by Kuipers (2003).



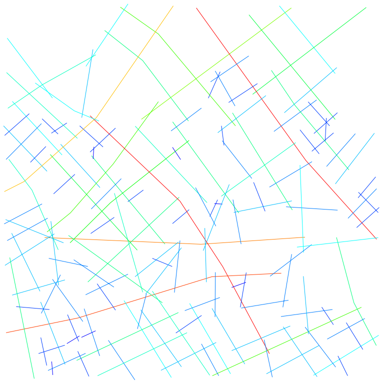
Global Integration

Local Integration



Connectivity

Choice



Line Length

Figure 5.14 (a to e): configurational and metric measures of Mindwalk 15º analysis

Global Integration

Local Integration

Connectivity

Choice

Line Length

Figure 5.15: the five most salient lines of the map resulting from employing a 15º aggregation angle

Merging lines also meant that correlations between configurational and metric variables increased considerably. As table 5.18 shows, the mean value of these associations is r_s: .833 (SD .075), compared with the rs: .73 obtained in Axial Node Analysis. The most interesting result is nonetheless the predictive power of configurational and metric variables. As table 5.19 shows, the measure that most efficiently predicted participants' paths regarding the main street of the map was Global Integration (r_s: .644), whereas the measure most highly associated with their responses to the three main stress was Choice (r_s: .719). No improvement was nevertheless detected when the three most important junctions had to be marked.

Table 5.17: Mindwalk (15º) Node Analysis. Descriptive data

	Choice	Conn	Global Integration	Local Integration	Line Length
N	186	186	186	186	186
Minimum	0.00	1.50	.94	0.81	2.19
Maximum	0.29	16.5	2.50	3.32	25.35
Mean	.06	5.75	1.66	2.18	9.40
Standar Deviation	.08	2.79	0.34	0.47	4.75

Table 5.18. Mindwalk (15º) Node Analysis: correlations between metric and configurational measures

	Choice	Conn	Global Integration	Local Integration	Line Length
Choice					
Connectivity	0.854				
Global Integration	0.738	0.820			
Local Integration	0.791	0.913	0.959		
Line Length	0.854	0.883	0.719	0.799	

Table 5.19 Mindwalk (15º) Node Analysis: correlations between metric and configurational measures

	1 main street	3 main streets	3 most important junctions
Choice	0.575	0.719	0.246
Connectivity	0.565	0.701	0.292
Global Integration	0.644	0.690	0.277
Local Integration	0.611	0.709	0.297
Line Length	0.510	0.699	0.287
Mean	0.581	0.703	0.279
SD	0.050	0.010	0.020

5.8.- Mindwalk (30º) Analysis

5.8.1- Mindwalk (30º) Line Analysis

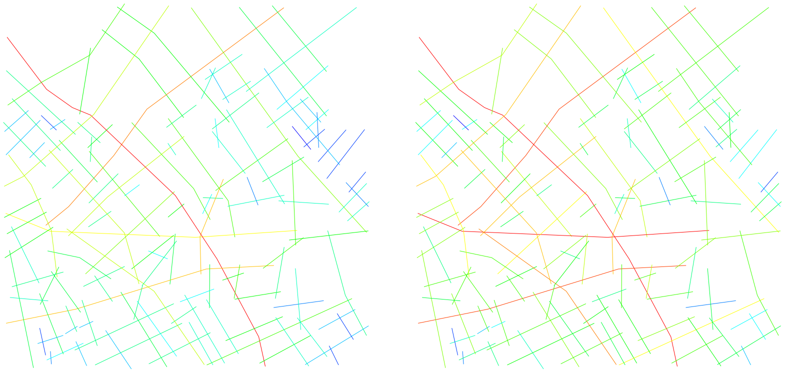
The analysis of metric and configurational values in Mindwalk 30º Line analysis shows coincident aspects with its 15 º counterpart. This is due to the fact that, as in Mindwalk 15º Line analysis, the aggregation of axial lines changed the way in which configurational and metric values were arranged, producing a more skewed distribution in which few long and well-connected lines appear as hierarchical in the map, whereas a vast number of short and poorly connected lines remain in the background. Table 5.20 presents the figures supporting these ideas, whilst figures 5.16a to 5.16e show a series of maps depicting the configurational measures of Global Integration, Local Integration, Connectivity, and Choice, as well as the metric measure of Line Length.

A rapid inspection of these maps reveals that the aforementioned synchrony between metric and configurational properties of lines accentuated. This means that highly connected lines were more likely to be, at the same time, highly integrated or extended ones. Proof of that is the fact that in all figures an extended path that crisscrosses the network diagonally, appears as the longest, the most locally and globally integrated, the most connected and the line of highest choice of the map. Figure 5.17 exemplifies this idea by highlighting the five lines of most configurational and metric salience in the system.

Here it can be noted that, like in Mindwalk 15º Line analysis, maps look very similar to each other, meaning that, independently of the measure being shown (Local or Global Integration, Connectivity, Choice, or Line Length), an almost identical set of lines commands the table. The main difference of this exercise with respect to Mindwalk 15º Line Analysis is that lines are now longer, a consequence of applying a more generous threshold angle in an irregular grid.

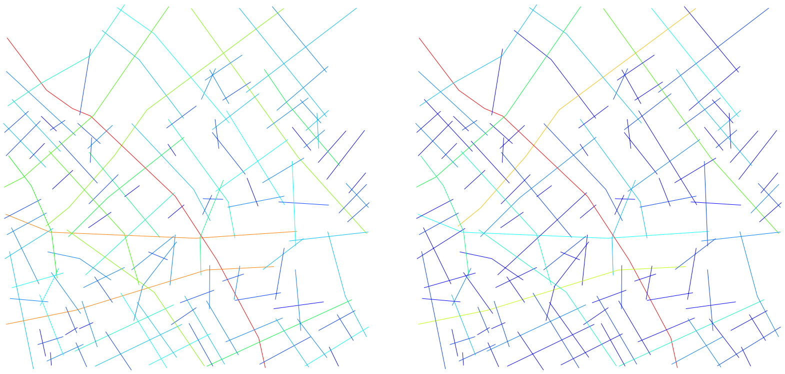
Following the procedure employed in former analyses, table 5.21 displays a series of correlations between configurational and metric values. As it can be seen, in most cases the value of these correlations are almost identical to the ones obtained in Mindwalk 15º Line Analysis, which suggests that the coordination between metric and configurational factors has come to a halt.

Table 5.22 presents a new series of correlations between metric and configurational variables and participants' choices regarding the main street, the three main streets and the three most important junctions of the map. Results here show that either when one main street had to be marked, or when three streets had to be outlined; configurational measures were superior in predicting people's choices than metric measures. Similarly, it was demonstrated that higher associations are obtained when three, rather than just one, street had to be marked. The main difference is that this time Global Integration and Connectivity are the measures that most efficiently predicted participant's choices regarding the three main streets and the main street of the system respectively.



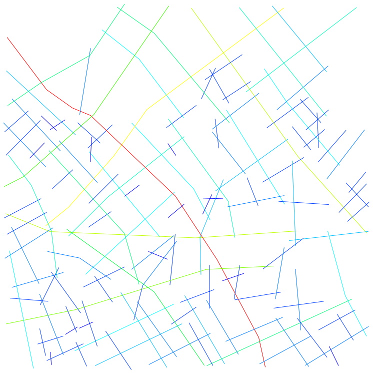
Global Integration

Local Integration



Connectivity

Choice



Line Length

Figures 5.16 (a to e): Mindwalk 30º analysis

Global Integration

Local Integration

Connectivity

Choice

Line Length

Figure 5.17. Mindwalk 30º Line analysis: the five most salient lines

5.8.2.- Mindwalk 30º Node Analysis

Mindwalk 30º Node Analysis is the last scenario to be tested in this chapter. Since it examines the same data of previous sections (all what changes is the model with which data was studied), the results are in most cases coincident with those detected in former assessments. In order to shorten this analysis, all descriptive data concerning mean and SD values of lines, as well as the degree of association of these values will be shown in Appendix 2.

The discussion will then focus upon the examination of the predictive power of configurational and metric measures with respect to participants` choices of the main street, the three main streets, and the three most important junctions of the map. Table 5.25 shows these results. Here it can be seen that the measure that most efficiently predicted people's choices about the three main streets was Global Integration (r_s: 0.682), whereas the most efficient measure in capturing respondents' judgments when three main streets had to be selected corresponded to Line Length (r_s: 0.771).

Table 5.20. Mindwalk (30º) Line Analysis. Descriptive data

	Choice	Conn	Global Integration	Local Integration	Line Length
N	129	129	129	129	129
Minimum	0	1	.77	0.42	0.70
Maximum	0.33	17	2.86	3.39	38.2
Mean	.02	3.69	1.55	1.88	6.25
Standar Deviation	.05	2.74	.38	.57	5.95

Table 5.21. Mindwalk (30º) Line Analysis: correlations between metric and configurational measures

	Choice	Conn	Global Integration	Local Integration	Line Length
Choice					
Connectivity	0.763				
Global Integration	0.488	0.635			
Local Integration	0.578	0.755	0.960		
Line Length	0.631	0.823	0.623	0.717	

Mean 0.697

Table 5.22. Mindwalk (30º) Line Analysis: predictive power of measures

	1 main street	3 main streets
Choice	0.339	0.417
Connectivity	0.357	0.444
Global Integration	0.394	0.440
Local Integration	0.385	0.432
Line Length	0.312	0.415
Mean	0.357	0.429
SD	0.033	0.013

Table 5.25: Mindwalk (30º) Node Analysis: correlations between line use and configurational and metric variables

	1 main street	3 main streets	3 most important junctions
Choice	0.632	0.766	0.227
Connectivity	0.635	0.759	0.275
Global Integration	0.682	0.734	0.271
Local Integration	0.664	0.728	0.282
Line Length	0.649	0.771	0.277
Mean	0.652	0.751	0.266
SD	0.020	0.019	0.022

5.9.- Summary of results

The series of analyses presented in this extended chapter seem to support the idea that configurational information of space is fundamental to help people in determining hierarchies in maps. This was demonstrated by the fact that, regardless of the methodology used to analyze choices made by participants (line or nodes), the amount of main streets lines selected by them (one or three), or the spatial model chosen to assess spatial networks (Axial, Segment or Continuity Lines analyses), configurational measures were more efficient in predicting people`s choices than metric factors.

The exercise also revealed that higher correlations were obtained when three, rather than one line, had to be marked. Finally, it was shown that Node Analysis seemed to better predict participants' choices than Line analysis. Unfortunately, none of these results could be observable for question B (the three most important junctions of the system), a result that suggests that retrieving hierarchical information from junctions obeys to different causes than retrieving hierarchical from paths. The next chapter will further study this phenomenon.

Table 5.26 shows the configurational or metric measure that most efficiently captured participants' answers for questions A, B and C. In order to shorten the analysis only results concerning Node analysis (the most efficient methodology to predict people's choices) are displayed.

Here it can be noted that in both Axial and Segment analyses, configurational variables were more efficient than metric ones in predicting how people retrieved hierarchical information. Results also suggested that Segment analysis was more efficient in predicting participants' choices than Axial Analysis, but that the former was less efficient than Mindwalk in capturing people's answers about main streets. This seems concordant with results obtained in real-world scenarios (Turner 2001; Hillier and Iida 2005) which have demonstrated that the employment of techniques more sensitive to angular deviation of routes can better capture people's movement patterns. However, when lines were merged, metric properties of networks also started to explain people's qualitative judgments of networks, for the best predictor of paths made by participants when three streets had to be marked was line length (r = 0.771).

In spite of these promising results, a cautionary note is necessary. As it was shown, configurational and metric measures tended to be highly associated between each other, meaning that a highly connected line was likely to be at the same time, a highly integrated or extended one. This pattern was more evident in Mindwalk analysis than in Axial or Segment analyses, which seems to suggest that the synchronization between metric and configurational factors increases as a result of line aggregation.

The problem with this trend is that in most cases the predictive power of metric factors such as Line Length is very similar to the predictive power of any of the configurational measures examined in this experiment. This means that it is not possible to declare, unambiguously, that individuals gave more importance to configurational aspects rather than to metric aspects of lines when retrieving these lines` relative importance. On the contrary, it is likely that the main strategy employed by subjects was to pay attention to metric aspects of lines (which are observable and measurable for the naked eye), rather than to assess configurational information of them (which are more concealed from scrutiny).

There is an obvious manner to solve this dilemma. If the longest line was at the same time the most *popular* street (the line chosen as a main by most individuals), and if the second longest line corresponded to the second most popular line of the map and so forth, there is no way to claim that other factors apart from metric ones influenced people's judgments. On the contrary, if a line's length was not directly associated to people's choices, it could be argued that metric factors could not fully explain these judgments.

Table 5.27 investigated this idea[4], by showing the degree of synchronization between metric and configurational measures of the map's most salient continuous lines. This was achieved by ordering the most distinctive lines in a sort of ranking, which depicts the ID number of the most integrated line in the map, and then of the second most integrated line in the map, and finally of the third most integrated line in the map. The same procedure was employed for the rest of the measures examined in this experiment, namely, Connectivity, Local Integration, Choice and Line Length. In order to see the level of synchrony between configurational and metric aspects of lines and the number of times

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[4] Because the highest correlations were obtained in Mindwalk 30º Line Analysis, this exercise only considered this model

participants chose these lines in the experiment, it is necessary to check the first three columns of the table. For example, the last column of table 5.27 shows that line Nº 58 was the longest, the most connected, the most globally and locally integrated and the line of highest choice in the map. Interestingly, 52.7% of participants marked line Nº 58 as the main street of the map, whereas 88.8% of participants selected this line as one of the three main streets of the network. But what about the second longest path of the map, line Nº 4? Was this line the second most popular street of the sample too?

Unlike path Nº 58, path Nº 4 was neither the second most popular street when three streets had to be marked, nor the second most popular street when just one street had to be selected. The same can be said of the third longest path (line Nº 22), which was the third most popular street when three streets were marked, but the second most popular street when just one street had to be chosen.

Table 5.27 shows that lines Nº 4 and Nº 22 had a lower degree of synchronization between metric and configurational values than line Nº 58. For example, line Nº 4 was the second most globally integrated line, as well as the line of second largest Choice value of the sample. Nonetheless, it was not the second most connected line of the sample, nor the second most locally integrated line of the sample. The same can be said about line Nº22, which despite being the third longest line of the sample, it did not form part of the triad of highly globally integrated lines, nor of the triad of lines with the largest Choice value of the sample.

In short, it seems that Line Length itself could not fully explain how respondents perceived hierarchies in maps, for only the lines in which metric and configurational aspects were aligned were selected as hierarchical streets by most participants.

Table 5.27 supports this idea. Here it can be seen that when one main street had to be chosen, 52.7% of people selected line Nº58, or the line in which all configurational and metric measures were aligned, whereas only one person chose line Nº4, the second longest line of the map but a line that did not have the same degree of synchrony between its configurational and metric factors, as the main street of the system. To some degree, similar results were found when three streets had to be marked.

Figure 5.18 further investigates this idea by showing the location of lines Nº 22, Nº 69, Nº 58 and Nº 4. Now it is possible to understand why line Nº 4, despite being a long street, was rarely chosen by subjects as a main street: unlike lines Nº 22 and Nº 69, line Nº 4 did not connect the map's core with its outskirts, but remained in a more isolated and prophetical position. It seems therefore that the criterion by which subjects retrieve hierarchical information from networks, is not limited to an assessment of the metric aspects of lines, but rather, it encompasses an assessment of the degree of synchrony between metric and configurational aspects of lines. The next chapters will study this idea more comprehensively.

Table 5.26: Summary of results of all experiments

	Type of Analysis			
Question	Axial	Segment	Mindwalk (15º)	Mindwalk (30º)
Three main streets (question A)	**0.636** (Choice)	**-0.658** (Mean Depth)	**0.719** (Choice)	**0.771** (Line Length)
One main street (question C)	**0.488** (Global Integration)	**-0.642** (Mean Depth)	**0.644** (Global Integration)	**0.682** (Global Integration)
Three most important junctions (question B)	**0.246** (Choice)	**-0.282** (Mean Depth)	**0.297** (Local Integration)	**0.282** (Local Integration)

Table 5.27. Mindwalk (30º) Line Analysis: correlations between line use and configurational and metric variables

	People's choices about one main street			People's choices about three main streets			Choice (ID)	Conn (ID)	Global Int (ID)	Local Int (ID)	Line Length (ID)
	ID	N	%	ID	N	%					
First	58	19	52.7	58	32	88.8	58	58	58	58	58
Second	22	10	27.7	69	27	75	4	22, 69	4	22	4
Third	69	6	16.6	22	23	63.8	69	4/7/ 88	53 / 69	69	22
other	4	1	*3*								
		35	*100*								

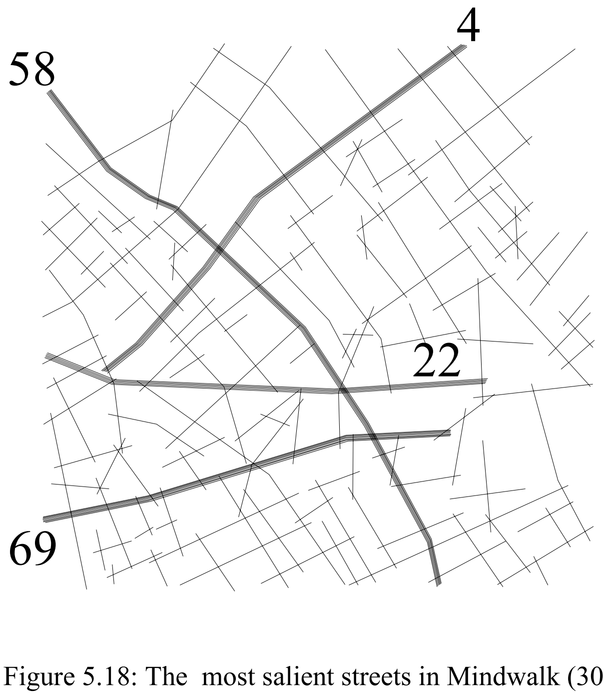


Figure 5.18: The most salient streets in Mindwalk (30º) analysis

5.10.- Discussion

There are several forms to read this experiment's results. One of them is to say that the fact that Mindwalk analysis was more efficient in predicting people's judgments about the main or the three main streets than Axial and Segment analyses, indicates that this model is better equipped to mirror people's cognitive mechanisms to understand space.

Some authors have argued that this is due to Mindwalk's capacity to capture the property of arteriality in maps (Morrison, 1981), which contends that important lines will be extensive and sinuous, whereas less important ones will be shorter and more broken. According to Morrison, one of the characteristics of arterial paths is that they reduce a person's travel and time costs. He also suggested that the principle of arteriality can be found in natural systems, such as hydrological networks.

Marshall (2004) has argued that the principle of arteriality is an underlying structural property of networks, one that is normally "taken for granted" (Marshall 2004) but rarely studied in depth by planning agencies. According to Marshall, arterial streets have the virtue of coordinating metric and topological aspects of grids, making it possible for people to infer the relative importance of streets in a network. *"We usually know a main road is so called because it is a "big road", a "busy street" or a "strategic road". The correlation between road standard flow and strategic status seems to be intuitively simple. Even if national road networks tend to be organized by designation, it appears to be a simple reflection of form or use. However, things are not necessarily as straightforward as this. If we look more closely, we find that designation is, generally speaking, not by form or use but by relation. And this is not a trivial academic distinction: it provides a key to understanding hierarchy and the structure of the urban layout"* (Marshall 2004:58).

Figueiredo (2007) has contended that the line aggregation process resulting from applying Mindwalk reveal some latent but silent spatial phenomena, for it internalizes the "*small worlds"* nature of spatial systems, or the fact that some linkages are more relevant for the functioning of these networks (they act as distributors of connections), than others. He therefore argued that Mindwalk is improvement to axial representations. *"The notion of continuity is already* *embedded in the axial system; the continuity lines reinforce the relationship between configurational properties and the hidden geometry of the axial maps"* (Figueiredo and Amorim 2005:8).

Apart from this methodological finding, this experiment served to further understand how people retrieve hierarchical information from networks. Concordant with what was suggested in chapter Four, here it was suggested that a key idea is that of synchronization, for individuals seemed more homogenous in their answers when configurational and metric factors of lines were coordinated than when this was not the case. The next chapter will investigate this phenomenon in more detail, hoping to reveal the cognitive mechanisms that allow individuals to retrieve hierarchical information.

ºChapter Six

Retrieving hierarchies of slightly modified maps

Abstract

This chapter investigates whether people's retrieval of spatial hierarchies in maps is an adaptive process, that is, if slight changes occurring in networks can result in different patterns of responses. Three scenarios of different configurational characteristics but that looked alike were designed to test this idea. A total of fifty-two subjects were asked to outline the main street, the three main streets and the three most important junctions of these scenarios. Their responses were then studied using Axial and Continuity Lines (30º) analyses.

Results showed that, despite the maps′ differences, people were very efficient in retrieving hierarchical information from networks. It was also demonstrated that people's choices seemed to attend to a combination of metric and configurational factors.

6.1..- Introduction

The last chapter showed that retrieval of hierarchical information in maps was dependant on the combination of metric and configurational properties. It was also shown that in most cases configurational aspects were more effective in predicting participants' answers than metric aspects.

But how adaptive is this reasoning? How sensitive are persons to subtle changes occurring to networks? In other words, To what extent can spatial reasoning be adapted to different circumstances? These are the main questions addressed in this chapter.

A moment's reflection suggests that, if individuals are able to infer hierarchical information in, say, map X, they will be equally capable to detect it in map Y, even if only minor changes were placed in these networks. The following sections will test this hypothesis.

6.2.- Method

Layouts

Three apparently similar but configurationally different scenarios were designed to test this hypothesis. As in the previous chapters, these were highly irregular structures resembling parts of typical European cities. Figure 6.1 shows them all.

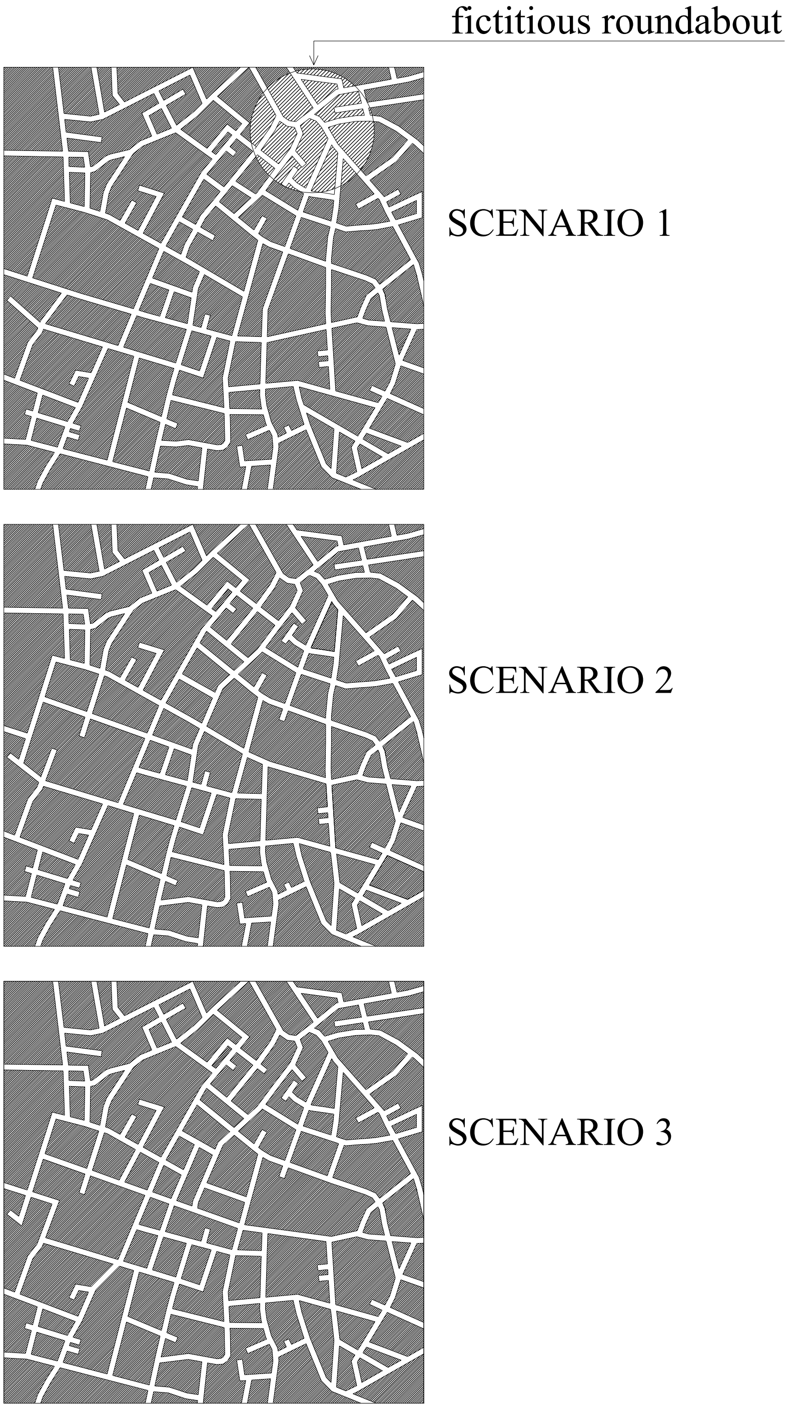


Figure 6.1: the scenarios tested in this experiment

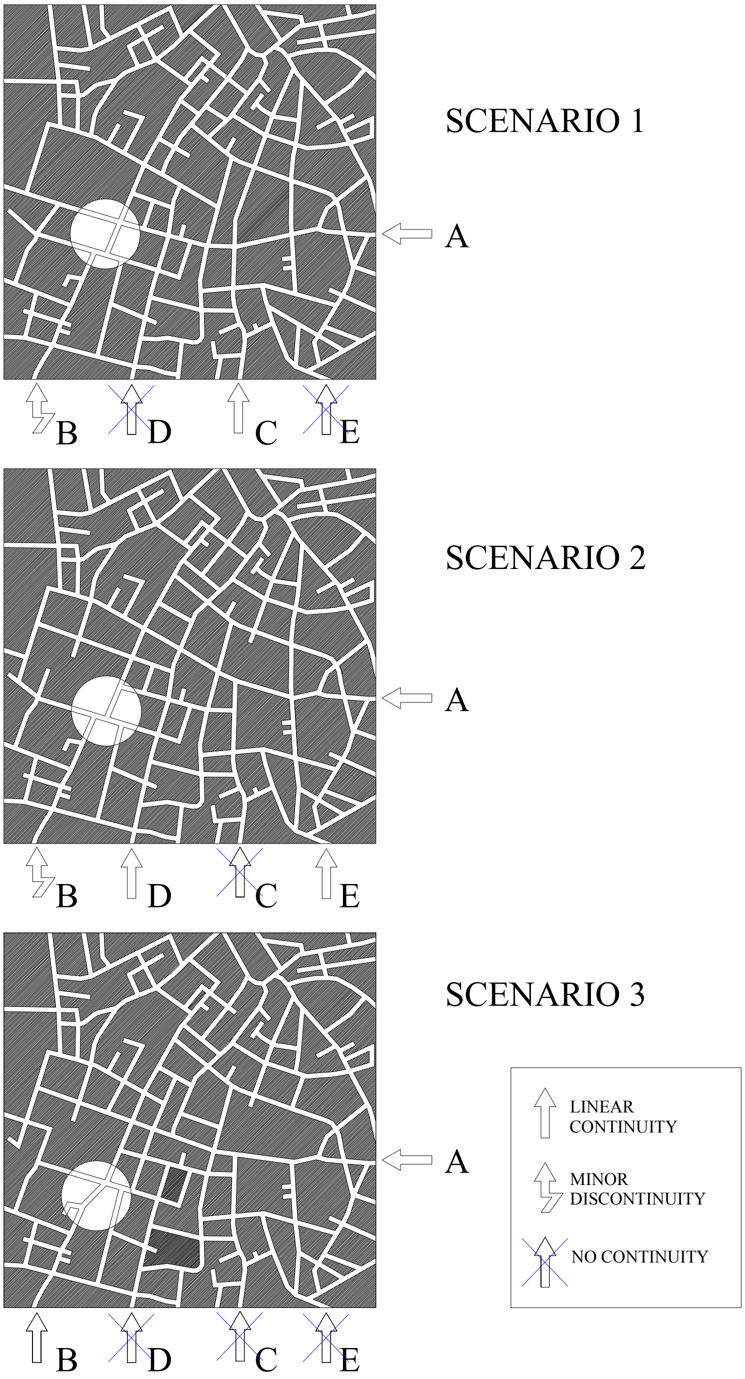


Figure 6.2: Continuous and discontinuous lines in scenarios 1, 2 and 3

Scenario One is characterized by the presence of a horizontal line placed at the centre of the map (see street A in figure 6.2). This line seems to continue beyond the map's borders, which makes the network to appear divided by an upper and a lower part. Apart from street A, no other horizontal road crossed the network without major interruptions. Contrary to what happens with horizontal lines, continuous vertical roads seem to be much more numerous. Four of them are clearly distinguishable in this scenario: streets B, street C, street D and finally street E.

However, only one of these paths, line C, could be described as totally continuous, for all others, lines D, B and E suffer minor or major discontinuations along their journeys. For example, both path D and path E are interrupted at some point in the map, meaning that a person travelling along them has to make various turns in order to employ their disconnected sections. By comparison, line B can be described as a semi continuous path because its misalignment is discrete (see small circle in figure 6.2). Another characteristic of all vertical lines is that they seem to be concurring to a sort of roundabout or park (also indicated in figure 6.2) placed at the top right of the map.

Unlike scenario One, in scenario Two no line crosses the network without major turns or changes of direction. For example, line A no longer links both sides of the map in a straight way, but is interrupted by an orthogonal line on its leftmost section. One the other hand, line B remains identical to scenario One, but a former interrupted path, line C, has been made a continuous one. The same can be said of line D, which corresponds to a sinuous path located at the right hand side of the map.

Finally, in scenario Three a series of small changes were realized to these paths again. Line A, for instance, was straightened, so to making it to appear as more continuous than in scenario Two. In spite of this modification, line A still terminates in a orthogonal road, but a continuation has been placed one block away. Another important change of scenario Three with respect to Scenario Two is that the slight discontinuation occurring to line B was replaced by a diagonal segment, which links both parts of this previously disconnected path (see small circle in this chart). The result is therefore a continuous vertical line, which works similarly to line B of the First scenario. In order to make this paths more prominent, in this scenario all other vertical paths (streets D, C and E) were interrupted, meaning that essentially there is one single paths that allows to cross the networks in the vertical direction. All these changes have been highlighted in figure 6.2.

Configurational analysis

Although similar in appearance, the environments of this experiment are rather different in terms of their configurational and metric properties. In order to investigate these differences', two different spatial models will be employed here: Axial and Continuity Lines (or Mindwalk) analyses.

Axial analysis

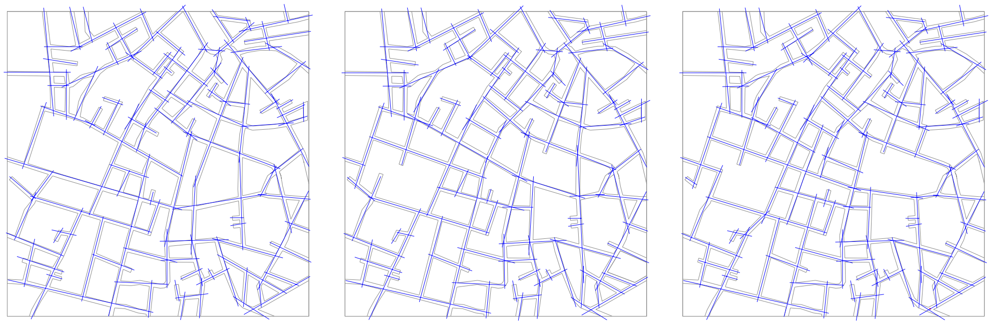
The first step of this analysis consisted in constructing axial maps for all scenarios, as figure 6.3 shows. Once this was completed, all axial maps were studied both in terms of the number of lines they involved, and in terms of the metric and configurational properties of these lines. In relation with the former dimension, it was noted that all maps differed in the number of axial lines they comprised. These variations were nonetheless discrete, for the axial map of Scenario One had 121 lines, whereas the axial maps corresponding to Scenarios Two and Three possessed 124 and 127 lines respectively. Once drawn, maps were analyzed using the computational package Depthmap to assess their configurational and metric proprieties. As in previous chapters, here the configurational measures of Global and Local Integration, Connectivity and Choice, as well as the metric property of Line Length, will be analyzed separately. Table 6.1 shows some descriptive information of these measures.

The first thing to note is that, despite their evident differences, environments One, Two and Three are rather similar, at least when their metric and configurational properties are studied at an aggregate level. For example, in scenario One the configurational measure of Global Integration had a mean value of 1.18, whereas in scenarios Two and Three the same measure reached the values of 1.19 and 1.15 respectively. Likewise, in the first scenario the metric measure of Line Length had a mean value of 5.76, whereas in the second and third scenarios this figure stood at 5.56 and 5. 71 respectively.

Little differentiation on the association between configurational and metric values in these worlds was registered too. This is demonstrated by tables 6.2, 6.3 and 6.4, which show the mean values of the association between metric and configurational measures in scenarios One, Two and Three. As is can be appreciated, the mean value in the first scenario was r =.752, whereas the mean values for the second and third scenarios stood at r =.748 and r= 731 respectively. In practical terms, this implies there is a high chance that a well-integrated line at local or global scales would be, at the same time, a highly connected and extended one.

Despite these suggestive results, Scenarios One, Two and Three are nonetheless rather different in terms of their intelligibility value. Intelligibility, defined as a system's capacity to provide global information from local contexts (Hillier 1996), reached r = 0.478 (world 1), r = 0.495 (world 2) and r = 0.459 (world 3), suggesting that environments were, to some degree, relatively unintelligible for subjects.

Notorious differences were also found when environments One, Two, and Three , are inspected visually. This can be appreciated in figure 6.4, which shows the configurational measures of Global integration, Local integration, Connectivity, Choice as well as the metric measure of Line Length, for the three environments employed in this experiment. For example, it can be seen that Global Integration in all scenarios is commanded by a vertical line located at the core of these worlds. However, while in scenario One and Two, Global Integration seems to be spread out towards the maps` edges, in scenario Three, this measure appears to be more circumscribed to a small area of the map. Similar differences can be also observed for the configurational measures of Local Integration (second row), Connectivity (third row), Choice (fourth row) as well as the metric measure of Line Length.



SCENARIO 1 SCENARIO 2 SCENARIO 3

Figure 6.3: Axial maps of scenarios 1,2 and 3

Table 6.1: Axial analysis, descriptive data

		SCENARIO 1	SCENARIO 2	SCENARIO 3
Number of lines		**121**	**124**	**127**
Global Integration	Mean	1.18	1.19	1.15
	SD	0.26	0.27	0.25
Local Integration	Mean	1.69	1.70	1.60
	SD	0.46	0.47	0.45
Connectivity	Mean	241.7	220.4	246.3
	SD	283.8	304.5	361.9
Choice	Mean	3.55	3.55	3.54
	SD	2.05	2.07	1.98
Line Length	Mean	5.76	5.61	5.57
	SD	3.61	3.4	3.31

Mindwalk analysis

As its names indicates, the Continuity Lines model, or Mindwalk, relies in the idea that urban space is perceived by humans as a continuum, meaning that individuals would ignore slight deviations occurring to streets and, instead would perceived these roads as sinuous structures. For the purpose of this study and considering the experience derived from previous chapters, the angle of aggregation of lines was set at 30º. This is to say that all lines encountering at angles of 30º or less, were merged.

The first thing to note is that this mechanism resulted in that about one fifth of the lines existing in the axial maps belonging to scenarios One, two and Three were eliminated by Mindwalk analysis. In fact, as table 6.5 shows, the number of lines existing in scenarios One and Two was 95 (from 121 and 124 respectively), whereas only 99 lines were left by the Continuity Lines analysis in scenario Three (from the 127 lines existing in Axial analysis).

But Mindwalk did not only reduced the number of lines existing in each scenario, but also changed the distribution of these lines` configurational and metric properties. As table 6.5 shows, the mean values of the configurational measures of Global Integration, Local Integration, Connectivity, Choice, as well as the metric measure of Line length, were all higher in Mindwalk analysis than in Axial analysis. Further, these values were more skewed than in axial analysis, which seems concordant with what was observed in Chapter Five.

Graphically, these phenomena can be perceived in figure 6.5, which presents a series of maps displaying configurational measures and metric measures for Scenarios One, Two and Three. As figure 6.5 shows, the main consequence of using Mindwalk is that metric and configurational properties of salient lines tended to converge. In simpler words, this meant that distinctive lines in configurational terms were distinctive lines in metric terms, too.

But this effect is not only confined to the most salient lines of worlds One, Two and Three, but to all lines of these scenarios. Tables 6.6, 6.7 and 6.8 demonstrate that this seems to the case, for the level of association between configurational and metric measures is substantially higher in the Continuity Lines analysis, than in Axial analysis. This trend is nonetheless uneven, meaning that while in the first and third scenarios the improvement is about r = 0.07, in the second scenario this improvement is a mere 0.007. It can be said, therefore, that world Two has remained resilient to the convergence of metric and configurational noted in its counterparts.

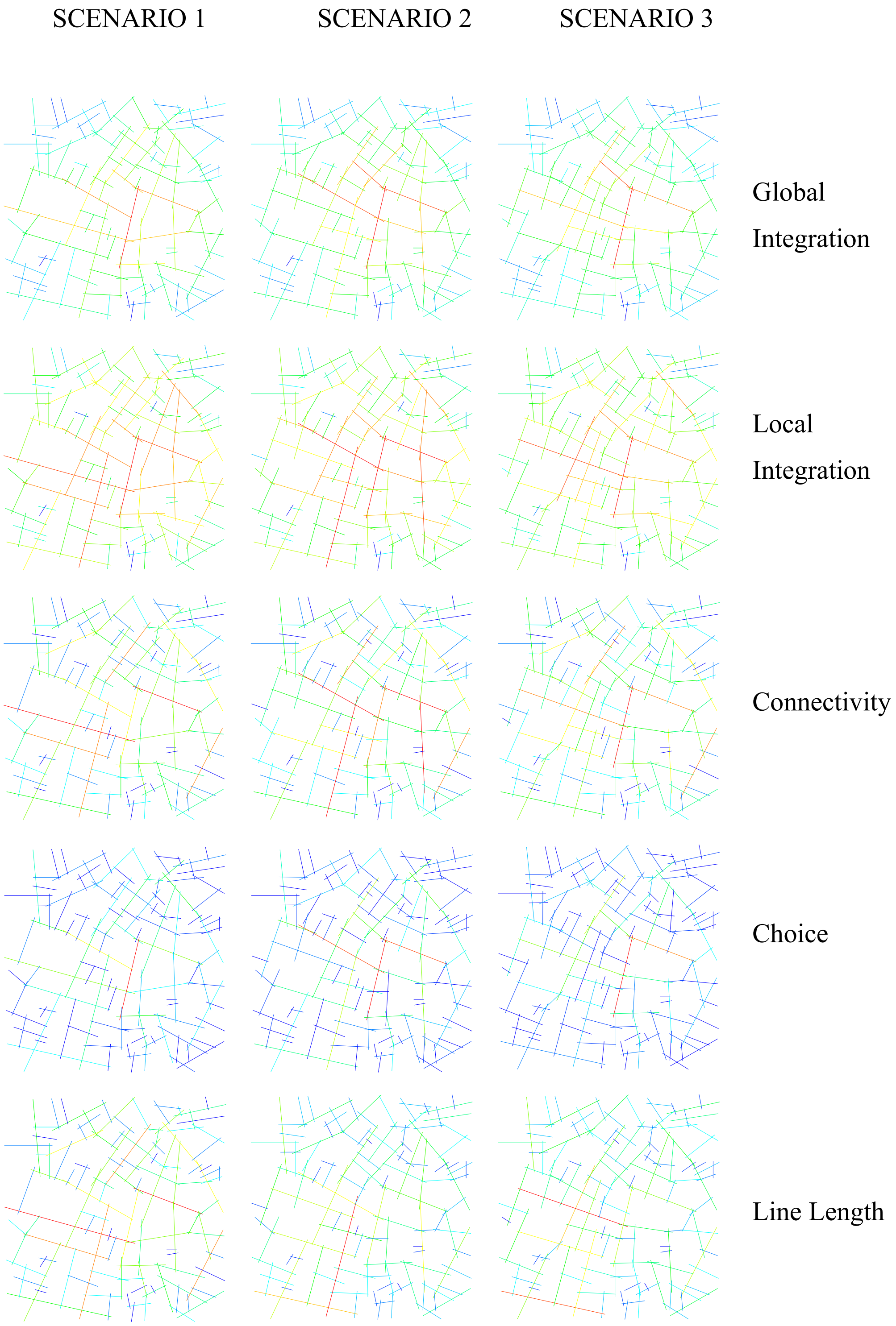


Figure 6.4: Axial analysis of scenarios 1,2 and 3

Table 6.2: Axial analysis of scenario 1, correlations between variables.

	Choice	Conn.	Global Int.	Local Int.	Line Length
Choice		.862	.762	.787	.735
Connectivity			.714	.866	.800
Global Integration				.884	.548
Local Integration					.680

Mean: .752

*Conn, stands for Connectivity; Global Int. for Global Integration; and Local Int. for Local Integration

Table 6.3: Axial analysis of scenario 2, correlations between variables

	Choice	Conn	Global Int.	Local Int.	Line Length
Choice		.858	.729	.761	.679
Connectivity			.704	.862	.801
Global Integration				.887	.520
Local Integration					.678

Mean:.748

Table 6.4: Axial analysis of scenario 3, correlations between variables

	Choice	Conn	Global Int.	Local Int.	Line Length
Choice		.799	.723	.729	.648
Connectivity			.689	.877	.783
Global Integration				.865	.525
Local Integration					.677

Mean: .731

Table 6.5: Mindwalk analysis (30º), descriptive data

		SCENARIO 1	SCENARIO 2	SCENARIO 3
Number of lines		**95**	**95**	**99**
Choice	Mean	0.03	0.04	0.03
	SD	0.05	0.09	0.06
Global Integration	Mean	1.37	1.48	1.40
	SD	0.33	0.36	0.33
Local Integration	Mean	1.73	1.77	1.74
	SD	0.50	0.52	0.49
Connectivity	Mean	3.36	3.38	3.32
	SD	2.60	2.77	2.58
Line Length	Mean	6.81	6.60	6.56
	SD	5.87	5.83	5.44

Table 6.6: Mindwalk analysis (30º) of scenario 1, correlations between variables

	Choice	Conn	Global Int.	Local Int.	Line Length
Choice		.907	.733	.773	.866
Connectivity			.761	.837	.919
Global Integration				.936	.722
Local Integration					.763

Mean: .822

Table 6.7: Mindwalk analysis (30º) of scenario 2, correlations between variables.

	Choice	Conn	Global Int.	Local Int.	Line Length
Choice		.569	.736	.734	.561
Connectivity			.801	.815	.904
Global Integration				.958	.736
Local Integration					.734

Mean: 755

Table 6.8: Mindwalk analysis (30º) of scenario 3, correlations between variables

	Choice	Conn	Global Int.	Local Int.	Line Length
Choice		.887	.738	.711	.853
Connectivity			.744	.817	.918
Global Integration				.912	.698
Local Integration					.741

Mean: 802

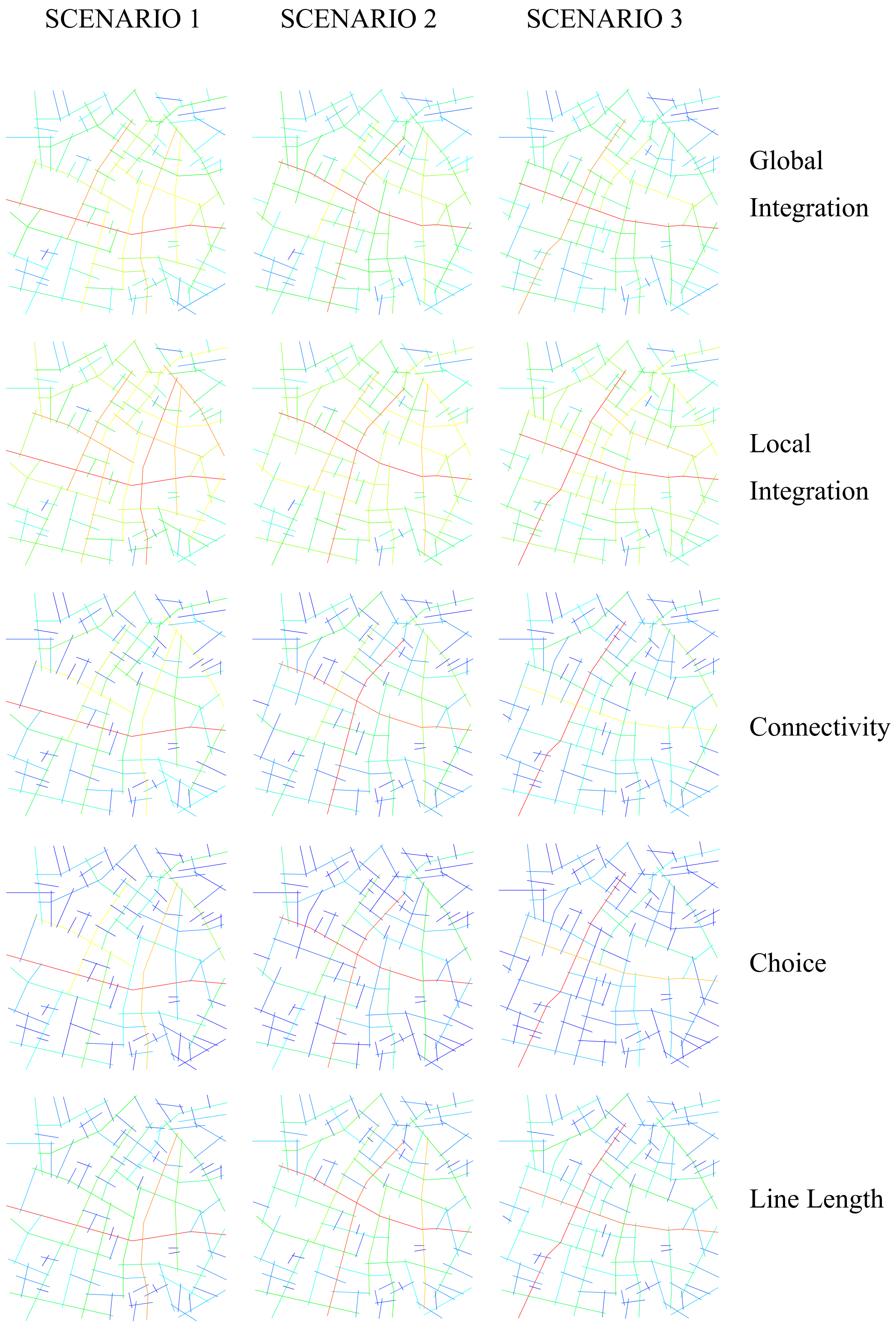


Figure 6.5: Mindwalk analysis (30º) of scenarios 1,2 and 3

Participants and method

A total of 52 people (30 women, 22 men) participated voluntarily in the experiment, most of whom were students at University College London or University of London. They were approached in the vicinity of UCL`s main campus and asked to participate in an experiment about map reading.

In order to avoid any bias in responses, all participants whose background was Architecture of Geography were excluded from the experiment. Most subjects were at their twenties (M=29.8, SD= 7.63) and all were native English speakers. None of them had participated in previous experiments.

Materials and procedure

The test used in this experiment was composed by nine maps and two distracting charts. In the first of these maps, the following instruction was presented: *"Please look carefully at the map and outline what you think are the MAIN streets (3) of the system"* (question A). Subjects were told to read carefully this instruction and to complete it as soon and acutely as possible. Once subjects completed the first task, they were asked to consider the second map, which asked them to encircle the THREE MOST IMPORTANT junctions (question B). After completing this task, they were told to complete the third map, which asked them to outline THE MAIN STREET OF THE SYSTEM (question C) [1].

After finishing the first three maps, subjects were given a distracting task[2] consisting in counting the number of rectangles existing in an image. They were then asked to respond to the same questions for scenarios Two and Three. A new distracting task was employed between these scenarios.

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[1] A copy of this experiment can be found in Appendix 3

[2] This aimed to make people to forget the appearance of the previous map. The task required subjects to assess the number of rectangles or triangles existing in a figure. Although this appeared trivial at first sight, the fact that the overlapping of triangles and rectangles created new ones demanded that subjects had to concentrate in the problem for few minutes.

Structure of the experiment

First scenario, Question A
First scenario, Question B
First scenario, Question C

DISTRACTING TASK 1

Second scenario, Question A
Second scenario, Question B
Second scenario, Question C

DISTRACTING TASK 2

Third scenario, Question A
Third scenario, Question B
Third scenario, Question C

SELF ASESSMENT[3]

Most people completed the experiment in about 15 to 20 minutes. Like in the previous experiment, few subjects asked for a clarification of the term "main street'. When this was not the case, the experimenter responded by suggesting to outline the street they considered as the most important.

The last part of the experiment required individuals to rate their self confidence on their answers in a 1-10 scale, being 1 the minimum and 10 the maximum.

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[3] A copy of this experiment is presented in Appendix Three

Results

Statistical differences

First, it was investigated whether differences in self-confidence ratings existed in participants depending on their age or sex. A t-test detected no difference in these matters, meaning that subjects ratings were not affected by their gender (t: 0.824; $p>0.05$), nor by their age (r_p : 0.141).

Behavioral data

The study of people's responses will be presented in two phases. One is of descriptive nature and attempts to understand how people inferred hierarchical information of networks. The other will instead study whether configurational and metric factors could explain these choices. In order to facilitate the understanding of results, the first phase will be divided in the analysis of paths (questions A and C, standing for the three main streets and the main street respectively) and nodes (question B).

A descriptive account of this experiment

Paths

Figure 6.6 shows participants´ answers regarding the three main streets and the main street of scenario One. Figures 6.7 and 6.8 do the same but for scenarios Two and Three respectively. A rapid inspection of these charts reveals some interesting facts. First, regardless of the scenario being tested, people tended to draw extended and straight paths as main streets, as if this concept would be inevitably linked to certain metric and geometric properties. Second, in most cases these paths connected opposite margins of maps (e.g the leftmost margin with the rightmost margin), functioning in fact as spatial corridors linking these maps to an assumed outside world. Third, when three main streets were drawn, the overwhelming majority of individuals drew horizontal *and* vertical paths, thus forming hierarchical networks that in fact acted as super-grid structures (see figure 6.9).

The most relevant aspect about people's paths is nonetheless how they changed according to the type of question and type of scenario being tested. For example, when one main street had to be chosen in scenario One (figure 6.6) the vast majority of subjects marked one horizontal street , one that linked the map's two opposite sides. Those who did not follow this pattern marked instead a shorter vertical path moving internally in the network. However, when individuals responding to the first scenario had to outline the three main streets, they responded in a much more disorganized way, as if no clear structure could be retrievable in the network. Figure 6.6 illustrates this idea.

Scenario Two (figure 6.7) tells a different story. Here it is shown that people's choices concerning one main street were not as unanimous as in scenario One, but their choices were not radically different when three streets were chosen either. It seems therefore, that in scenario Two spatial hierarchies were more easily encoded, regardless of if one, or more than one main street, had to be outlined.

Scenario Three (figure 6.8) works, to some extent, in a similar way than scenario One, for it shows that paths made by people when responding to question C moved in a vertical and horizontal ways. However, when three main streets were marked, the pattern resembled the one observed in scenario Two.

In order to measure this phenomenon more objectively, an exercise was undertaken. This consisted in counting the number of junctions occupied by people when responding to questions A and C. For example, suppose that world A contained 100 junctions and two persons are told to outline the main street of it. Imagine that person X made a path involving junctions 1,2 3 and 4, whereas person B did a path involving the junctions 5,6 ,7 and 8. It can be argued that the sum of these paths was 8, or the 8% of nodes available in world A.

Seeing it this way, important differences are noticeable in worlds One, Two and Three. For example, in the first scenario individuals` answers concerning the "main street" covered twenty-four junctions, or 19.5% of junctions of this world, while when they had to mark the three main streets of the map, their paths covered eighty-eight nodes, which equals to 71.5% of all nodes (see table 6.9). This contrasts with what happened in the second scenario, where the percentage of junctions occupied by the sum of individuals` paths reached 50% of the total, when one street had to be marked, and 66.5% of the total when three streets were outlined. In between of these two poles the third scenario showed that subjects selected forty-four nodes (or 34.4% of the total) when determining the main street of the system, but seventy-three nodes (56.6%) when choosing the triad of main streets. As it can be observed, the initial belief that there were important differences between scenarios One, Two and Three in terms of the amount of nodes selected by individuals, was confirmed.

Figures 6.10, 6.11, 6.12 and 6.13 attempts to further investigate this phenomenon by studying participants` paths regarding the main street and the three main streets of maps. In order to facilitate this task, horizontal (or nearly horizontal paths), were analyzed independently from vertical (or nearly vertical), paths. Paths were arranged according to two factors: how extended and how straight they were. Straightness, on the other hand, was measured by counting the amount of sharp turns [4] involved on them. The result is a scale in which extended and broken paths were placed at the top end of the table, while shorter and more sinuous ones have been placed at the bottom.

The first of the figures, figure 6.10, shows the results of applying this methodology to study people's answers regarding the selection of the main street of scenario One, scenario Two, and scenario Three. For the sake of clarity, all charts belonging to the first scenario were installed in the leftmost column, whereas those belonging to the second and third scenario were installed at the centre and at the right of this figure respectively.

The number appearing on top of these columns indicates the amount of subjects that decided to make vertical paths in worlds One, Two and Three. Likewise, the number appearing on top of each chart indicates the percentage of subjects from the previous value that traced either long and sinuous paths or broken and short ones. The same procedure was used in the case of horizontal paths, as figure 6.11 illustrates. Lastly, Figures 6.12 and 6.13 repeated the exercise in relation to people's answer of the three main streets.

At a first glance there are several interesting facts to be called upon. First, there was a tendency to draw main streets as extended paths. When this was not the case, that is, when subjects drew shorter paths as main streets, it was due to the

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[4] Sharp turns were those close to the 90º mark

existence of straight turns or fork junctions occurring on salient paths. Proof of that is the fact that all shorter paths were drawn when orthogonal lines or fork junctions intersected sinuous paths, as the last rows of figures 6.10 ,6 .11, 6.12 and 6.13 show.

Second, paths made by participants tended to be as linear as possible. For example, 90.8% of those who marked horizontal paths as the main street of world One, and 69.6% of those who did the same but in world Two, drew almost straight paths as main streets, as Figure 6.11 illustrates. The same can be said of the horizontal paths marked by individuals as the three main streets. As figure 6.12 shows, 85.7% of participants contesting scenario One, 47.3% of participants of world Two, and 44.% of participants of scenario Three, chose almost straight lines as main streets of these systems.

The third aspect of importance regards the impact of fork junctions and dead-ends along salient lines. The first phenomenon, the effect of a fork junction along a salient path can be seen in the last rows of figure 6.11, which show, respectively, participants` horizontal paths regarding the main street of worlds One, Two and Three. As it can be appreciated, 4.6%, 23% and 8,7% of individuals responding to these worlds, paused at the encounter of a fork junction. Likewise, about 5%, 23% and 9% of the horizontal paths made by participants when responding to question A (the three main streets of the map) in environments One, Two and Three respectively, stopped when there was a diversion along the "main street" they chose. Although these percentages were far lower than the ones corresponding to those who ignored the fork junction installed along line A, the truth is that the existence of fork junctions fork introduced some degree of uncertainty in people, and seemed to deter some individuals from continuing linear trajectories.

Closely related to this phenomenon, most participants stopped at the encounter of misalignments occurring in salient paths, as the fact that 41% of those that drew vertical paths as main streets in contesting scenario One and 45% of those who did the same in scenario Two, demonstrates.

Following this line of enquiry, another interesting phenomenon was detected. This is related to the asymmetrical effect that minor or major discontinuations along salient paths produced in people.

Figure 6.6: participants’ answers for scenario 1 (questions A and C)

Figure 6.7: participants' answers for scenario 2 (questions A and C)

Figure 6.8: participants' answers for scenario 3 (questions A and C)

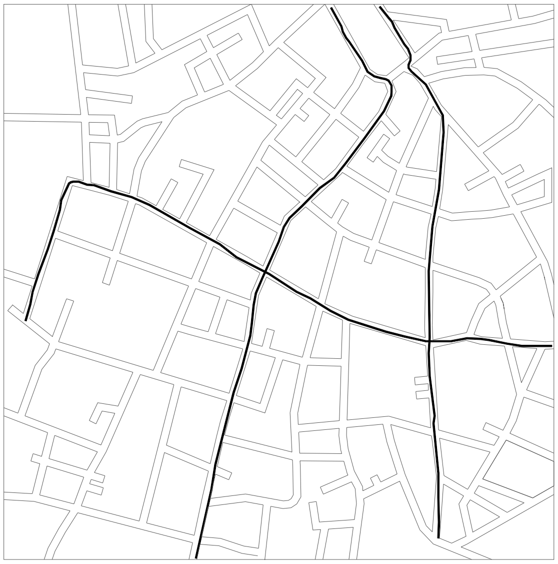

Figure 6.9: a common answer made by participants

Table 6.9: descriptive account of participants' choices

		1 street (question C)		3 streets (question A)	
	Number of nodes	nodes selected (number)	Node occupancy (%)	nodes selected (number)	Node occupancy (%)
Scenario 1	123	24	19.5	88	71.5
Scenario 2	122	61	50.0	81	66.4
Scenario 3	128	44	34.4	73	56.6

For example, some people ignored minor or major misalignments occurring to salient lines in order to construct extended but somewhat "broken" paths, drawing as a result what it could be called *Z paths.* As it names suggests, a Z path is a path formed by two extended and collinear segments (the upper and lower parts of a Z), which are connected by an orthogonal segment (the diagonal segment of a Z). Usually, the latter segment is shorter than any of the former segments.

Three types of Z paths could be distinguished in this experiment. The first type corresponded to minor misalignments occurring in salient streets, meaning that the orthogonal segment was far shorter than any of the collinear segments. The second type of Z path occurred when the orthogonal segment was of similar size than any of the remaining segments. Finally, the third type of Z path occurred when the orthogonal segment placed in between the collinear segments was larger than, at least, one of them. Figure 6.14 exemplifies these distinctions, by showing three typical cases of Z paths observed in this experiment: minor misalignments, mid-size misalignments, and major misalignments.

Figures 6.10 to 6.13 show that the three types of Z paths differed in terms of their popularity. Minor Z paths were far more frequent than medium-size ones, and those, in turn, were more popular than its major counterparts. Proof of that is the fact that 17.6%, and 18.2% of persons who drew vertical paths in worlds One and Two drew minor *Z paths* (see figure 6.12), whereas only 3.8% and 8% of those who drew horizontal paths in scenarios Two and Three (see figure 6.13), drew major Z paths. The next section shows a series of "rules" that seem to have been followed by people when choosing main streets.

1.- Whenever possible, try to draw extended paths

2.- "Follow your nose" and try to deviate as little as possible from linear trajectories

3.- When this is not possible because a fork junction stands along your chosen main street, select the street with the least angle of deviation. If you are not sure about that, truncate your path at the fork.

4.- If you encounter right angles at the end of your chosen main street, stop

5.- However, if the length of the leg perpendicular to your chosen main street, is negligible (that is, if it is of similar size to your main street's width), you are allowed to ignore this misalignment. But if the length of the leg perpendicular to the path you are in seems to be considerable, stopping might be the best option.

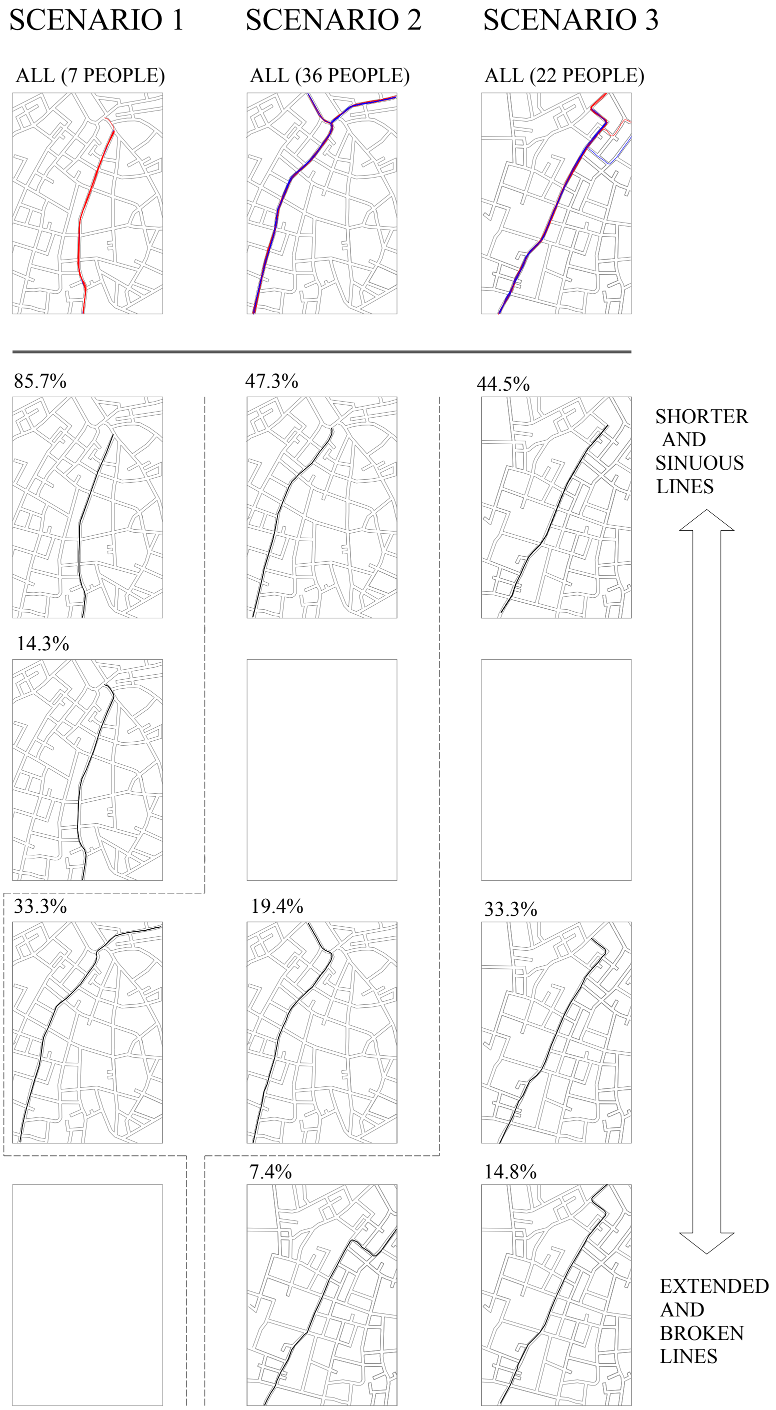

Figure 6.10: Vertical paths for question C

Figure 6.11: Horizontal paths for question A

Figure 6.12: Vertical paths for question C

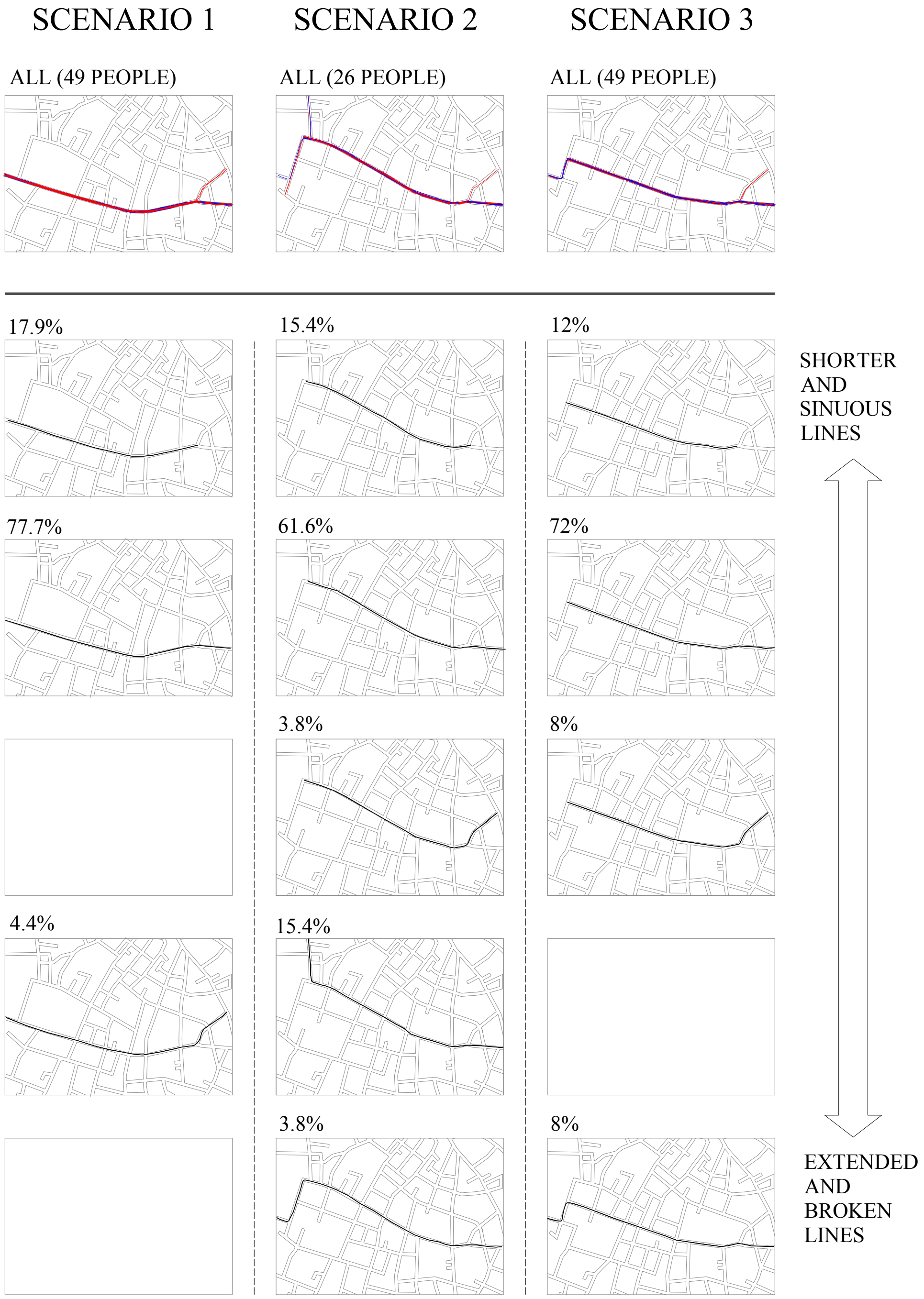

Figure 6.13: Horizontal paths for question C

Figure 6.14: Types of Z paths observed in this experiment

Nodes

Previous experiments have shown that participants' retrieval of important junctions were less associated to metric or configurational factors, than those regarding hierarchical paths. In order to explain this phenomenon, in this chapter a detailed analysis of nodes will be carried out.

Figure 6.16 shows participants` answers about the three most important junctions of scenarios One, Two and Three. To facilitate the understanding of data, a figure showing the number of individuals selecting each junction, have been placed in all these scenarios. In the first scenario, forty people (or 77% of participants) marked a central junction as one of the three most important intersections of this map. The same phenomenon occurred in scenario Two, where thirty-eight individuals (or 76% of them) agreed in considering a junction at the right hand side of the map as a relevant intersection. Lastly, in the third scenario thirty-nine subjects (or 75% of the sample) made a similar choice.

Based on these results, it seems evident that, like streets, judgments concerning nodes were highly skewed, that is, a small proportion of nodes received an overwhelming number of answers, whereas the vast majority of them was unselected. The question is: why did people choose these junctions and not others?

Aiming at responding this question, another exercise was undertaken. This consisted in classifying people's choices regarding the most important junctions of scenarios One, Two and Three, in three main categories: if they corresponded to intersections of paths chosen as main streets (condition One), if these marks were placed along main streets but not at intersections of these paths (condition Two), and finally, if these marks fell outside any hierarchical paths marked as a main street (condition Three). Figure 6.15 clarifies these conditions by showing answers concerning the three main streets made up by a hypothetical participant.

Results of this exercise are displayed in Table 6.10. As it can be appreciated, in the first scenario 41% of points signaled as important junctions corresponded to intersections of paths considered as main streets, whilst in worlds Two and Three this percentage climbs to 45.8% and 44.2% of choices respectively. Likewise, about 47%, 46% and 41% of participants responding respectively to scenarios

One, Two and Three, marked nodes placed along (but not at the intersection), of one the three main streets previously outlined by them. It follows that in all scenarios about one out of 10 choices were in fact placed outside one of the main streets chosen by p

These results indicated that both nodal and linear hierarchies are related, meaning that it is likely that individuals will consider one junction as important if is positioned at the encounter, or close to the encounter, of salient paths. What is perhaps more relevant is the fact that subjects were not allowed to inspect their previous answers, so coincidences in the matter could be considered as reflecting profound cognitive processes.

Another interesting aspect coming from the analysis of people's choices refers to the broad meaning given to the concept of "junction". As figure 6.16 shows, about 10% of respondents drew "blobs", rather than points, when responding to question B. With the sole exception of one person, all these answers occurred in a specific area of worlds One, Two and Three, which is characterized by the concurrence of several streets to a sort of roundabout or square. Figure 6.17 presents the area in question.

Table 6.10: participants' choices regarding question B

SCENARIO	CONDITION	%
1	On a different location	11.8%
	Along one of the 3 main streets (but not at their intersection)	47.2%
	At the intersection of the three main streets	41.0%
2	On a different location	8.4%
	Along one of the 3 main streets (but not at their intersection)	45.8%
	At the intersection of the three main streets	45.8%
3	On a different location	14.7%
	Along one of the 3 main streets (but not at their intersection)	41.0%
	At the intersection of the three main streets	44.2%

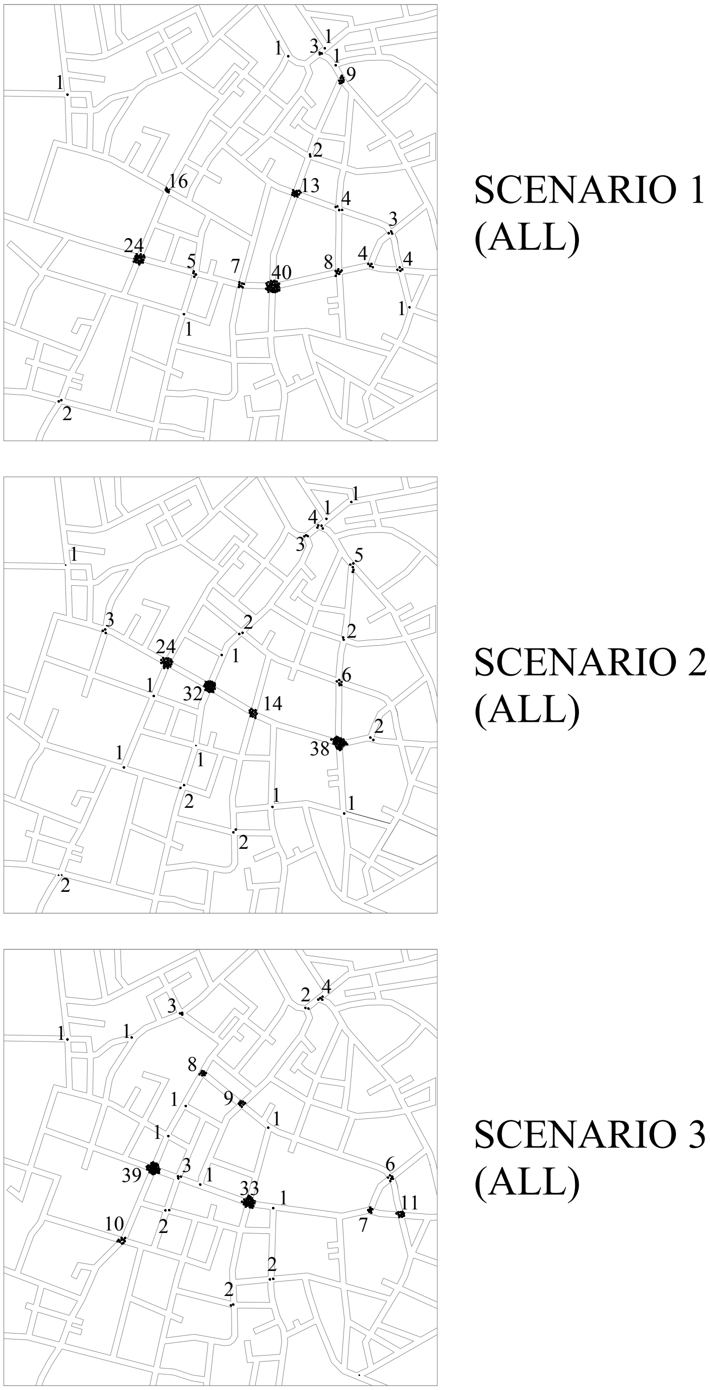

Figure 6.15: participants' answers for question B (numbers indicate how many individuals chose this location)

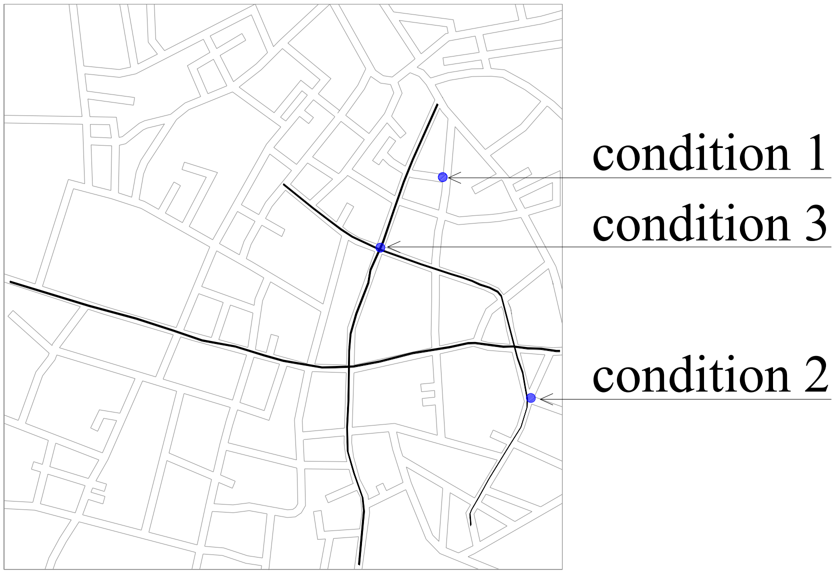

Figure 6.16: a study of participants’ answers for question B


SCENARIO 1
SCENARIO 2
SCENARIO 3

Figure 6.17: ¨ambiguous¨ junctions detected in scenarios 1,2 and 3

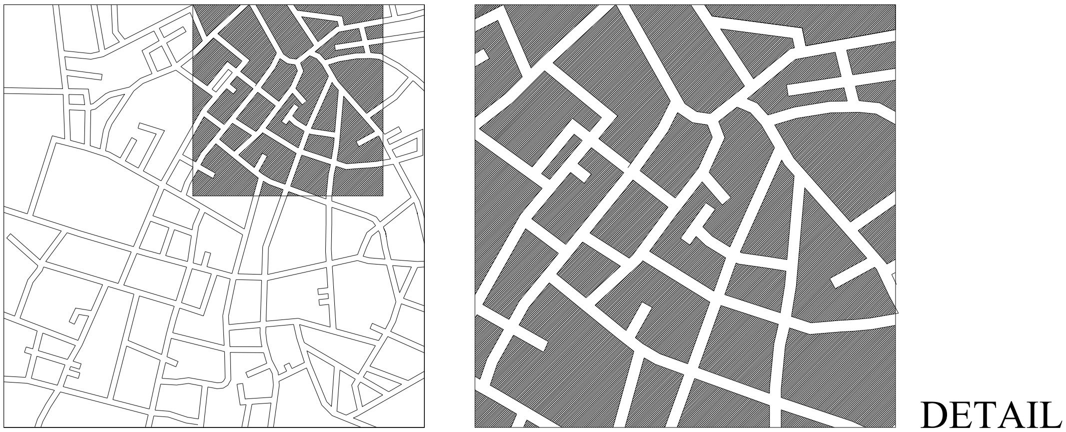

Figure 6.18: area of most ambiguous junctions

Since the aim of this section was to find out which syntactic and/or metric measure could better predict choices made by participants when responding to any of the questions, the first step was to define the method by which configurational and metric properties of networks will be compared against behavioral data.

Previous chapters have employed two mechanisms to study behavioral data: the line analysis and the node analysis. The first consisted in examining people's paths according to the number of axial or continuous lines they involved. The second method, node analysis, consisted in examining people's paths according to the number of *choices nodes* they comprised. Since the most efficient of these methods (in terms of its capacity to predict choices made by participants), was the node analysis, in this chapter people's responses were examined using such mechanism.

It was also shown that Axial analysis, despite not being as efficient as Mindwalk analysis in predicting people's choices, was a still a robust method to investigate how people retrieved hierarchical information from maps. For this reason, this chapter employed both Axial and Mindwalk (30º) analyses [5], to examine spatial data.

Following the procedure realized in previous chapters, all scenarios were decomposed into a series of choice nodes, or nodes that allowed users to amend, or to continue, their trajectories. This meant that junctions leading to cul de sacs were not considered as choices nodes, nor those junctions that did not permit subjects to make a spatial "choice". Figure 6.20 shows the series of choices nodes corresponding to scenarios One, Two and Three of this experiment.

Once choice nodes were drawn, the next step consisted in determining these nodes` mean configurational and metric values. As in Chapter Five, this was achieved by first summing the configurational and metric values of each of the axial or continuous lines concurring to each node, and then dividing this value by the number of concurrent lines. Suppose for instance that node Y received three axial lines: namely A, B and C. In order to obtain node Y`s mean Global

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[5] As in the previous chapter, the reason why Segment analysis was not employed is that each map generates a large number of "trivial rings" (between 15% to 20% of all lines), which have to be discarded in order to analyze the network configurationally.

Integration value, it was necessary to first identify the Global Integration value of lines A, B and C. Then, these values were summed up, and divided by three, the number of concurring axial lines. The same process was undertaken for the configurational measures of Local Integration, Connectivity and Choice, as well as for the metric measure of Line Length. It is worth noting that each network was composed by a different set of nodes, which means that comparisons between behavioral data and spatial data demanded to calculate mean metric and configurational values of nodes as if they were totally independent systems.

Table 6.11 shows some descriptive data of nodes in Axial and Mindwalk (30º) analyses. Although these models use different scales and therefore their configurational and metric values cannot be compared themselves, it is possible to evaluate how configurational and metric properties of networks are distributed by examining Mean and Standard Deviation (SD) values of these measures. Seeing it this way, it is again evident that merging lines have skewed values, thus widening the distance between a discrete number of extended and configurationally very salient lines, and a larger group of shorter and configurationally less salient ones.

Table 6.12 shows how spatial and behavioral factors were associated to each other in worlds One, Two, and Three in Axial analysis. Table 6.13 does the same but when the Continuity lines analysis (set a 30º) was employed.

The first thing to note from observing these tables is that in both Axial and Mindwalk analyses, mean correlations values are higher when three, rather than one streets had to be selected. The exception is nonetheless scenario Three (in Mindwalk analysis) which displays the same value (r =0.8) in both cases. Similarly, it was found out that higher correlations resulted from using Mindwalk analysis (30º) than from using Axial analysis. For example, the highest associations between participants` choices regarding the three main streets in Axial analysis were r =.558 (scenario One), r = .524 (scenario Two) and r =..629 (scenario Three), whereas in Mindwalk analysis these correlations reached the values of r = .732, r = .792 and r =.866 respectively. The third aspect to be called upon regards the discrete predictive capacity that Axial or Mindwalk models achieved when three important junctions were selected. In Axial analysis, for instance, these correlations did not surpass r = 0.36, whilst in Mindwalk analysis the maximum value reached r = .512. In most cases, however, correlations did nor pass the value of r = .5.

The final aspect of importance refers to the predictive power of configurational or metric measures in Axial analysis or Mindwalk analysis. As table 6.13 shows, Global Integration and Choice were the most efficient measures in predicting people's answers concerning the main street, and the three main streets, of scenarios One, Two and Three in when Axial analysis. However, when lines were merged using a 30º angle of aggregation, the metric measure of Line Length started predicting people`s choices. Proof of that is the fact that the measure that most efficiently predicted people's choices of the main street, and the three main streets in scenario One was the metric measure of Line Length (r = .68 and r = .72 respectively). This seems concordant with findings observed in chapter Five, which showed that Choice and Global Integration were as the most efficient measures in capturing how persons retrieved hierarchical information coming from maps when an Axial model was occupied, but also that metric factors appeared equally important when Mindwalk model was employed.

Table 6.11: Axial Node and Mindwalk Node (30º) analyses. Descriptive data

ANALYSIS	SCENARIO		Global Int	Local Int	Conn	Choice	Line length
Axial	1	Mean *(SD)*	1.59 *(0.32)*	2.1 *(0.39)*	5.65 *(2.14)*	0.07 *(0.05)*	11.8 *(5.58)*
	2	Mean *(SD)*	1.75 *(0.37)*	2.17 *(0.43)*	6.03 *(2.73)*	0.09 *(0.07)*	12.05 *(5.65)*
	3	Mean *(SD)*	1.62 *(0.35)*	2.1 *(0.41)*	5.55 *(2.5)*	0.08 *(0.08)*	11.2 *(5.5)*
Mindwalk 30º	1	Mean *(SD)*	1.37 *(0.33)*	1.73 *(0.49)*	3.34 *(2.59)*	0.03 *(0.05)*	6.82 *(5.84)*
	2	Mean *(SD)*	1.47 *(0.36)*	1.77 *(0.52)*	3.37 *(2.77)*	0.04 *(0.08)*	6.7 *(5.82)*
	3	Mean *(SD)*	1.4 *(0.33)*	1.74 *(0.49)*	3.32 *(2.57)*	0.03 *(0.06)*	6.56 *(5.42)*

*Conn, stands for Connectivity. Global Int. for Global Integration and Local Int. for Local Integration

Table 6.12: Axial Node Analysis. Predictive power

SCENARIO	QUESTION	Global Int	Local Int	Conn	Choice	Line Length	mean
1	One street	**.396**	.359	.353	.345	.369	.360
2		.395	.369	.350	**.478**	.339	.380
3		.423	.454	.439	**.467**	.414	.440
1	Three streets	.551	.508	.463	**.558**	.370	.490
2		**.524**	.486	.474	.502	.340	.460
3		.535	.576	.556	**.629**	.418	.540
1	Three junctions	**.336**	.319	.280	.360	.299	.320
2		.320	.297	**.360**	.334	.235	.310
3		.269	.277	.269	**.293**	.232	.260

▨ highest value

Table 6.13: Mindwalk Node Analysis (30º). Predictive power

SCENARIO	QUESTION	Global Int	Local Int	Conn	Choice	Line length	mean
1	One street	.567	.482	.583	.650	**.680**	.590
2		.557	.496	**.600**	.574	.521	.550
3		.748	.699	.812	**.921**	.850	.800
1	Three streets	.618	.582	.659	.730	**.732**	.660
2		.748	.695	**.792**	.718	.778	.740
3		.795	.718	.799	**.866**	.812	.800
1	Three junctions	.387	.366	.468	.481	**.505**	.440
2		.402	.378	.467	.449	**.512**	.440
3		.399	.371	.437	**.483**	.450	.420

▨ highest value

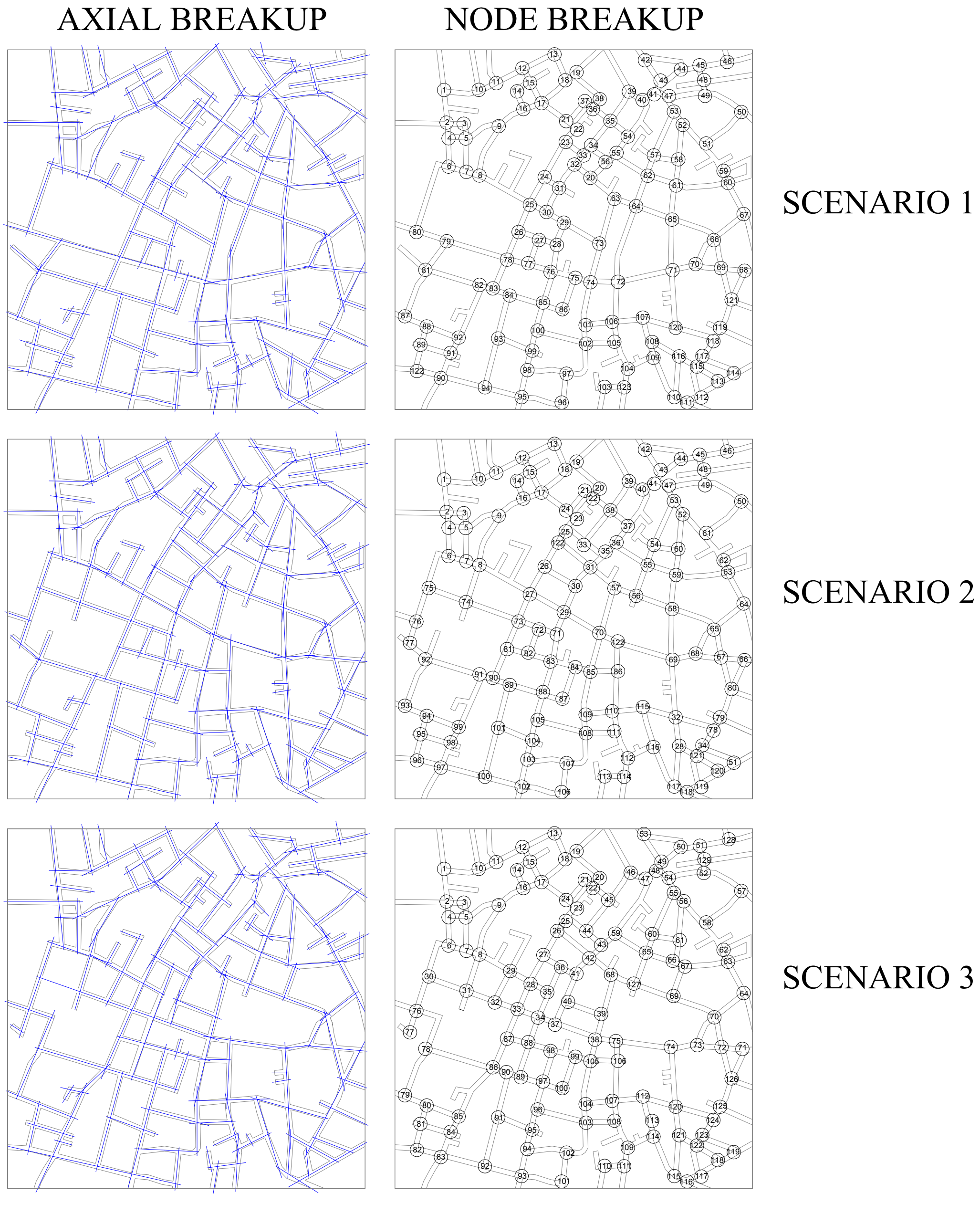

Figure 6.19: Axial breakup and Choice Node breakup for scenarios 1,2 and 3

6.4.- Discussion

There are various phenomena of interest in this chapter. First, it was shown that most individuals tended to draw extended and linear paths as main streets. This seems to support one of the fundamental assumptions posed by space syntax: that human movement is linear. Although it could be argued that subjects were not asked to execute any physical displacement but merely to draw lines, the fact that most persons marked straight, or nearly straight paths as main streets, suggest that conservation of linearity is a fundamental spatial behavior.

But linearity seemed to be a rather flexible concept. As demonstrated by the analysis of people's paths, people were more inclined to ignore slight misalignments occurring to salient streets, than major discontinuations occurring to them. While in the former case the resulting path appeared as almost linear (and might have therefore mentally encoded as a linear one), in the latter case the resulting path appeared as broken line and might have therefore perceived as imposing a larger "cognitive cost" for subjects.

At a more analytical level though, results shown here seems to support some of the findings reported in Chapter Five, in which it was indicated that configurational factors are as important as metric ones in shaping people`s retrieval of spatial hierarchies. Proof of that is the fact that even when lines were merged, configurational variables were more efficient in predicting subjects` judgments than metric ones.

But this argument fails in a crucial aspect. As reported previously, configurational and metric variables are highly associated, meaning that there is no way to confidently claim that people were observing configurational, rather than metric aspects of networks, in order to retrieve hierarchical information of them. On the contrary, common sense indicates that the opposite is more likely, that is, that persons attended to metric factors of lines as a means to retrieve hierarchical information from the maps employed in this experiment. In other words: Could be the case that people merely chose as main streets the longest lines of each map?

Aimed to solve this dilemma, another exercise was undertaken. This attempted to see two things: first, whether the configurational and the metric aspects of salient lines were synchronized or aligned in each of the scenarios tested in this experiment, and second, if such an synchrony (or asynchrony) could have affected people`s judgments.

Table 6.14 and table 6.15 clarify this idea, by showing, respectively, participants` choices regarding the main street, and the three main streets, of scenarios One, Two and Three of this experiment. For the sake of brevity, results presented here correspond to those obtained when the Continuity Lines model was used (set at 30º). Note that numbers appearing under the columns "ordinal ranking" do not correspond to configurational or metric values but to each line´s ID, as delivered by Mindwalk.

Table 6.14: Coordination of metric and configurational factors in Mindwalk analysis (30º) for question C

Question C		most used line			Choice (ID)	Conn (ID)	Global Int. (ID)	Local Int. (ID)	Line Length (ID)
SCENARIO		ID	N	%					
1	first	**2**	45	86.4	2	2	2	2	2
	second	**94**	6	13.5	94	5, 4, 50	4	94	94
	third		0	0.0	5	4	94	4	4
2	first	**38**	36	69.2	4	38	4	4	4
	second	**4**	13	25	28	4	38	38	38
	third	**57**	7	13.4	3	3	3	3	43
3	first	**4**	24	48	4	4	93	4	4
	second	**93**	25	48	93	93	4	93	93
	third	**50**	2	4	81	50	30	30	88

Table 6.15: Coordination of metric and configurational factors in Mindwalk analysis (30º) for question A

Question A		most used line			Choice (ID)	Conn (ID)	Global Int. (ID)	Local Int. (ID)	Line Length (ID)
SCENARIO		ID	N	%					
1	first	**94**	52	100	2	2	2	2	2
	second	**2**	51	98	94	**5, 4, 50**	4	94	94
	third	**50**	15	28.8	5	4	94	4	4
2	first	**4**	50	96.1	4	38	4	4	4
	second	**38**	48	92.3	28	4	38	38	38
	third	**29**	36	69.7	3	3	3	3	43
3	first	**93**	49	94.2	4	4	93	4	4
	second	**4**	48	92.3	93	93	4	93	93
	third	**8**	33	63.4	81	50	30	30	88

Table 6.16: Coordination of metric and configurational factors in Mindwalk analysis (30º) for question B

Question B		most used node			Choice (ID)	Conn (ID)	Global Int. (ID)	Local Int. (ID)	Line Length (ID)
SCENARIO		ID	N	%					
1	first	**72**	40	76.9	72	72	78	72	72
	second	**78**	24	46.1	78	78	71	78	78
	third	**25**	16	30.7	25	53	76	53	71
2	first	**69**	38	73	29	29	29	29	29
	second	**29**	32	61.5	27	27	27	27	69
	third	**27**	24	46.1	69	69	31	69	27
3	first	**33**	39	75	33	33	33	33	33
	second	**38**	33	63.4	26	36	37	26	26
	third	**72**	11	21.1	23	28	73	28	38

For example, in table 6.15 line Nº 2 appears as the most connected, the longest, the most globally and locally integrated line, as well as the line of highest choice of scenario One. It is, indeed, the most popular line of this scenario, as the overwhelming majority of participants chose this line as the main street of this system. For example, forty-five people (or 86.4% of individuals) chose this line as the main street of Scenario One, showing that when metric and configurational aspects of networks are aligned in lines, subjects reckon them as hierarchical.

The second most popular line in scenario One was line Nº94, marked by 6 subjects (or 13.5% of the sample). Line Nº 94 was the second most extended path of world One, the second most locally integrated line of this world, as well as and the line of highest Choice of it.

However, line Nº 94 was neither the second most connected nor the second most integrated line, since these positions corresponded, respectively to lines Nº 5, Nº 4 and Nº 50. It seems therefore that the lower degree of convergence between metric and configurational values of line Nº 2 with respect to line Nº 94's, might explain the fact that line Nº 2 was chosen as the main street of the map by less than 15% of individuals, compared with line Nº 94's 86.4%.

Unlike the first scenario, worlds Two and Three did not show the same level of consistency between metric and configurational values in those lines that received the highest number of answers. Nor did they show the level of agreement among participants about main streets, either. For example, in scenario Two line Nº 38 was chosen by 69.2% of participants, whereas in scenario Three line Nº4 was selected by 24 individuals (48% of the sample). None of these lines, however, were at the same time the most connected, the most globally and locally integrated, the longest or the lines with the highest Choice value of their systems.

But if there was a high degree of correspondence between configurational and metric aspects in the most popular street of scenario One, the same cannot be said of the second and third most popular streets of world Two and Three. In fact, while the second most popular line of scenario was chosen by 94% of participants, the third most popular line was selected by only 28.8% of participants. Unlike this, in world Two the three most popular lines were selected by 96%, 92% and 69% of participants, whereas in scenario Three these percentages were 94%, 92 and 63% respectively. In sum, it seems that the fact that in scenario One there was a high level of agreement among participants about the main street, but a relative disagreement about the identity of the three main streets, might be explained by the correspondence between metric and configurational factors in the longest line, and the relative divergence of these properties in other less hierarchical streets.

If paths made by participants are observed again (figures 6.6, 6.7 and 6.8) it is clear that these results make sense. For example, most individuals marked a single path in scenario One when one main street had to be marked, but drew several lines when three streets had to be drawn. On the contrary, in scenarios Two and Three subjects` choices were less categorical when just one main street had to be marked, but were equally diverse when three streets had to be outlined.

A similar approach could be used to find out how individuals selected the three most important junctions of the maps proposed in this experiment. Table 6.16 presents an ordinal arrangement of the nodes using the same methodology employed for the study of paths. For the sake of brevity, only those results coming from the employment of the Continuity Lines model (30º), will be discussed here[6].

The first thing to note is that, in almost all cases, the corners that most people chose as one of the three most important junctions were highly salient nodes, both in configurational and metric terms. For example, in scenario One, the node of highest mean Connectivity value, was also the node of highest mean Global and Local Integration values, as well as the node of highest mean Line Length value. This was node Nº 72. But was node Nº 72 a popular node too?

Table 6.18 shows that this was the case, for forty subjects, or 76.9% of individuals, chose it as one of the three most important junctions of world One. With few differences, the same pattern can be observed in all scenarios, showing that people are to a great extent capable of understanding hierarchical information regarding the location of "important junctions" in spatial networks, by observing how synchronized are these junctions` metric and configurational properties.

The convergence/divergence framework presented here seems to be concordant with the ideas presented in chapters Four and Five, which showed that people´s retrieval of hierarchical information in maps seems to obey to a coordination of metric and configurational properties of networks, and more specifically, to the degree of alignment between these factors. This does not mean that subjects do

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[6] Results of Axial analysis are presented in Appendix 3

not retrieve hierarchical information of space when no coordination between metric and configurational variables of space exists in salient lines, but that the construction of shared knowledge, knowledge that seems to be naturally encoded by individuals, would be more difficult to achieve. Furthermore, it will be argued that when no coordination exists between configurational and metric factors of salient lines, people's judgments will be more unpredictable and subjective.

It is inevitable to separate these findings from space syntax` theories In fact, Hillier (1999) has maintained that urban space is characterized by a synchrony between metric and configurational, which means that longer lines would tend to be integrated ones. *"The metric factor of line length is the decisive variable in defining how easy or difficult it is to retrieve a description of the system. where the same total length of line is divided into a few long lines and many short ones, as we typically find in cities, then the moving observer sees more space over the time spent in movement than if the lines are of even length, and the information obtained from the longer ones is more redundant and therefore more structural"* (Hillier 2003:18).

The following section will further explore these ideas but focusing on of one of the most intriguing aspects revealed in this chapter: how retrieval of hierarchies takes place when salient streets are misaligned.

chapter Seven

The consequences of misaligning salient streets

Abstract

This paper investigates whether linear discontinuities occurring in salient streets affect the way in which people retrieve hierarchical information of spatial networks. The main task consisted of identifying "the main street" in a map, whose arrangement was slightly modified according to four different scenarios. In scenario One no discontinuity occurred in the longest and most connected street. In scenario Two a minor discontinuity was placed at this street. In scenario Three a greater discontinuity affected the main street. Finally, in scenario Four linear continuity was partially restored through a diagonal.

Results show that misaligning salient streets has profound consequences on the ways people retrieved hierarchical information of these streets. Specifically, it was demonstrated that there is a direct relation between the size of the misalignment and people's willingness to ignore them when tracing main streets.

7.1.- Introduction

The last chapter showed that retrieval of hierarchical information in maps is to some extent dependant on the existence of continuous or semi continuous structures forming salient paths. It was shown too that individuals tended to identify these paths as ¨main streets¨, insofar as they involve an alignment of configurational and metric variables.

Another important finding of the previous chapter refers to the effect of slight and minor misalignments occurring to salient paths. It was demonstrated that subjects employ a flexible reasoning to deal with discontinuities occurring in salient streets, that is, they were more inclined to ignore minor discontinuations than major ones. This is the focus of this chapter.

7.2.- Method

Layouts

Since the aim of this experiment was to see to what extent slight misalignments occurring in highly salient grids could affect subjects` capacity to retrieve hierarchical information of spatial systems, the first step was to construct an environment where metric and configurational variables of its most salient lines were synchronized. Two environments coming from the previous chapter were adapted for that purpose.

The first of these worlds looked like a typical organic city, where a series of curvilinear streets meeting at oblique angles, coexist with a reduced pool of slightly sinuous and extended roads. Its most salient path moved rather horizontally, forming a sort of open "V" that divided the environment into two halves. Hence, it was named the Horizontal world (or, in short, world H). The second of these worlds was also irregular but its most salient street moved in a vertical way, although with a slight inclination to the right. Unlike the first environment, this scenario did not divide the map into two halves of similar size, but left one of these sections (the rightmost one) larger than the other (the leftmost one). Because of the direction of its most salient line, it was identified as Vertical world (world V). Figure 7.1 shows both environments.

In order to see if both worlds V and H were in fact perceived as having two hierarchical lines, in the first phase of this experiment it was measured whether individuals could easily identify the main streets of these worlds. 44 individuals (23 males, 21 females, mean age 28.4 years, SD 8.73, all students at UCL), were then asked to identify the main street of the first of these worlds, the Horizontal one. Charts were rotated by 0º, 90º, -90º and 180º, thus forming four different scenarios. Eleven participants responded to each of them[1]. Following the procedure presented in other tests, individuals were asked to rate how confident they were about their responses on a 1 to 10 scale (where 1 was the minimum and 10 maximum).

Results of this experiment are shown in figure 7.2 As it can be appreciated, forty-one out of forty-four (93%) outlined line H as the main street of the map, proving that, regardless of the position in which the map was presented, a clear hierarchical road was perceived. Confidence assessments reached 7.25 (SD 1.83), with no differences between those defined by males or females (t:0.89; p>0.01).

With these results in hand, the next phase of the experiment defined three more scenarios for both the Vertical and Horizontal worlds.

- Minor misalignment (scenario Two): a slight discontinuation[2] occurred at some point of streets V and H[3], thus forming two semi continuous segments in each of these lines. The particularity of this move was that the two resulting segments were not completely set apart, but shared a common vertex (see figures 7.2 and 7.3). This created an ambiguous junction, in which a person standing in the middle of each of these segments V and H was impeded from gaining a full view of what was in front of him, but could get a partial idea of the environment lying ahead.

- Major misalignment (scenario Three): the former misalignment was doubled in size, which modified the ambiguous situation of the previous

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[1] Only the Horizontal condition was tested. This obeyed purely to time restrictions and the difficulty to obtain volunteers.

[2] The size of the discontinuation was set to be identical to the width of any of the streets in environments V and H.

[3] In order to make results comparable, the misalignment of streets V and H was placed at about ¾ of these streets.

scenario. In practical terms, this meant a subject standing in the middle of streets V or H could see less of the environment ahead of him than in scenario Two.

- Diagonal alignment (scenario Four): a 15º diagonal was placed between the disconnected segments of scenario Three, thus restoring, at least partially, the linearity of streets V and H observed present in scenario One.

Figures 7.3a, 7.3b and 7.3c show respectively scenarios 2, 3, and 4 belonging to the Vertical condition. Figures 7.4a, 7.4b and 7.4c do the same but for the Vertical condition.

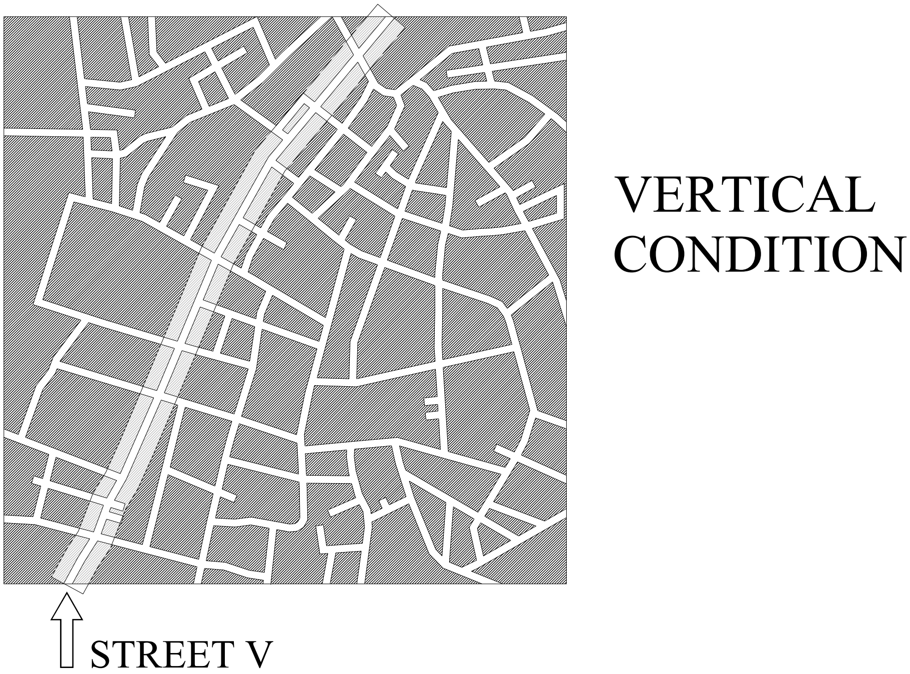


Figure 7.1a (top): Scenario 1, Horizontal condition. (the arrow indicates the main street)

Figure 7.1b (bottom): Scenario 1, Vertical condition. (the arrow indicates the main street)

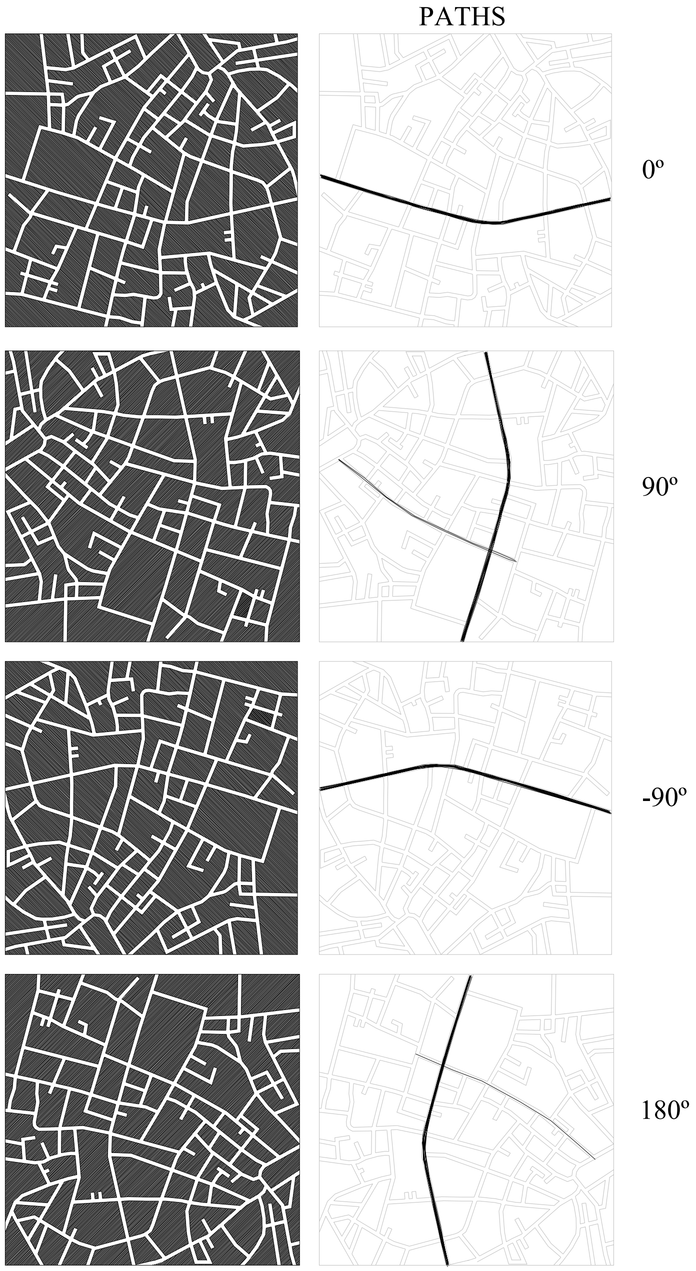


Figure 7.2: Four versions of scenario 1 (Horizontal conditions) employed for training purposes. Numbers at the right indicate the angles of rotation.

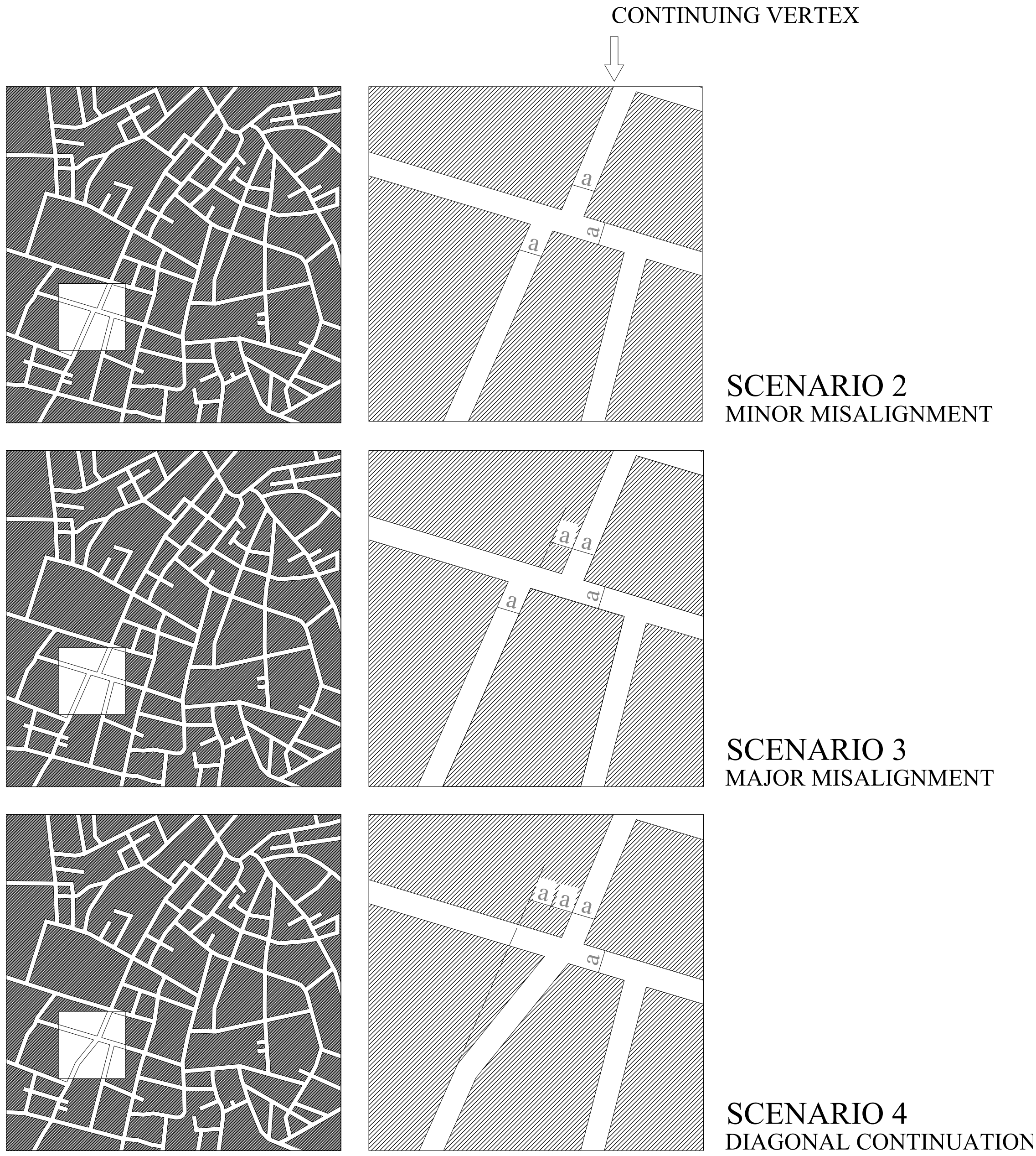


Figure 7.3: Three additional scenarios tested in the Vertical world.

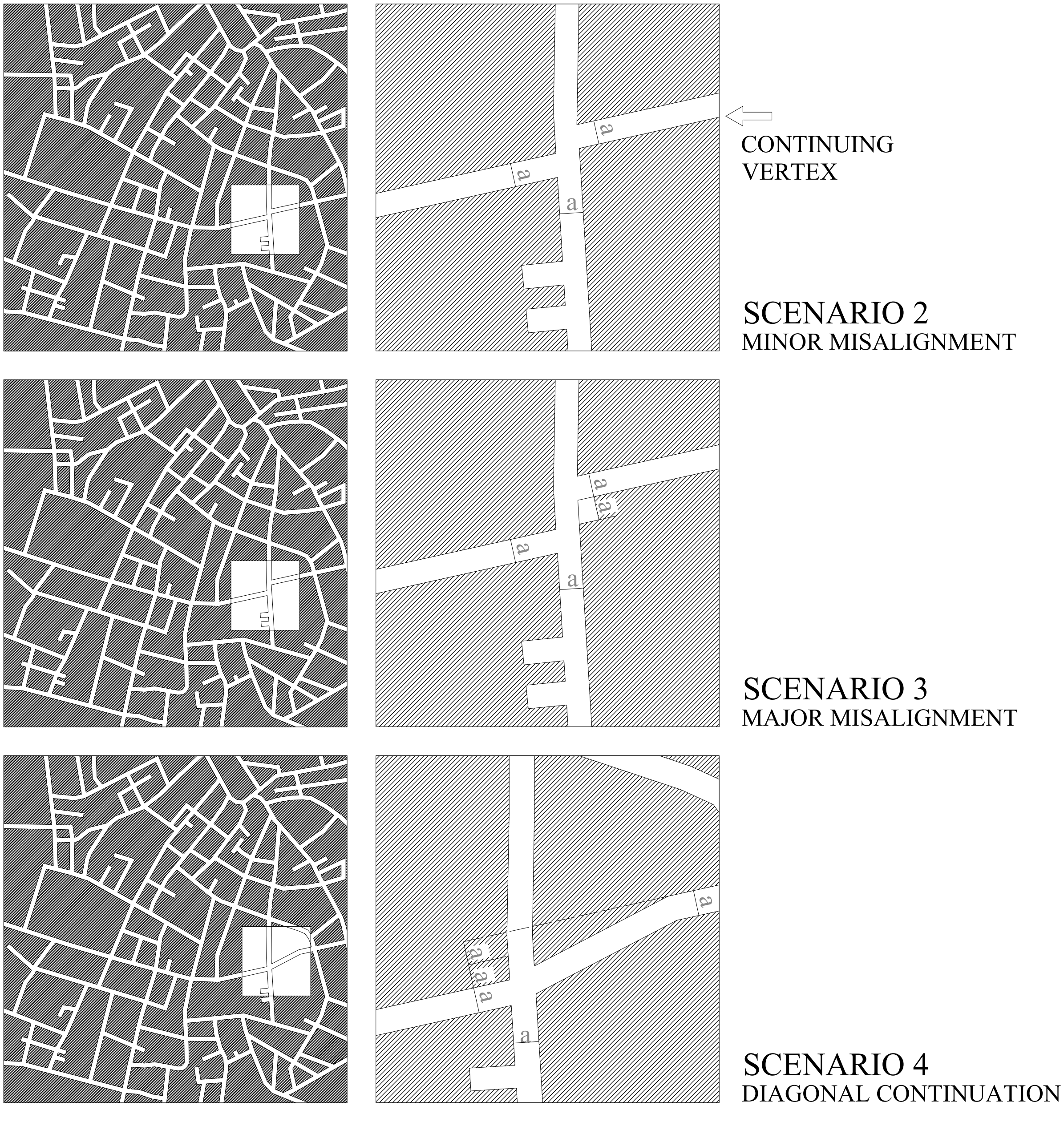


Figure 7.4: Three additional scenarios tested in the Horizontal world

Axial and Continuity Lines analyses

Axial analysis

In order to study the role of spatial and metric factors in shaping people's spatial judgments about hierarchies in maps, the first step of this analysis consisted of constructing the axial maps of the control scenario, the minor misalignment scenario, the major misalignment scenario, and finally the diagonal scenario. Since each of these scenarios possessed a Vertical and a Horizontal version, the amount of axial maps drawn for the analysis totaled eight networks. Figure 7.5 shows the axial maps corresponding to scenario One, for both the Vertical and Horizontal worlds. Figure 7.6 illustrates all remaining conditions of this experiment.

The attentive reader might have noted that, in spite of the fact that the misalignment of streets H and V is twice as big in the third scenario than in the second scenario, from a configurational and metric point of view, these worlds are identical. In effect, both worlds have exactly the same number of axial lines arranged in exactly the same manner. All what changed in scenario 3 is the location of lines V and H (belonging to the Vertical and Horizontal conditions respectively), not the type of connections of these lines. In terms of configurational and metric assessments, therefore, both worlds could be renamed as worlds V2/3 and H2/3. But what were the configurational and metric consequences of discontinuing streets in these worlds?

Table 7.1 displays mean metric and configurational values of scenarios 1, 2/3 and 4 derived from an axial analysis. As it can be appreciated, only minor changes are observed when aggregated values of lines are studied, a seemingly logical result given the fact that only one line was slightly modified..

Unlike this trend, intelligibility values of scenarios 1 to 4 seem to be more sensible to the misalignments occurring in the Vertical and Horizontal worlds, as table 7.2 shows. For example, world V`s intelligibility values were 0.654 (Control scenario), 0.646 (minor/major misalignment scenario), and finally 0.651 (diagonal scenario). Similarly, in world H intelligibility values stood at 0.675 (Control scenario), 0.683 (minor/major misalignment scenario), and 0.679 (diagonal scenario).

As it can be seen, the misalignment of paths V and H did not affect worlds V and H`s symmetrically. While in the Vertical world the misalignment of street V resulted in a slight drop of intelligibility, in the Horizontal world this move produced an improvement of intelligibility.

Why does intelligibility behave in this manner? Does this mean that intelligibility is not a reliable measure of an environment's degree of coordination between local and global aspects, as Hillier (1996) suggested?

Not necessarily. Rather, the phenomenon could be explained by the ultimate nature of intelligibility, which reflects the relation between a lines's Connectivity and its Global Integration value. If, as it occurs in scenario H1, a highly salient line is well-integrated but not very well-connected (see figure 7.7), any modification that improves the association between connectivity and integration should logically strengthen intelligibility.

Figure 7.8 shows the configurational measures of Global Integration, Local Integration, Choice and Connectivity as well as the metric measure of Line Length for scenarios 1, 2/3 and 4 of the Vertical condition. Figure 7.9 does the same for the Horizontal condition.

At a first glance, it is clear that axial analysis captures the underlying structure of both the Vertical and Horizontal worlds. For example, the lower section of line V that belongs to the Vertical world appears as the most locally integrated the longest and the line of highest choice of this scenario. The same can be said of the leftmost segment of line H, belonging to the Horizontal scenario, which is the most connected, the most locally integrated and the longest line of this system.

In spite of these facts, it is fairly clear that Axial analysis does not capture some properties of thlines V and H appear as relatively unimportant streets. Proof of this is the fact that the uppermost segment of line V, and the rightmost segment of line H, are not highly integrated or connected lines. This is because axial analysis penalizes slight deviations occurring to lines, precisely the kind of phenomenon experienced by lines V and H, of the Vertical and Horizontal worlds.

The columns furthest to the right of figures 7.8 and 7.9 show the configurational measures of Global and Local Integration, Connectivity, Choice, as well as the metric measure of Line Length when misalignments and diagonal streets are introduced into worlds V and H. The first of these figures, figure 7.8, shows that the main consequence of offsetting street V is that this line seems to loose part of its metric and configurational salience. For example, while in the Control scenario the lower section of line V was one of the longest, and most locally integrated streets, in the minor/major misalignment condition, this segment appears as an ordinary line in terms of its Local Integration and Connectivity values. Likewise, while in the Control condition the lower section of lineV appears as one of the longest lines of the map, in the minor/major misalignment condition such line becomes much darker, meaning this line is, configurationally, now less important.

Unlike the Vertical world, configurational and metric values of the most salient line of the Horizontal world are more stable. Here it can be seen that the leftmost part of line H is the most connected, the longest, and one of the lines of highest Local Integration value in scenarios 1, 2/3 and 4. By comparison, the rightmost segment of line H is far less distinctive, for it moves in an intermediate range in terms of its Global and Local Integration, Connectivity, Choice and Line Length values. However, when misalignments and diagonal linkages are introduced in line H both configurational and metric values change significantly. For example, as a consequence of dividing this line in two, Global Integration, Line Length and Connectivity values have passed from bright to dark colours, reflecting the fact that a topological cost has been imposed to these lines by misaligning line H.

In sum, axial analysis shows that the misalignment of lines V and H in the Vertical and Horizontal worlds respectively, did not affect importantly mean configurational and metric values of these worlds, but it did produce significant changes in terms of the metric and configurational salience of some of their streets.

Continuity Lines analysis

Unlike the previous chapter, this section of the thesis did not consider the employment of Segment analysis. This decision is due to the fact that Segment analysis tends to produce a large number of trivial rings, or very short segments resulting from the encounter of two or more than two streets. Since these segments do not represent any meaningful section of the map (and frequently are barely visible), it is necessary to eliminate them before running the analysis. In order to avoid this problem, and considering that eight maps are to be studied, it was decided not to use Segment analysis in this opportunity.

As per in the previous chapter, Continuity Lines analysis (or Mindwalk) was employed using a threshold angle of 30º, which proved to be highly efficient in mirroring how people retrieved hierarchical information of lines. This angle permitted to transform lines V and H into sinuous paths, thus making it possible to reflect the operation of the principle of Good Continuation.

Aggregating lines has metric and configurational implications too. As Table 7.5 shows, the series of lines existing in scenarios 1, 2/3 and 4 are more integrated, connected and longer than in Axial analysis. Configurational and metric values are more skewed too, meaning that systems are now more hierarchically organized than in Axial analysis.

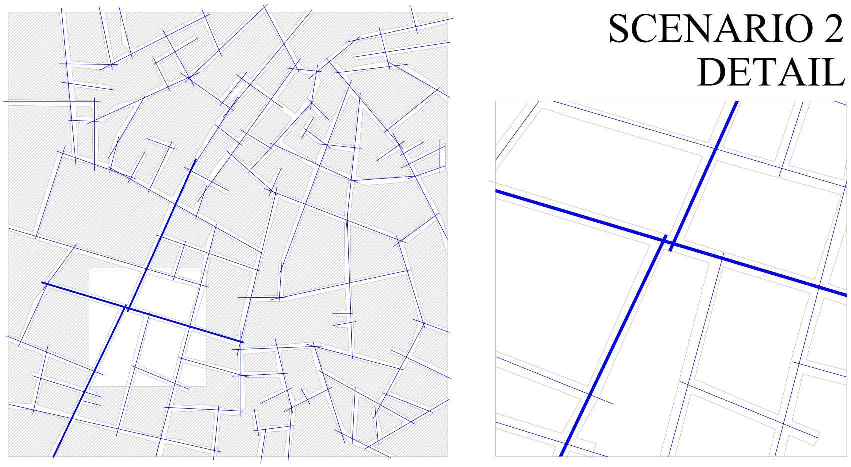
Figure 7.11 and 7.12 shows graphically this phenomenon for the Vertical and Horizontal worlds respectively. A visual inspection of the first of these charts (figure 7.11), reveals that merging lines has meant that path V is now salient line, both in configurational and metric terms. For example, in scenario 1, street V is the most connected, longest and locally integrated of the sample. However, when this line is interrupted, as it happened in scenarios 2 and 3, all configurational factors loose their preeminence, and only line V remains as the longest line of the network. Reversing this trend, scenario 4 shows that placing an oblique connection between the two disconnected segments of line V, somehow reestablishes the arrangement observed in the Control scenario. This means that in the diagonal scenario line V is, again, the most connected, the longest, and the most locally integrated line, as well as a highly distinctive line in terms of its Choice and Global Integration value. Figure 7. 12 show that a similar story can be found in the Horizontal world.

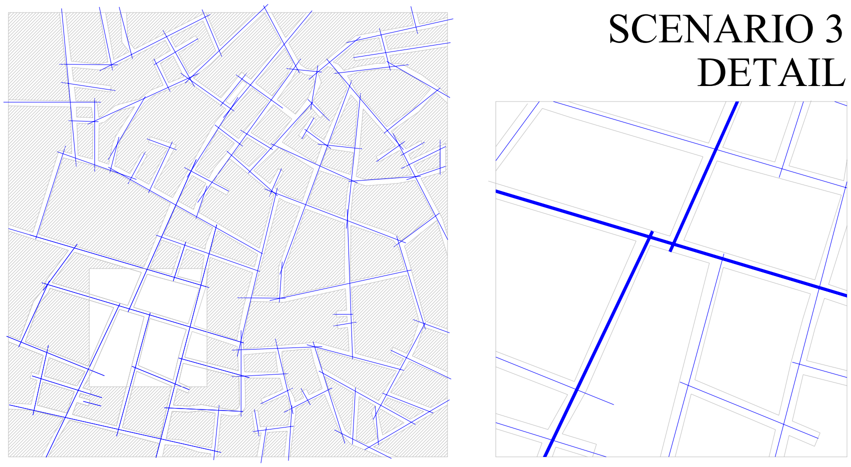
How did these changes affect people`s choices? How did subjects retrieve hierarchical information of networks when these networks were misaligned?.

SCENARIO 1
VERTICAL
CONDITION

SCENARIO 1
HORIZONTAL
CONDITION

Figure 7.5: Axial breakup of Scenario 1





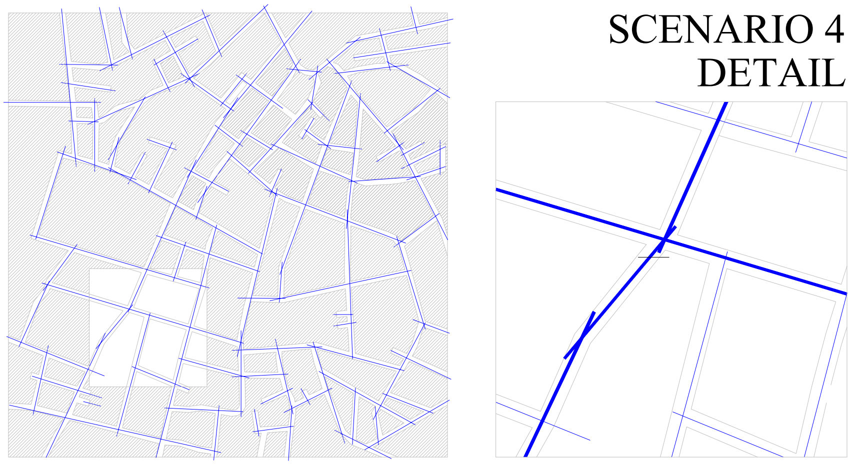
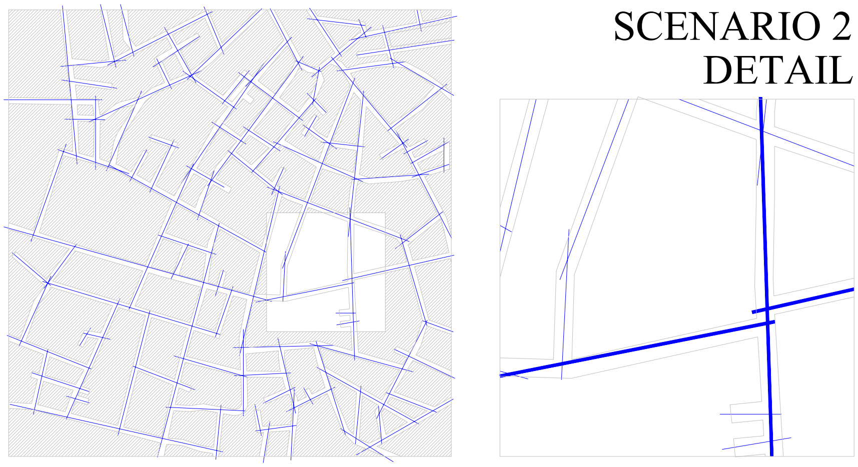
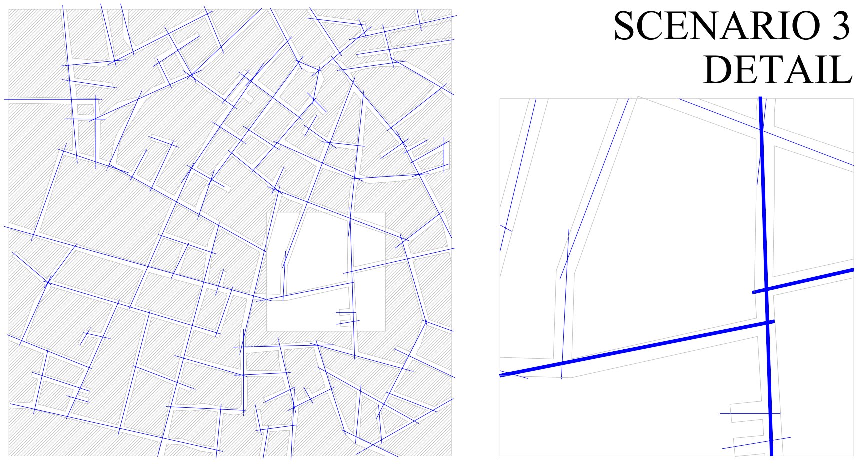


Figure 7.6a (first row): Scenario 2, Vertical condition

Figure 7.6b (second row): Scenario 3, Vertical condition

Figure 7.6c (third row): Scenario 4, Vertical condition





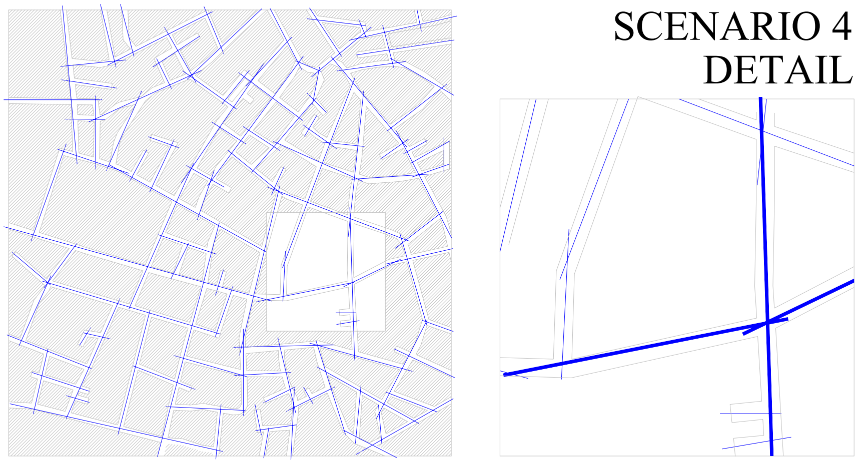


Figure 7.7a (first row): Scenario 2, Horizontal condition

Figure 7.7b (second row): Scenario 3, Horizontal condition

Figure 7.7c (third row): Scenario 4, Horizontal condition

SCENARIO 1 SCENARIOS 2/3 SCENARIO 4

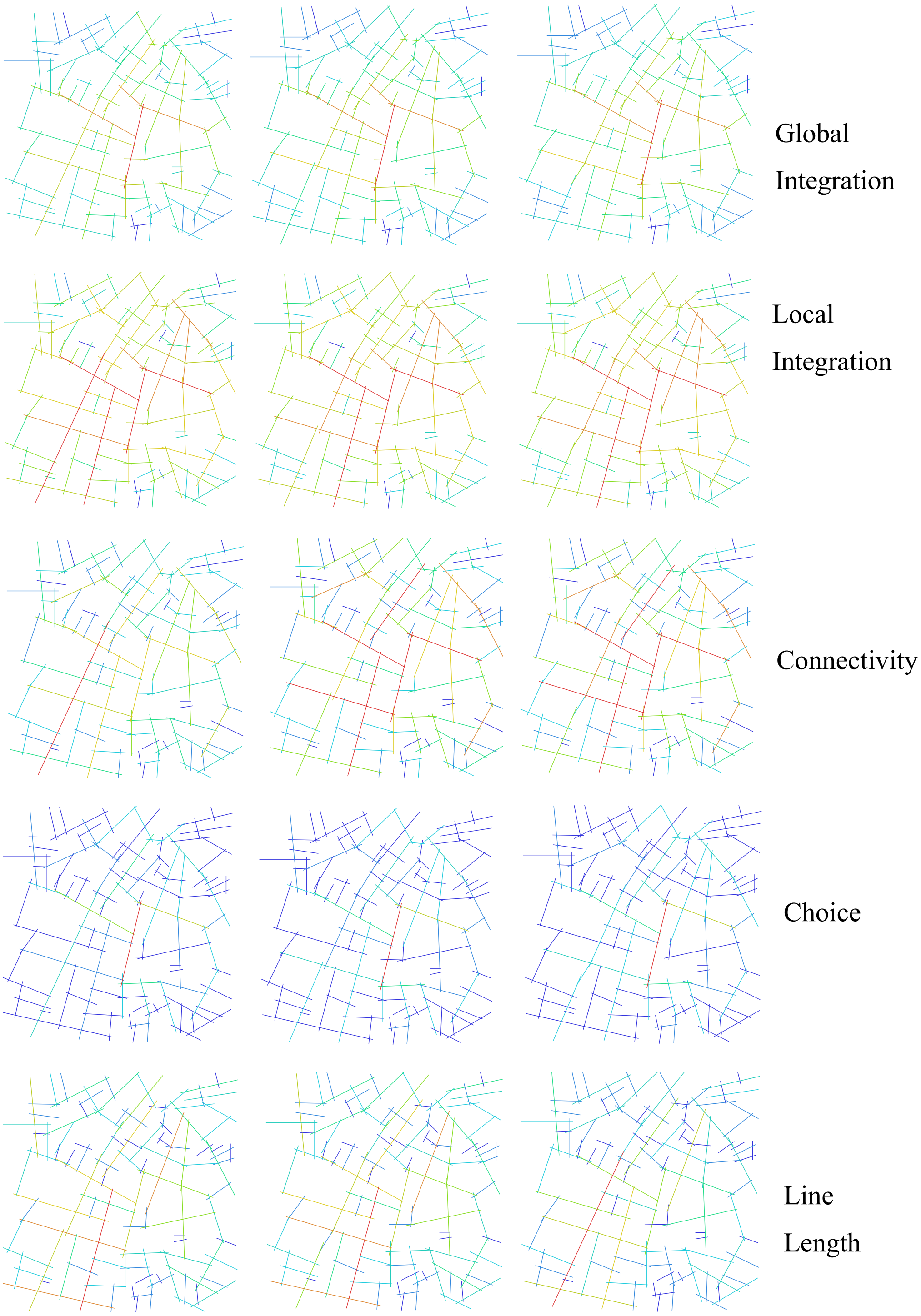


Figure 7.8: Axial analysis of scenario 1, 2/3 and 4, Vertical condition

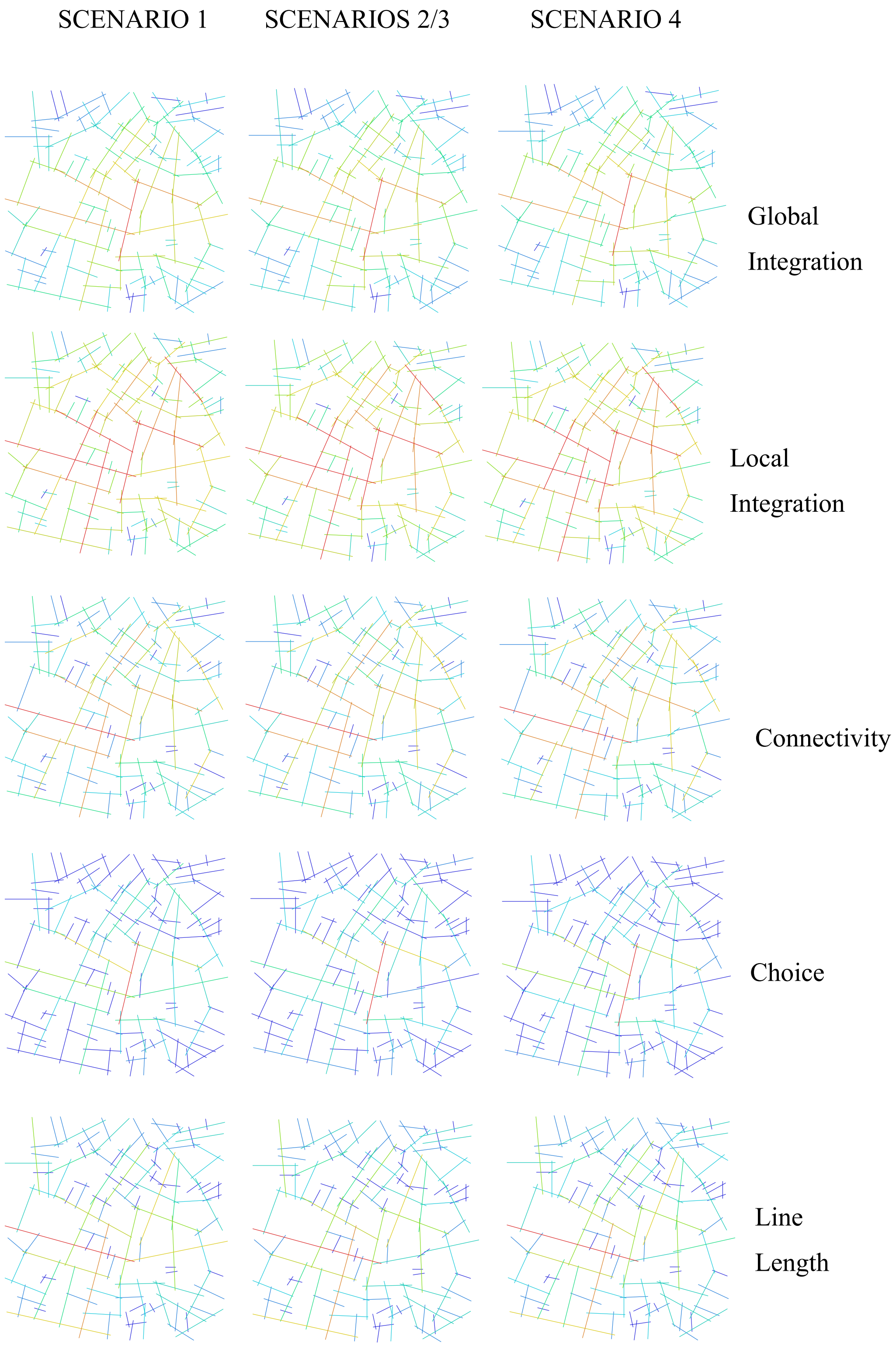


Figure 7.9: Axial analysis of scenario 1, 2/3 and 4, Horizontal condition

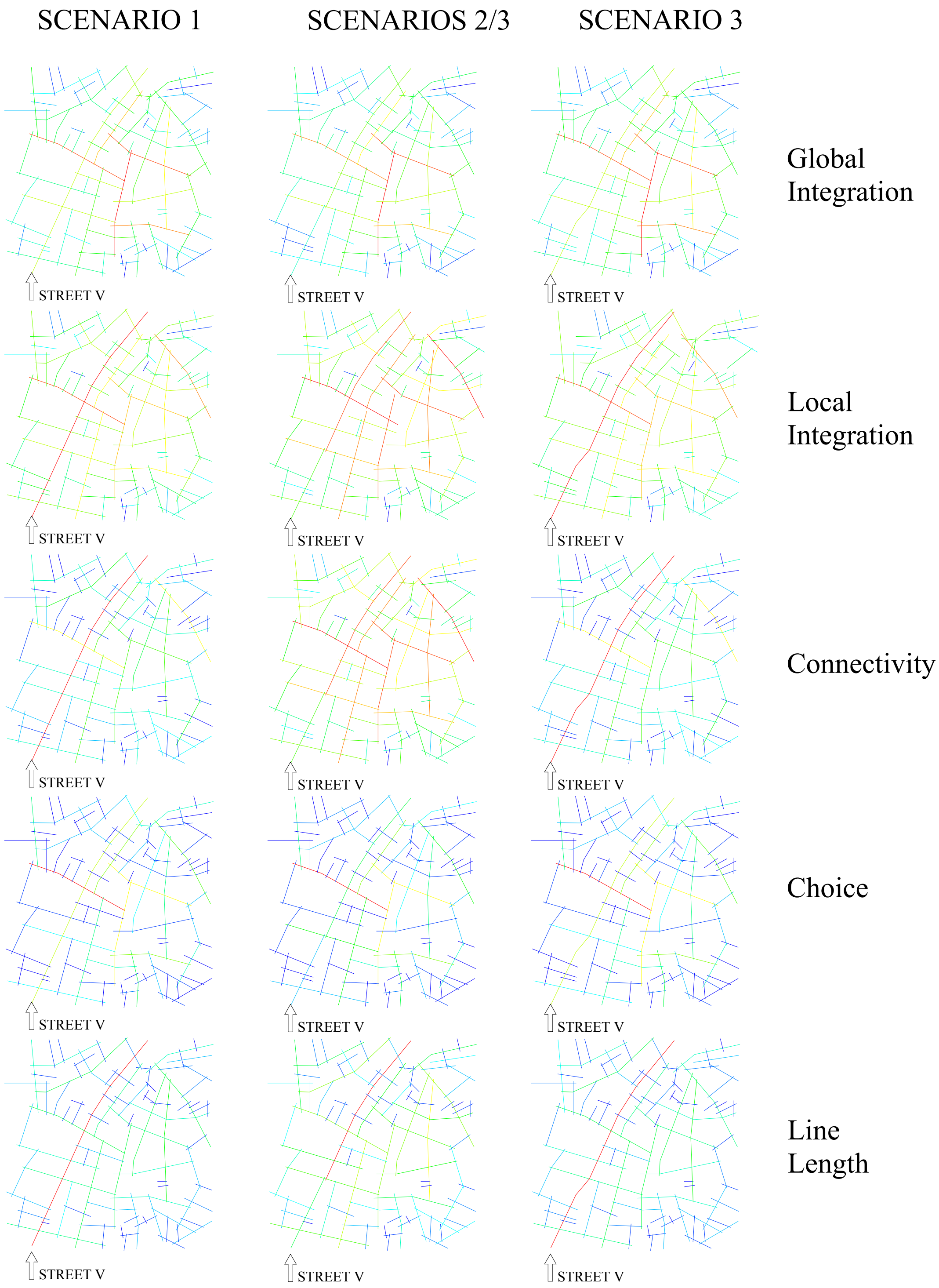


Figure 7.10: Mindwalk analysis (30º) of scenario V1, V2/3 and V4

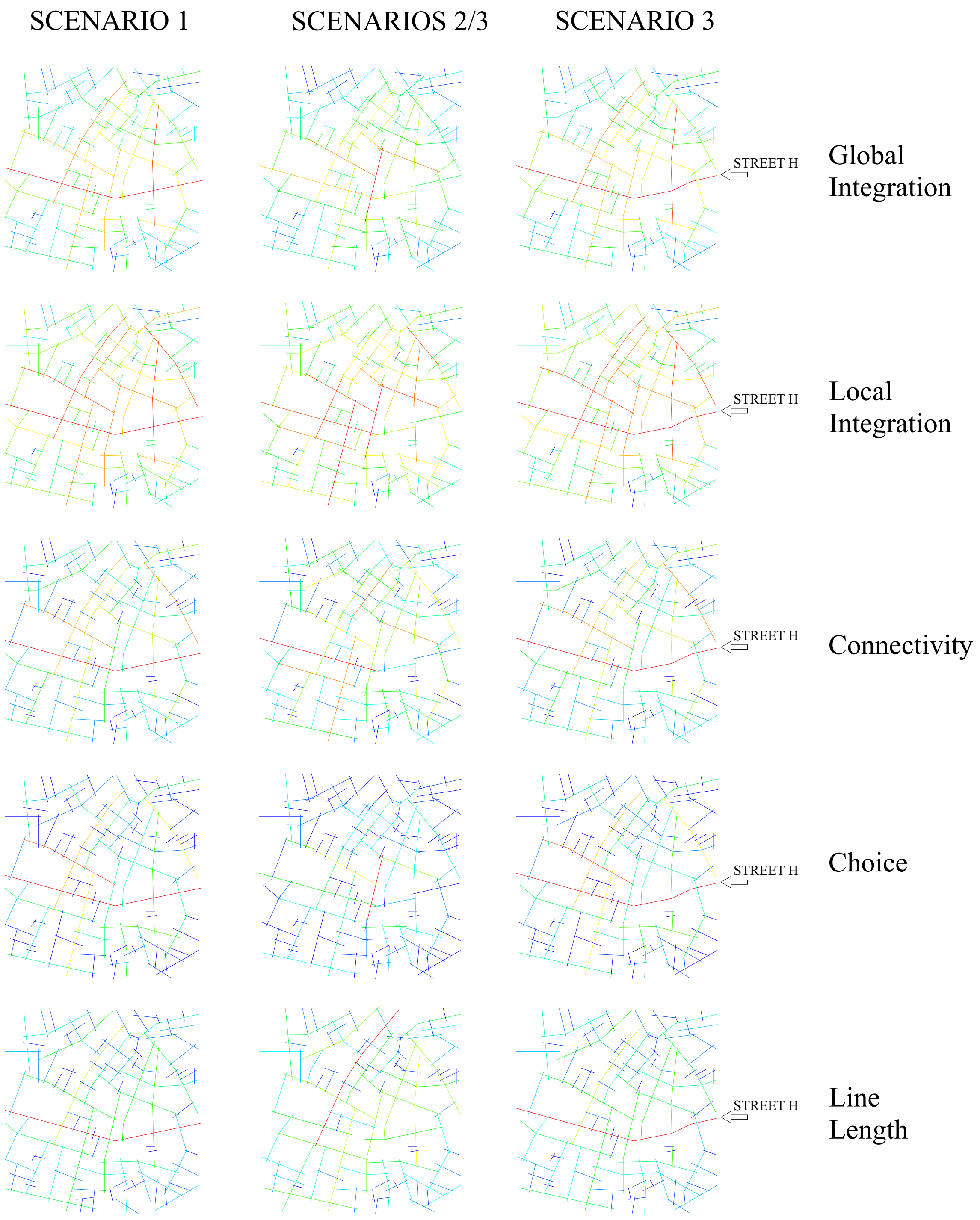


Figure 7.11: Mindwalk analysis (30º) of scenario H1, H2/3 and H4

Table 7.1: Axial analysis. Mean configurational and metric values

	Axial lines (N)	Choice	Conn	Global Int.	Local Int.	Line Length
V1 (Control)	119	192.01	3.48	1.17	1.67	5.68
V2/V3	120	196.06	3.45	1.14	1.63	5.64
V4	121	195.02	3.5	1.17	1.67	5.67
H1 (Control)	112	218.46	3.42	1.12	1.64	5.71
H2/H3	113	216.9	3.41	1.12	1.64	5.51
H4	114	215.31	3.41	1.14	1.65	5.49

Table 7.2: Intelligibility in Axial analysis

Scenario	Intelligibility
V1 (Control)	0.654
V2/V3	0.646
V4	0.651
H1 (Control)	0.675
H2/H3	0.683
H4	0.679

Table 7.3: Mean configurational and metric values in Mindwalk analysis (30º)

	Continuity lines (N)	Conn	Global Integration	Local Integration	Line Length
V1 (Control)	90	3.48	1.17	1.67	5.68
V2/V3	91	3.45	1.14	1.63	5.64
V4	90	3.5	1.17	1.67	5.67
H1 (Control)	96	3.42	1.12	1.64	5.71
H2/H3	97	3.42	1.13	1.64	5.50
H4	96	3.41	1.14	1.65	5.49

Table 7.4: Intelligibility in Mindwalk analysis (30º)

Scenario	Intelligibility
H1 (Control)	0.747
H3 (“broken”) model	0.738
H4	0.747
V1 (Control)	0.717
V3 (“broken”) model	0.731
V4	0.717

7.3.- Method

Materials and Design

The layouts described above were used as independent stimuli, thus forming a pool of eight different scenarios. Each participant responded to just one of these worlds, which were balanced with respect to gender and age of participants.

Participants and procedure

A total 340 unpaid subjects (168 men, 172 women) took part on this experiment. Most of them were students or staff at University College London. In order to discard any training-related bias, subjects whose backgrounds were Geography or Architecture were excluded from taking part in this experiment. Each subject responded to one of the eight maps tested in this experiment. No subject had participated in any other of the experiment of this thesis. Table 7.5 shows descriptive data of this experiment.

As in other tests, subjects were approached individually and asked to participate in an experiment involving the understanding of maps. They were told then to outline the "main street" of the map with a pen, and then to rate how confident they were on their answers. A 1 to 10 scale was occupied for this purpose.

Results

First, it was investigated whether subjects` self assessments were influenced by their gender. Two t-tests showed no difference for the Vertical condition (t:2.773; p>0.01) or for the Horizontal condition (t: 0.824; p>0.05). Second, it was investigated whether an individual's age was associated to his or her self-confidence. An one–way analysis of variance (ANOVA) showed that no differences among participants existed either (F: 1.169;p>0.05 for the Vertical world, and F: 1,027;p>0,05 for the Horizontal world).

Table 7.5: Descriptive data of the main experiment of this chapter

	Men	%	Women	%	Total
Vertical condition					
V1 (Control)	24	54.5	20	45.5	44
V2 (minor misalignment)	19	43.18	25	56.82	44
V3 (major misalignment)	21	47.7	23	52.3	44
V4 (oblique line)	17	39.5	26	60.5	43
subtotal	81	46.28	94	53.72	175
Horizontal condition					
H1 (Control)	26	59.1	18	40.9	44
H2 (minor misalignment)	23	56.1	18	43.9	41
H3 (major misalignment)	17	43.6	22	56.4	39
H4 (oblique line)	21	51.2	20	48.8	41
subtotal	87	52.7	78	47.3	165
Total	**168**	**49.4**	**172**	**50.6**	**340**

The next step investigated whether subjects` confidence changed in any of the scenarios employed (1,2,3 or 4). The results showed that when no misalignment occurred (scenarios H1 and V1), subjects` confidence reached the values of 7.7 and 7.33 respectively, but that these values decreased when misalignments in lines H and V were introduced. For example, scenarios H2 and V2`s mean confidence ratings were 6.91 and 6.39 respectively, whereas subjects` ratings in scenarios H3 and V3 stood at 6.25 and 5.75 respectively. However, in scenarios H4 and V4 confidence improved again, reaching the values of 6.83 and 7.41 respectively. Figure 7.12 shows this trend.

In order to test if these differences were statistically significant an one-way analysis of variance (ANOVA) was carried out. This detected differences at a $p<0.5$ level for both the Horizontal ($F(3, 170) = 3.5$; $p>0.1$) and the Vertical condition (F(3, 127) = 4.2; p>0.1)[4]. Post-hoc comparisons using a Hukey HSD test indicated that the mean score of scenario V3 (M= 5.75, SD=2.17) was significantly lower than the mean score of scenarios V1 (M= 7.3, SD=2.27) and V4 (M= 7.41, SD=2.04). By comparison, in the Horizontal condition the same test only detected differences between scenarios H1 (M= 7.7, SD=1.98) and H3 (M= 6.26, SD=2.15).

The next stage consisted in studying participants' answers. Figure 7.13 depicts paths made by individuals when responding to scenarios H1 and V1, that is, when no misalignment occurred to lines V or H. As it can be appreciated, all individuals selected the longest and best connected line as the main street in scenario V1, whereas all except one subject marked street H as the main street in scenario H1.

Figure 7.12: mean self confidence values ratings in this experiment

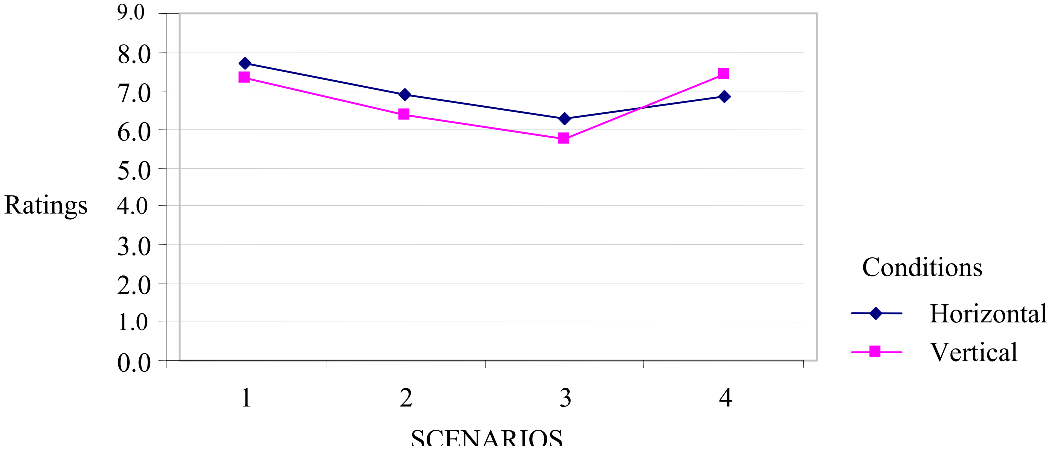


Figure 7.14 shows paths made by individuals in scenario Two, when a slight misalignment was placed in streets H and V. Looking at this chart, it is evident that people's answers are less unanimous than in scenario One, for paths are not confined to an unique line but several ones. In fact, a total of three subjects chose alternative lines in scenario V1 (6.8%), whilst in scenario H1, six individuals (14.6% of respondents) chose roads other than street H. But if the number of

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[4] The effect size, calculated using eta square, was of medium range (Cohen, 1998) at a 0.058 and 0.09 for both Horizontal and Vertical conditions.

people choosing alternative paths as main streets varied in the Vertical condition with respect to the Horizontal condition, so did the type of street selected for such purposes. This means that those who did not outline line V as the main street of world V marked a series of alternative roads, whereas those who did not mark street H as the main street of world H preferred just one line.

Figure 7.15 shows that people's willingness to choose other than lines V and H as main streets increased as a result of enlarging the misalignment of such lines. The last series of images show paths made by participants in scenario Four. As it can be seen, most people chose again lines V and H as the main streets of world V and H respectively. The result is similar (but not identical) with the one observed in scenario One, where the overwhelming majority of people chose lines V and H. This time, however, a larger number of individuals chose alternative paths as main streets of worlds V and H, suggesting that although the diagonals were efficient in restoring the continuity of lines V and H, their effectiveness was limited. For example, four individuals of scenario V4 (7.3%) and four individuals of scenario H4 (9.7%) chose paths other than V and H as main streets. Results of this exercise are presented in table 7.6.

Another interesting phenomenon worth mentioning is people's willingness to outline, entirely or partially, lines V and H as main streets. Figure 7.17 attempts to clarify the point by showing two typical answers made by individuals in scenarios Two and Three[5]. The first of these answers (see first row) consisted of ignoring the misalignment occurring in streets V or H and to draw continuous paths. The other (see second row) consisted in stopping at the misaligned junction, so to trace partial or interrupted paths. In order to evaluate these differences in a more systematic way, people's answers were divided into three main groups:

- Partial paths: when a person only marked the longest leg of streets V or H as the main street.
- Complete paths: when a person drew streets V or H as continuous paths.

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[5] For the sake of brevity, only scenario 1 will be used to exemplify these answers.

- Alternative paths: If a person choose an alternative street (neither H nor V) as main streets. [6]

Results of this exercise are shown in table 7.6, which shows that important differences in the number of individuals who marked complete or partial paths existed between the scenarios. In scenario V2 and H2, respectively, 43.9% and 18.2% of subjects marked entire paths, ignoring the minor misalignment that occurred at some point on lines V and H, whereas 48.8% and 15.9% of individuals drew partial paths. By comparison, about 7% and 14% of individuals responding to scenarios V2 and H2 chose alternative lines.

In scenario V3 and H3, those who drew entire paths were only 15.4% of the Vertical environment and 18.2% of the Horizontal. On the other hand, the percentage of people who marked partial paths in world V3 was 64.1% and 50% in H3. Lastly, the percentage of subjects that chose neither line V nor line H as main streets reached about 10% in world V and 32% in world H.

Finally, in scenarios H4 and V4 no subject marked lines H and V in a partial way, that is, no subject considered that only a fraction of these streets could be considered as a main street. This does not mean that all individuals marked lines V and H as the main streets of worlds V and H respectively, for almost 10% of participants chose alternative lines. Figure 7.18 permits to appreciate these differences more clearly.

Statistical analyses of these figures showed that, although no differences existed in the Vertical and Horizontal conditions within scenarios 1, 3 and 4 in terms of the number of subjects choosing either complete or partial paths, some differences did exist in scenario 2 (chi-square 8.117, $p<0.05$).

The attentive reader might have noted that these results are somehow at odds with those observed in previous experiments, which showed that retrieval of hierarchies in maps seem to depend on the level of synchrony between the map's configurational and metric information. This is exactly what happened in chapters Four and Six, which showed that minor modifications of spatial networks leads to changes in people's qualitative judgments about them. It also happened between

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[6] It is worth noting that no person chose the shortest segments of streets H or V as "main streets".

the scenario One and scenario Two, or between Scenario One and Scenario Four. But why did people answer differently when no change in the level of coordination between configurational and metric variables took place?

Table 7.6: partial and complete paths in scenarios 1,2 3 and 4

	Complete Paths (N)	%	Partial Paths (N)	%	Other Streets (N)	%
Vertical condition						
V1 (Control)	44	100	0	0	0	0
V2 (Minor misalignment)	18	43.9	20	48.8	3	7.3
V3 (Major misalignment)	6	15.4	25	64.1	8	20.5
V4 (Diagonal)	37	90.2	0	0	4	9.8
	105	63.6	45	27.3	15	9.1
Horizontal condition						
H1 (Control)	43	97.7	0	0	1	2.3
H2 (Minor misalignment)	31	70.5	7	15.9	6	13.6
H3 (Major misalignment)	8	18.2	22	50	14	31.8
H4 (Diagonal)	39	90.7	0	0	4	9.3
	121	69.1	29	16.6	25	14.3

A possible answer might lie in how maps are visually experienced by subjects, and more specifically on how subjects might infer the visual consequences that minor or major misalignments might have for those who navigate on them. As Hillier has suggested (Hillier, 1996), one of the main consequences of misaligning streets is that people will obtain less "redundant information" of the environment, thus making it more difficult for them to retrieve the underlying structure of the world.

In order to test this idea, another exercise was undertaken. This consisted in simulating a person's visual experience when moving along paths V and H, as figure 7.19 illustrates. The fictitious individual was placed in the middle of lines

H and V and near their misaligned junctions. For the purpose of this exercise and considering that a person's forward looking is constrained by his physical capabilities, only half-isovists (180º) were employed[7]. Figure 7.20 shows the field of view of an individual navigating in each of the scenarios defined in this experiment (1,2,3 and 4) in the Vertical world. Figure 7.21 does the same for the Horizontal world.

As it can be seen, results show that when minor and major misalignments where placed in paths V and H, individuals` forward looking was progressively shortened and instead, isovists seemed to gain amplitude towards their edges. Further, the effect of placing a diagonal between lines V's or H`s disconnected segments (scenario Four), restored, although not completely, the visual continuity observed in scenario One. Could be the case that not only configurational and metric, but also visual properties of space, shaped respondents` choices?

Here it will be proposed that a possible answer to this question might lie in a relatively unexplored visual measure: Drift. Proposed by Ruth Conroy-Dalton as part of her PhD, Drift is a measure that represents the vector between an isovist's origin and its centroid. Conroy-Dalton discovered that Drift was a robust predictor of people's movement patterns in a virtual environment, for it seemed to indicate that people follow *their noses*, that is, they tended to move linearly in space (Conroy-Dalton, 2003). The author also discovered that people tended to pause at locations of low Drift lengths. Aiming to assess whether visual properties of space themselves played a role in determining people's answers, the Drift values of the fictitious individual were calculated, as figures 7.21 and 7.22[8] illustrates.

A visual inspection of these results shows that these vectors could be grouped into two main categories: the Forward-moving category and the Turning category. Forward-moving Drift vectors are those that point in the direction of lines V and H, while, Turning Drift vectors point in the direction of paths other than V of H. Table 7.7 attempts to put these results in a simple way.

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[7] Isovist theory was briefly presented in chapter Three.

[8] The length of each vector varies because they reflect the fact that Drift Magnitudes are not identical.

Results of this experiment are suggestive: while in worlds V1 and H1, Drift vectors indicate towards paths V and H respectively, in worlds V2, H2, V3 and H3, these vectors pointed to lateral lines. Finally, these bearings appeared redirecting people to lines V and H in scenarios V4 and H4.

But did people's answers obey to configurational or metric properties of space?

In order to respond this question, another exercise was carried out. Following the ranking procedure shown in Chapter Six, this time the most salient lines of all scenarios were compared to the number of people that chose these lines as main streets. For the sake of brevity, this time Mindwalk (30º) will be employed to study the level of synchronization between configurational and metric properties of space. Table 7.8 illustrates this exercise.

The first thing to note is that, unlike previous exercises, the misalignment of lines V and H have not altered the level of coordination between metric and configurational properties of the map's most distinctive streets. For example, in all scenarios of the Vertical world, path V was the longest line[9]. It was the most popular line too, for most subjects chose this path as the main street. The same occurred in the Horizontal condition. However, while in scenarios V1-V4 and H1-H4 , lines V and H were at the same time highly distinctive lines in terms of configurational properties, in scenarios V2-V3 and H2-H3 lines V and H were no longer configurationally salient ones. In short, when no misalignment occurred along lines V and H, these lines were simultaneously the longest and configurationally salient paths, whereas when minor and major misalignments were placed in lines V and H, configurational salience was dissociated from metric distinctiveness.

As table 7.8 shows, this fact seemed to affect profoundly people's answers. For example, in scenario V1 all people marked line V as the main street, while in scenario H1 all but one individual selected line H did the same. However, as misalignments were introduced in lines V and H, an increasing number of subjects started choosing alternative lines as main streets. Others, instead, chose the shortest legs of paths V and H as the main streets of worlds V and H respectively.

If these results are observed in conjunction with people`s confidence in each scenario, the picture is clear: <u>dismantling a synchrony between metric and</u>

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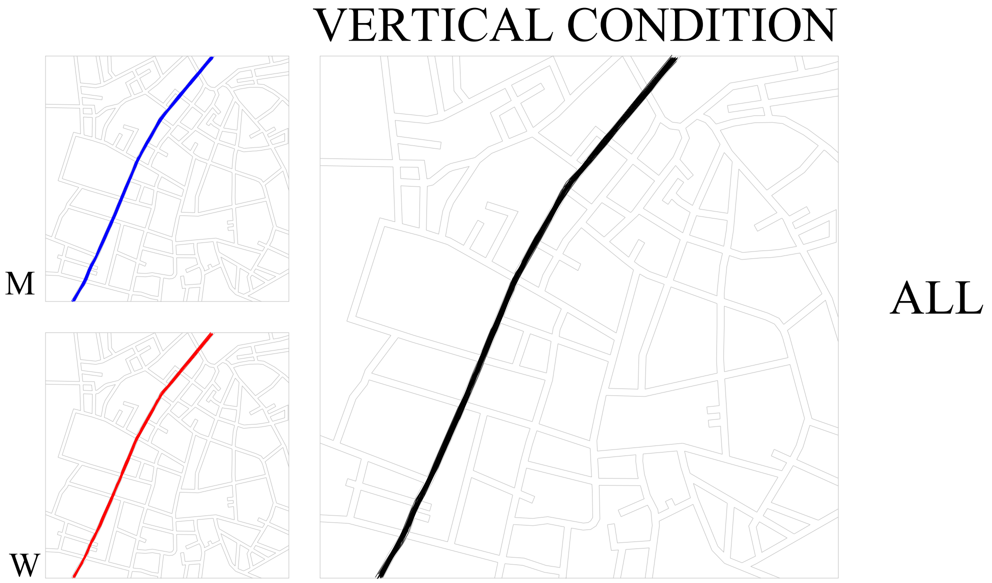
[9] Note that in scenario 4 line V`s ID is Nº 4 instead of Nº 3. This is due to an automatic procedure executed by Mindwalk to allocate ID numbers.

configurational aspects of networks makes the task of retrieving spatial hierarchies in networks more difficult, subjective and unpredictable.



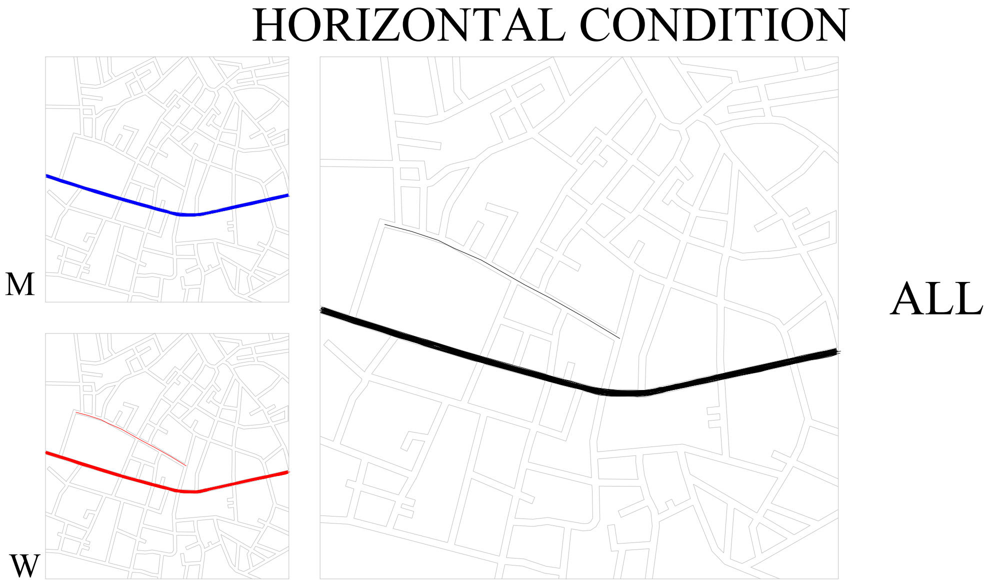
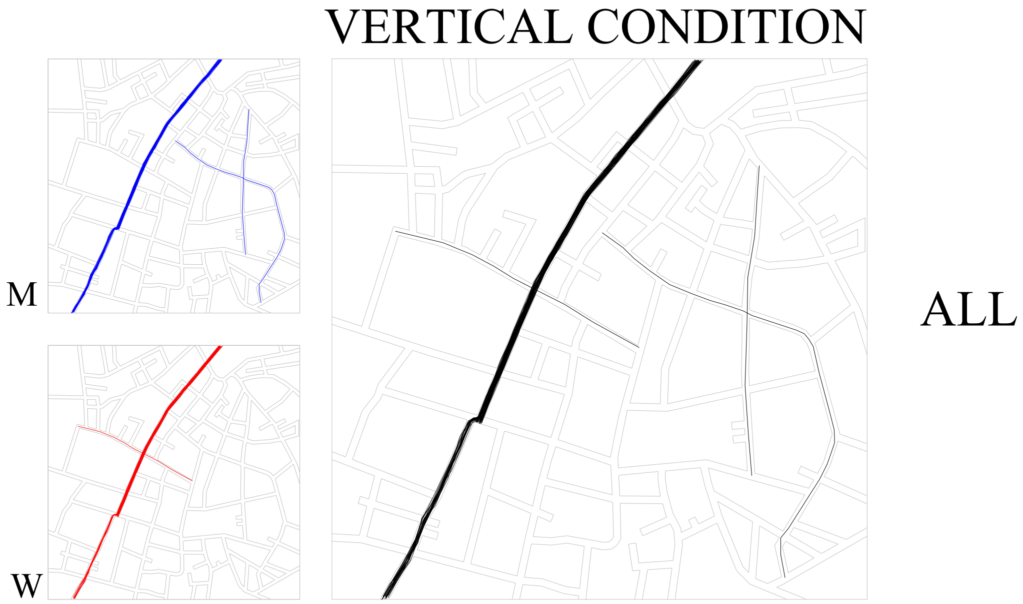


Figure 7.13a (top): Participants´ answers in scenario 1 (control). Vertical condition

Figure 7.13b (bottom): Participants´ answers in scenario 1 (control). Horizontal condition



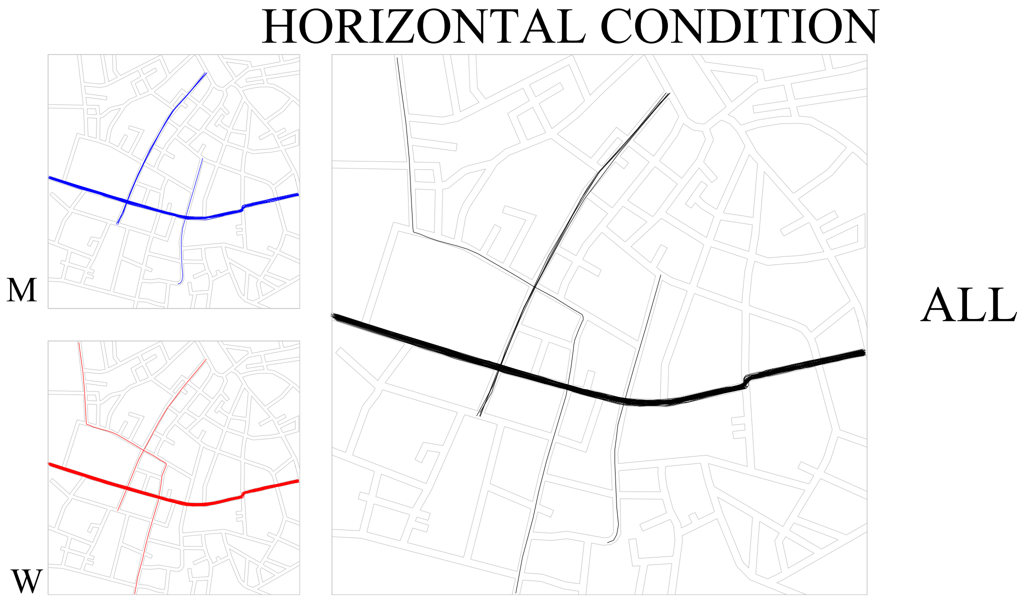
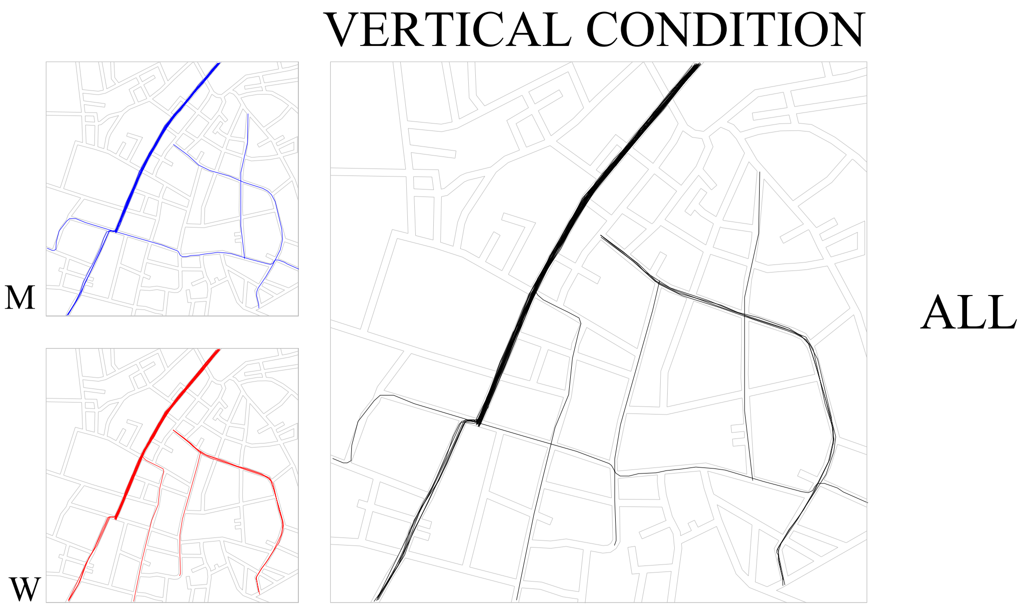


Figure 7.14a (top): participants´ answers in scenario 2. Vertical condition

Figure 7.14b (bottom): participants´ answers in scenario 2. Horizontal condition



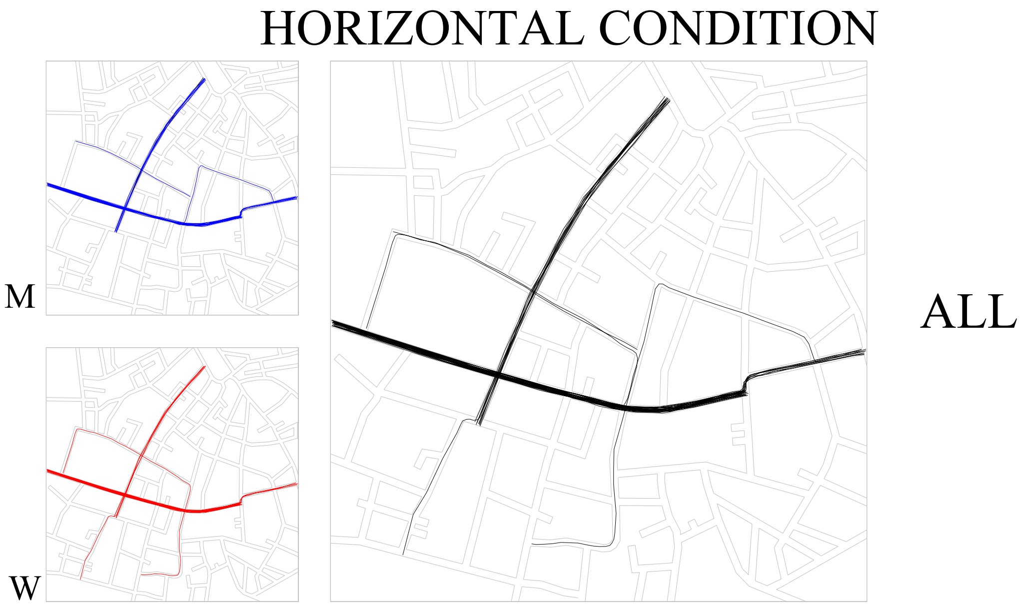
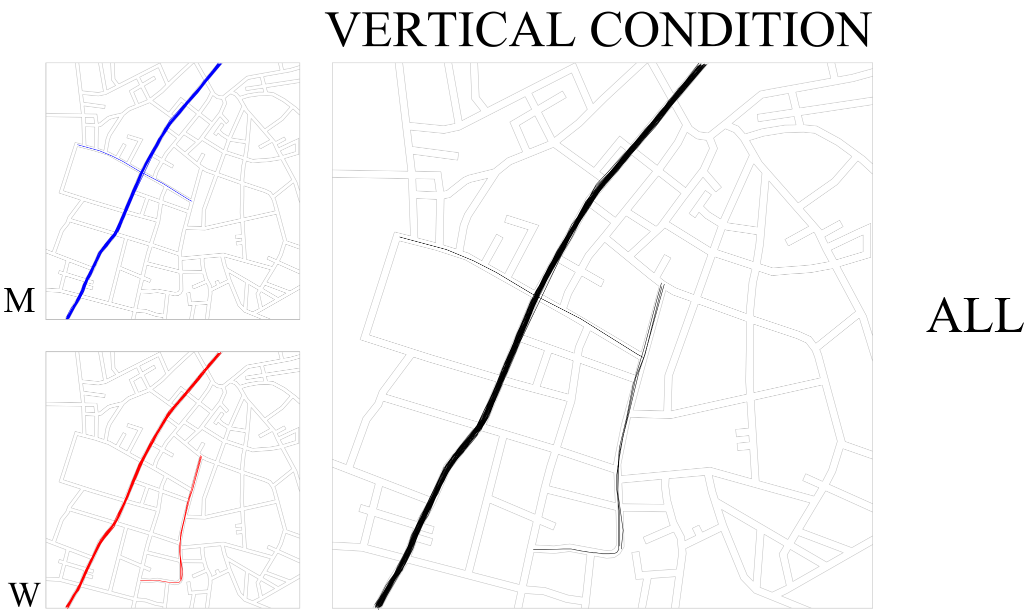


Figure 7.15a (top): participants´ answers in scenario 3. Vertical condition

Figure 7.15b (bottom): participants´ answers in scenario 3. Horizontal condition



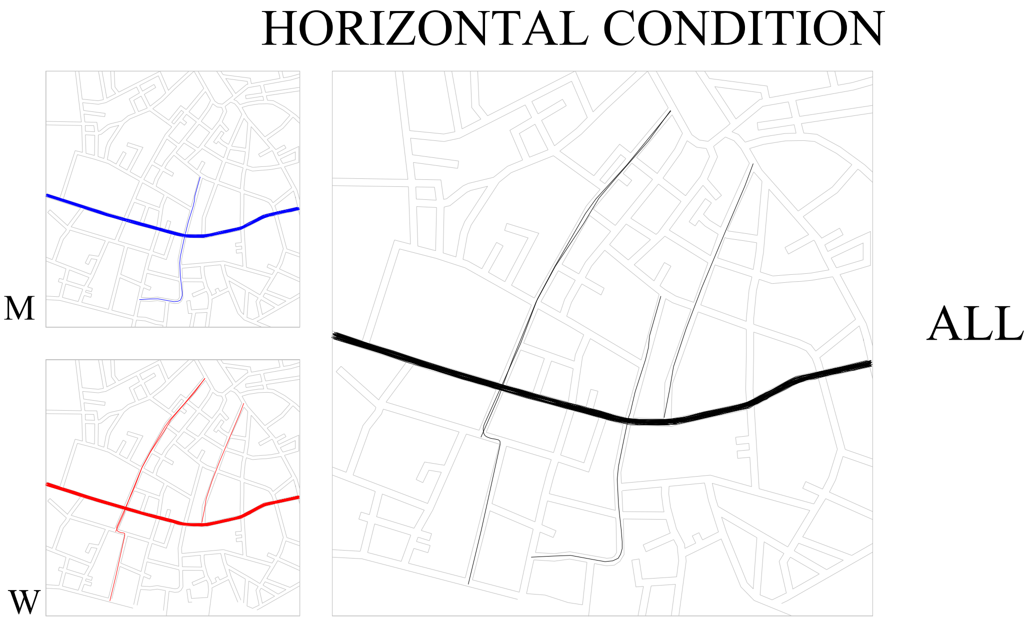


Figure 7.16a (top): participants´ answers in scenario 4. Vertical condition

Figure 7. 16b (bottom): participants´ answers in scenario 4. Horizontal condition

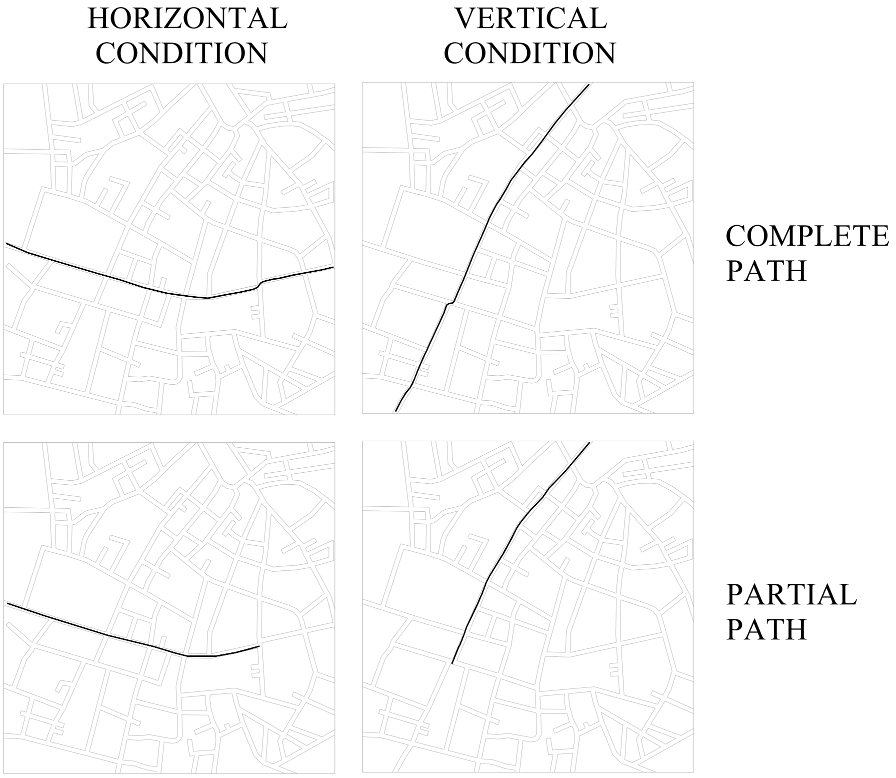


Figure 7.17: Example of complete and partial paths made by participants

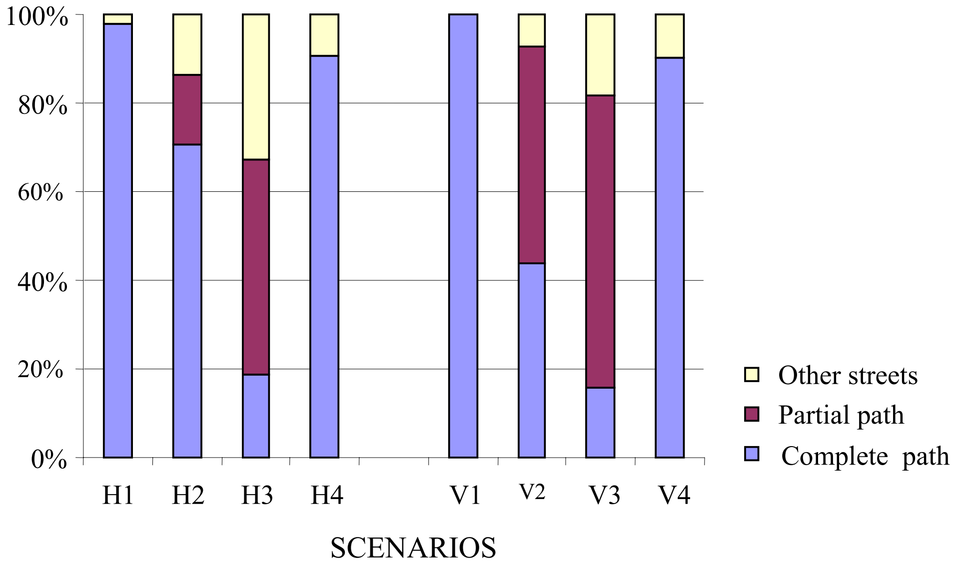
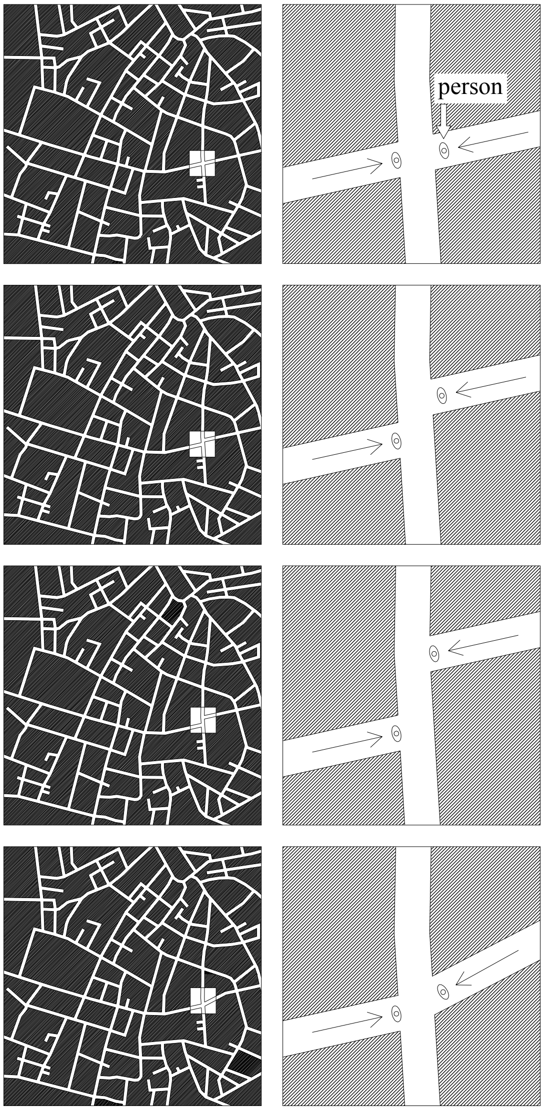


Figure 7.18: Complete and partial paths made by individuals



SCENARIO 1
DETAIL

SCENARIO 2
DETAIL

SCENARIO 3
DETAIL

SCENARIO 4
DETAIL

Figure 7.19: Modeling a person's field of view in the Horizontal world

Figure 7.20: Half-isovist at misaligned junctions in scenarios V1, V2, V3 and V4

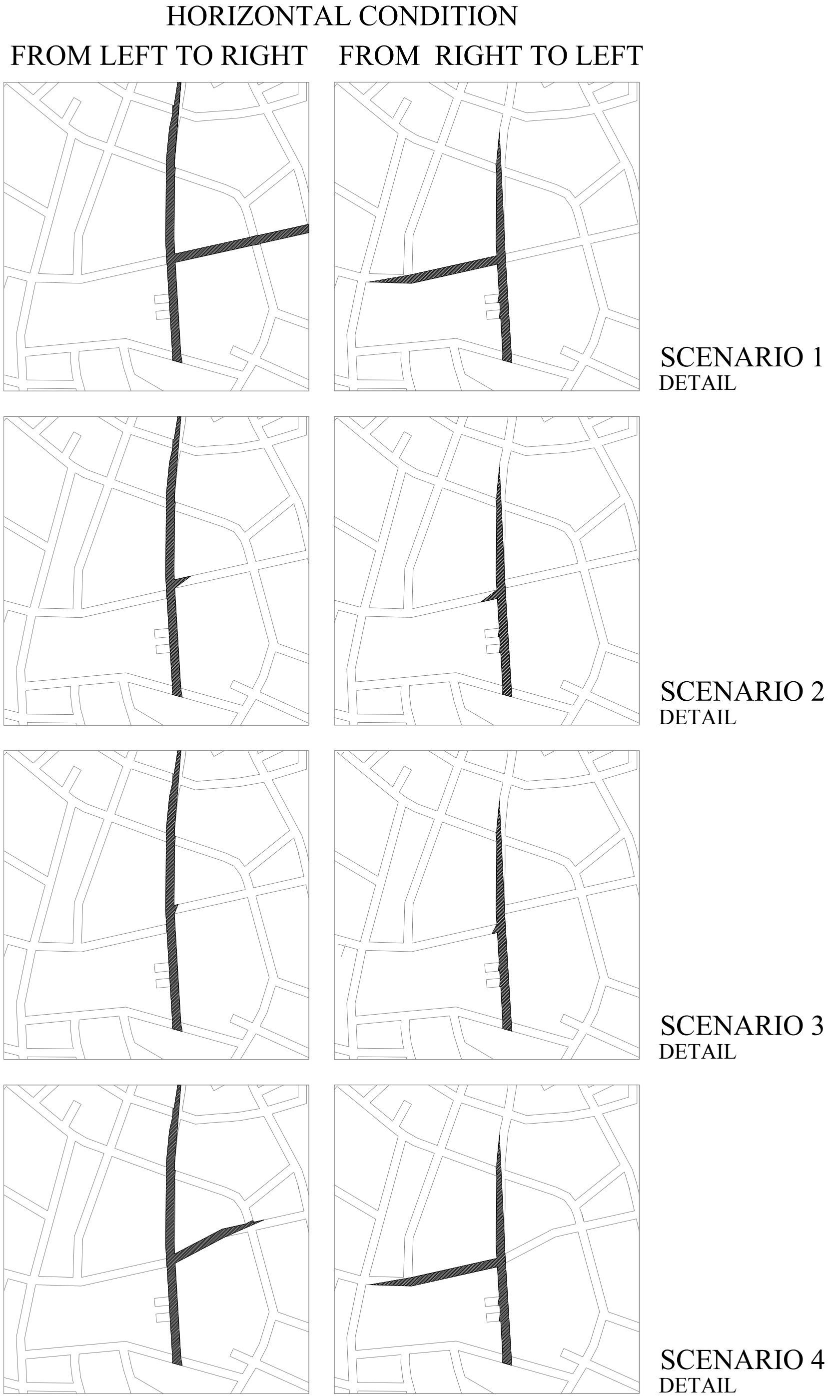


Figure 7.21: Half-isovist at misaligned junctions in scenarios H1, H2, H3 and H4

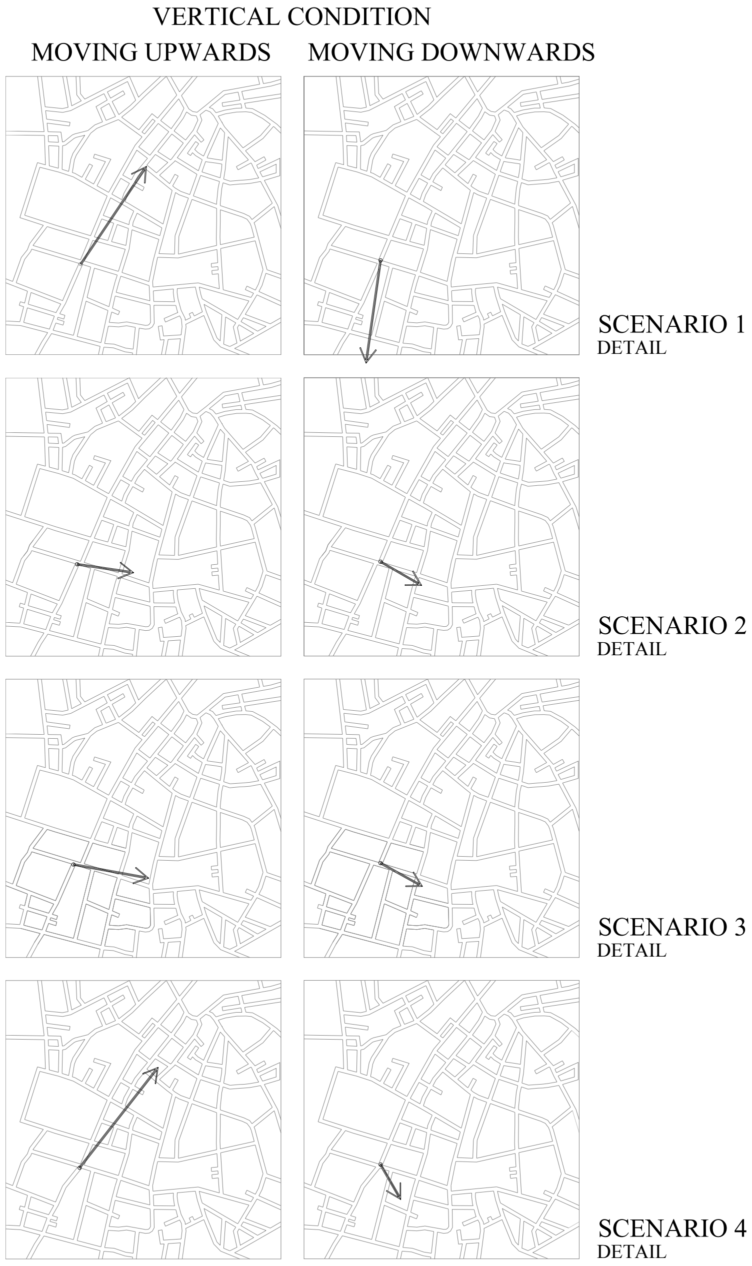


Figure 7.22: Drift vectors for scenarios V1, V2, V3 and V4

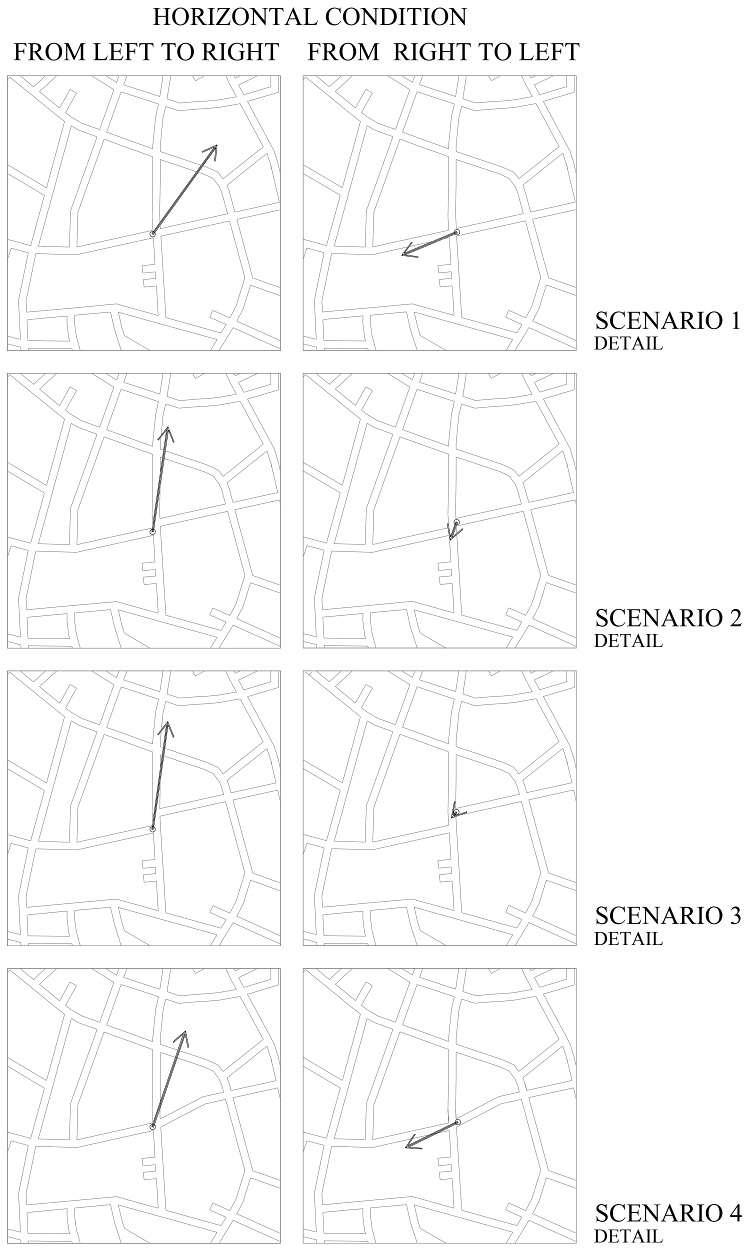


Figure 7.23: Drift directions for scenarios H1, H2, H3 and H4

Table 7.7: Drift categories

Scenarios	Direction of travel	Drift angle (in degrees)	Drift
V1	Left to right	56.1	Forward-moving
	Right to left	262.2	Forward-moving
V2	Left to right	351.7	Turning
	Right to left	330.2	Turning
V3	Left to right	349.9	Turning
	Right to left	331.2	Turning
V4	Left to right	52	Forward-moving
	Right to left	300.2	In between
H1	Upwards	54.5	Forward-moving
	downwards	202.9	Forward-moving
H2	Upwards	81.9	Turning
	downwards	250.7	Turning
H3	Upwards	82.2	Turning
	downwards	229.6	Turning
H4	Upwards	71.4	Forward-moving
	downwards	206.3	Forward-moving

Table 7.8: Degree of synchrony between configurational and metric measures

Mindwalk 30º Analysis	Most used line			Choice (ID)	Conn (ID)	Global Int. (ID)	Local Int. (ID)	Line Length (ID)
	ID	N	%					
V1	3	44	100	4	3	29	3	3
V2	3	38	7.3	4	4,46	29	46	3
V3	3	31	79.5	4	4, 46	29	46	3
V4	4	37	90.9	5	4	29	4	4
H 1	1	43	97.7	1	1	1	1	1
H2	1	38	86.4	4	4, 48	31	41	1
H3	1	30	68.2	4	4, 48	31	41	1
H4	1	39	90.9	1	1	1	1	1

7.4.- Discussion

Results of this experiment point in the direction of this thesis` fundamental idea: that spatial hierarchies are more unanimously retrieved by individuals when metric and configurational properties of space are synchronized. In other words: it is not enough for a line to be the longest of the system: to be perceived as hierarchical this line should be configurationally salient as well.

In addition to these results a new series of interesting issues were unveiled here. The most relevant of them is that slight and major misalignments of salient streets have an asymmetrical impact in people`s hierarchical judgments of networks. Concordant with what was suggested in chapter Six, this experiment demonstrated that people are more inclined to ignore minor misalignments occurring to salient streets than to bypass major misalignments.

To date, this problem has received scarce attention in cognitive studies. This seems to be at odds with the greater focus received by other cognitive simplifications, like those concerned with the aforementioned principle of Good Continuation (Kôffka 1935; Kôhler 1947; Griffin 1948, Klippel, 2007). In that respect, the findings obtained in this experiment can enrich the current discussion about people´s mental strategies to deal with spatial information. So far, this discussion has mainly revolved around the encoding of angular information of space (Tversky and Lee 1998, Montello, 1991), and has suggested that this process is affected by the existence of "natural axes" in the human body. This is the case, for example, of Tversky and Lee, for whom *"the human body, especially our one's own, serves as a natural reference object. The projections of the natural horizontal and vertical axes of the body head/feet, front/back and left/right, are a privileged reference frame"* (Tversky and Lee 1998:65-66). As a result, people would encode spatial information in a simplified (and frequently distorted) way. "*We represent the urban system to ourselves not simply as a discrete geometry, but as a simplified discrete geometry, in the sense that a series of near straight lines of the kind that are commonly found in cities are internally represented as a line, so that the whole system comes to resemble an approximate grid*" (Hillier 2001:22).

The attentive reader might have found a paradox in the argument though. This can be summarized as follows: previous results have suggested that retrieval of hierarchies in spatial networks is facilitated when metric and configurational properties of lines are aligned, meaning that a street would be more easily and more unanimously, perceived as hierarchical if its configurational and metric properties are synchronized. So why, if scenarios Two and Three had identical configurational and metric properties, did people respond differently?

Here it will be proposed that a possible answer lies in how maps are ultimately read. Contrarily to what might be expected in terms of maps being understood in an allocentric way (that is, as seen from the sky), this investigation has suggested that maps are also observed using an egocentric perspective, that is, that subjects virtually navigate on them. There are some precedents supporting this idea. Steck and Mallot (2000), for example, have demonstrated that people normally shift their perspectives when navigating, meaning that they oscillate between employing an egocentric or an allocentric point of view depending to what is more salient in the environment. Huttenlocher and colleagues (1994), on the other hand, have demonstrated that children as young as two can switch their perspectives when exploring the environments by using maps. Lastly, Tversky at al have suggested that subjects not only naturally switch their perspectives of space, but also that *"when people perceived and represent environments, they seem to do so from multiple perspectives simultaneously"* (Tversky 2000:410)

Although scenarios Two and Three were identical from a configurational and metric point of view, they were rather distinct from a navigational point of view. They, in short, provided different types of affordances for those who potentially had to navigate on them (Gibson 1950; Gibson 1979). This seems in agreement with Kuipers` idea of mental skeletons. According to Kuipers (2003), individuals constantly simulate trips in cities by mentally using and leaving primary, secondary and tertiary paths. This means that slight or major misalignments occurring to primary routes of this skeleton would be internalized as "cognitive costs" in people's minds, since these additions would ultimately increase the amounts of steps necessary to access primary routes

Seeing it this way, it seems logical that people responding to scenarios Two and Three in different ways, for the "cognitive cost" of navigating on them was not identical. In fact, while in scenario Two (minor misalignment) a person could still looked ahead, in scenario Three such forward-looking was reduced to almost zero. This hypothesis seems to be supported by the fact that when a diagonal was placed in maps (scenario Four), most individuals outlined again lines H and V as main streets. However, responses were not as unanimous as in scenario One, nor were their fields of view as extended.

To some extent, results here do not only shed light on cognitive theories but also on space syntax`s. Hillier, for example, has suggested that taxi drivers internalize topological costs in a different way than laypersons (Hillier, Turner et al. 2007). According to Hillier, taxi drivers would be less inclined to prioritize topo-geometric factors than metric ones when navigating in cities, meaning that they will use internal and secondary streets more often than non-taxi drivers, producing as a result more complex and broken trajectories. As a result taxi drivers internalize spatial information in a counterintuitive manner (Peruch, Giraudo et al. 1989).

It is tempting to argue that repeated experience of an environment leads people to form a sort of taxi driver reasoning. For example, it is usual that one's highly traversed local routes are not always continuous, or in more scientific terms, one might be more inclined to prioritize the route length over its topological simplicity {Hillier, 2000). Results presented in this chapter indicate that this might be the case, for participants choices of scenarios Two and Three might be interpreted as initial stages of mental representations aiming at ignoring discontinuities occurring in salient paths in order to facilitate their recalling.

Another way to look at this problem is to suggest that subjects were ultimately adopting a categorical reasoning to deal with spatial abnormalities. This seems concordant with long-standing cognitive theories (Simon 1957), as well as with more recent ones (Rosch 1975; Tversky 1992), which have emphasized a qualitative character of human thinking. The next chapter will attempt to put all these ideas into a comprehensive explanatory framework.

Chapter Eight

Discussion and conclusions

Abstract

The aim of this chapter is twofold: first, to summarize some of the most relevant findings encountered in chapters Two to Seven, attempting to insert these findings in a more comprehensive academic context, and second, to present some of the most promising areas of research that could be investigated in the future.

8.1.-Introduction

The initial problem that this thesis attempted to respond to can be summarized as follows: space syntax, as a theory preoccupied with the relation between space and society, has historically maintained that configurational properties of space are fundamental in shaping people`s spatial understanding, but so far has offered little evidence supporting this claim[1]. In other words, even if it has been demonstrated that configurational aspects of space are highly associated with the way in which space is occupied by people (both statically and dynamically), it is yet unclear whether people are mentally *thinking* in configurational terms, since this information is hidden from formal scrutiny. In order to respond to this problem, this thesis showed a series of experiments in which people were asked to retrieve information from maps. The following section will summarize these experiments´ main findings.

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8.2.- A brief review of results

The first experiment was a collaborative work between the Ordnance Survey (Britain´s cartographic agency), University College London and the University of Huddersfield. It aimed to understand whether isovist`s properties (Benedikt 1979; Benedikt and Burnham 1985), could predict people`s problem-solving strategies when employing maps. About fifty subjects were told to indicate their direction of gaze in a two-dimensional map if a given vista were to be seen.

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[1] This idea relates to the circularity problem posed by Montello in 2007, as presented in the first chapter.

Results showed that most individuals used a default strategy consisting of attending to some of the most salient features of maps or vistas, rapidly matching common elements of both sources in order to solve the task. Thus, if for example a high and distinctive tower appeared in a scene, most people rapidly searched for this shape in plans. Despite its popularity, this strategy was neither the most effective nor the most precise manner to solve the problem. Instead, it was shown that those who were guided by the spatial geometry of space, that is, those who seemed to solve the problem attending to isovist properties, made more correct answers than those who didn't.

In spite of the fact that this experiment did not explicitly ask people to retrieve configurational information from a map, it served to understand that relational and geometrical information of space could be employed to solve domestic tasks. Encouraged by these findings, the following chapters modified the way in which maps were presented to people so as to fully tackle this research`s main question.

The first of these experiments consisted of asking subjects to implicitly navigate in a map until finding its *main street*. Three scenarios were defined for that purpose: one in which all lines had the same width (Scenario 1), one in which the widest roads was short and not very well-connected (Scenario 2), and one in which the widest road was the longest and most conncted road (Scenario 3). After completing the task, people were asked to assess the level of confidence of their answers.

Results showed that in Scenario 1, most participants chose sinuous and extended lines as main streets, while in Scenario 2 about 62% of respondents chose the widest line and about 35% of participants chose two highly-connected and extended lines. Finally, in Scenario 3 all but one respondent chose the widest path. At the same time, people's confidence changed according to the scenario being tested. For example, in the first scenario, confidence reached 6.57, whereas in scenarios 2 and 3, this value was 6.27 and 8.07 respectively. It was then suggested that when metric factors are more "aligned" to configurational factors, individuals can retrieve hierarchical information more easily and more unanimously than when metric and configurational factors are not coincident.

Chapter Four further investigated this idea, by asking individuals to outline the main street, the three main streets, and the three most important junctions of an fictitious map. Using Axial, Segment and Continuity Lines analyses to study the network from a configurational and metric point of view, this experiment showed that the Continuity Lines (or Mindwalk) model was more accurate than Axial or the Segment analyses in capturing how people retrieved hierarchical paths. This tendency was also observed in the Mindwalk model itself, as a 30º aggregation threshold was more accurate in predicting people`s choices than a 15º. It was also observed that higher correlations between behavioral and spatial data were found when three, rather than one, street had to be chosen.

Apart from these findings, this experiment served to support the central idea of this thesis: that retrieval of hierarchies in maps is simplified when configurational and metric factors are synchronized.

Chapter Six continued this line of enquiry, by asking to people to mark the main street, the three main streets, and the three most important junctions of three maps that looked alike but whose configurational and metric characteristics differed. After examining the maps using some of the spatial models employed in the previous chapter, and comparing these properties against people`s answers, it was discovered (again), that hierarchical information is more easily retrieved by people when configurational and metric aspects of space are syncronized. It was also shown that people´s answers were more subjective and more difficult to predict when no coodination existed between configurational and metric properties. Another finding of this chapter regards the effect that minor and major misalignments occurring in salient paths produced in people. It was shown that slight misaligments occurring to highly distinctive paths (in terms of their configurational and metric properties), tend to be ignored by people, but major misaligments are less likely to be treated in this way.

The last experiment, shown in chapter Seven, investigated the consequences of misaligning configurationally and metrically salient paths. It asked more than three-hundred participants to mark the main street of eight maps belonging to two conditions. In order to measure the relative *weight* of metric and spatial factors in shaping how people retrieved hierarchical information from maps, in this experiment metric and configurational factors were put in opposition in two scenarios, which means that while in scenarios 1 and 4 the longest line was the most connected line, in scenarios 2 and 3 this was no longer the case, for the longest line was not the most connected one.

The main findings showed that responses made by individuals were more heterogeneous in scenarios 2 and 3 than in scenarios 1 and 4. Since the same ocurred to people´s self-confidence it was argued, again, that the concordance of metric and configurational factors allowed people to retrieve hierarchical information from maps in a (seemingly) straighforward manner. However, this experiment also showed that even when configurational and metric properties of maps are identical, people paid attention to navigational properties of maps, meaning that people`s answers were more homogeneous and their confidence higher, when highly salient lines (configurationally and metrically) allowed would-be travellers to see as far ahead as possible. This led to the suggestion that people might not be reading maps from an alocentric perspective, but from an eggocentric one.

To summarize, the main findings of this thesis are:

- Retrieving hierarchical information from maps is simplified when configurational and metric variables are synchronized. This means that people will identify a line as being strategically important if this line is extended and configurationally distinctive.
- In such circumstances, people´s answers will tend to be homogeneous and their confidence high. When this is not the case, peoples´s answers will be more hetereogeneous and their confidence will lessen.

In conjunction with this finding, this thesis has shown that:

- When asked to retrieve hierarchical information from maps, people do not only assess configurational and metric information, but also geometrical information. This means that, to be considered important, paths have to be as linear as possible.

- Misalignments and forked road-junctions ocurring along configurationally and metrically distinctive paths (which, according to what was stated before will be perceived as important by people), will induce some degree of uncertainty in subjects. However, when misalignments are relatively minor, people will tend to ignore them, forming as a result slighlty non-linear or meandering paths. When discontinuations are more substantial, people will perceive these routes as forming truncated and hence shorter, yet more linear paths.
- Retrieving hierarchical information from maps does not only demand people to assess configurational and metric information, but also to evaluate how easy it is to imagine yourself (perspective taking) navigating through these maps. This seems to indicate that maps are not read by people purely from an allocentric perspective, as if they were seen from the sky, but from an e~~g~~gocentric perspective, meaning that people seem to virtually *navigate* on them (Huttenlocher et al, 1994; Tversky 2000).

8.3.- The need for explanatory theories: towards a cognitive syntax

In 1972 Chomsky argued that (Chomsky 1972:24). *"one difficulty in the psychological sciences lies in the familiarity of the phenomena with which they deal. One is inclined to take them for granted as necessary of somehow ¨natural¨"* Unlike mathematics or physics, Chomsky argued, where some of the basic discoveries are beyond the sphere of human intuition (and hence are somehow ¨unveiled¨ by the expert), behavior regarding human reasoning normally lacks novelty and often is “taken for granted“. They are considered, in synthesis, as *facts* and therefore are frequently ignored from a scientific scrutiny
Another characteristic of familiar phenomena, Chomsky said, is that we do *need* to explain them (they are ultimately “there”), and that we tend to think that explanations are transparent and shallow when in fact they are not. He suggested

instead that cognitive processes are deep and sophisticated mechanisms that should be treated as comprehensively and seriously as phenomena coming from mathematical of physics. He then advocated the necessity to construct explanatory theories of natural processes. *"The search for theories must begin with an attempt to determine the system of rules and to reveal the principles that govern them"* (Chomsky 1972:26)

In some ways Chomsky`s ideas summarize the main question of this thesis. Aiming to see if some of the regularities between spatial configurations and movement patterns in cities and buildings (Peponis, Hadjinikolau E. et al. 1989; Hillier, Penn et al. 1993; Hillier and Iida 2005), have cognitive correlates, this thesis has ultimately dealt with a natural phenomena; how individuals perceive hierarchies in maps, in order to respond to an elusive question; how configurational information is mentally apprehended by people.

Space syntax has so far responded these questions obliquely. Using an elegant and sophisticated argument, it has argued that spatial understanding in people starts by what it might be called an enactive process, in which people attend to two spatial laws, the law of centrality and the law of visibility, in order to construct spatial layouts like cities, and then by what it might be called an emergent process, by which people would use those most connected paths of these networks. This, says Hillier, would give rise to an economy of movement (Hillier, Penn et al. 1993), one in which *"configuration is the primary generator of pedestrian movement, and, in general, attractors are either equalisable or work as multipliers on the basic pattern established by configuration"* (Hillier, Penn et al. 1993:31). But how do these enactive principles emerge?

So far, space syntax has responded to this question by making suggestive statements. Such as *"the fact that our minds recognized configurations () shows that our ability to recognize and understand configuration is prior to the assignment of names"* (Hillier and Hanson 1984:2), or *"the spatial configuration is at the root of the way we cognize built environments"* (Young Ook and Penn 2004:502). In the same vein, Penn (2003) suggested that a "cognitive space" exists in the mind, and that this reasoning is concerned with topological, rather than metric, properties of space. Hillier (2003) on the other hand, has affirmed that topological and metric aspects of space are mentally “organized” in order to arrive to a mental representation of the environment. To Hillier, this process is executed unconsciously by people by directly experiencing the environment, thus becoming a sort of “fact” that permits them to synchronize the conceptual (how people infer the overall structure of the world) and perpetual (how people visually perceive the environment).

Here it will be argued that none of these ideas permit to a full understanding of how configurational information is internalized in people. Further, it will be contended that so far these ideas have yet not progressed towards what it might be called a cognitive syntax: a system of heuristics and theories aiming to explain how people internalize configurational information in their minds, and how such a process affects navigation in real-world scenarios. One exception in that regard is Conroy-Dalton´s British Library`s theorem (Conroy-Dalton 2003), which stated that, all other things being equal, people would select paths whose first leg deviates as few as possible from their destination.

This thesis has attempted to (at least partially), fill this gap. By proposing that configurational dimensions of space gain opacity, that is, are brought into foreground when these dimensions are put in opposition to metric factors of space, this thesis suggested that the seemingly innate human ability to retrieve spatial hierarchies, is in fact a rather complex and sophisticated cognitive mechanism. This is due to the fact that this mechanism is based on an assessment of the degree of synchrony between metric and configurational factors of salient, distinctive streets. The obvious question is nonetheless: How does this mechanism work?

In order to respond to this question, a heuristics will be proposed (see figure 8.1). This proposes that the retrieval of hierarchies in maps is a process affected by three aspects: the perception of cartographic conventions or distinct street widths placed on certain lines in a map, the perception extended lines in a map, and the assessment of configurational information of these lines. This is to say that people will first notice whether some lines are wider or have been coloured in such a way that they look relevant (e.g they are painted in red), in order to form an initial idea of these lines´ relative importance in the network. Although these processes are automatic (they are visual processes of pre attentive nature), they are at the same time non-innate mechanisms, meaning that they have had to be learned at some point by people.

The second process, which is also of a pre-attentive character, consists in the identification of longer paths in a map. A crucial role in such process is played by the Gestalt`s principle of Good Continuation, which enables individuals to ignore slight turns occurring to streets, so to construct larger and sinuous paths. In spite of its pre attentive nature, the identification of extended paths is to some degree less discursive than the identification of wider or coloured streets. This is because the former process is not necessarily a convention, that is, is not necessarily defined as a part of a set of arbitrary principles that people have to obey to understand a map. Instead, longer streets seem to be perceived as important because, as Hillier has suggested, they tend to provide individuals of non local information about an environment. In that respect, it seems of no surprise that people tend to consider extended paths as important, after all, experience has taught them that longer paths are frequently the well-connected ones.

The final process refers to the assessment of the configurational information of long lines. This is probably the key issue in this model, for here it has been argued that, rather than mentally assessing the importance of configurational aspects of these lines as such, what people do is to evaluate to what extent there is a synchrony between metric and configurational factors in these lines. This means that people will consider that line X is a main street if, apart form being a long street within its context, line X is also a well-connected and integrated path. People will then retrieve non local information of salient lines in order to make their judgments.

The model suggests that when persons are asked to retrieve hierarchical information of spatial networks, they will assess these three dimensions in an iterative way, forming mental hypotheses about the relative importance of each path. It will be argued that these interpretations will fall in two main zones. If no contradictory information exists between any of the aforementioned spheres, that is, if the widest or most cartographically salient line is at the same time the longest and most connected and/or integrated one, people`s answers will move into what it has been called their "comfort zone" (see triangle at the centre of figure 8.1). This zone will be characterized by a high consensus among individuals, as well as by high levels of confidence. This is to say that subjects will respond to questions regarding hierarchies in simple and uncomplicated manner, as if they were responding to some common sense, obvious queries. To put it another way, if there is no synchrony between the metric and the configurational properties of salient streets, groups will not arrive to what Surowiecki called *collective wisdom* (Surowiecki 2004).

According to Surowieki, there are some kinds of problems, like for example the identity of the next winner of a well-known tournament, which are normally better solved by the collective wisdom of groups, than by the individual judgment of most of the participants of these groups. *"An intelligent group, especially when confronted with cognition problems, does not ask its members to modify their position in order to let the group reach a decision everyone can be happy with. Instead, it figures out how to use mechanisms-like market prices, or intelligent voting systems- to aggregate and produce collective judgments that represent not what one person in the group thinks but rather, in some sense, what they all think"* (Surowiecki 2004:XIX). Seeing it this way, the mechanism by which people retrieve hierarchical information of networks seems to follow the logics of a collective wisdom, for this mechanism does not belong to any particular individual, but to hundreds of subjects working anonymously.

According to the heuristics proposed in this thesis, when the metric and the configurational properties of salient lines existing in a map are not synchronized, subjects will enter a so-called "ambiguous zone". In this zone, participants' choices will be more subjective (or less predictable), and at the same time, participants` self confidence will decay. In sum, the notion of collective wisdom will not take place. Both chapter Four and chapter Seven showed that this might be the case.

Surowiecki contends that one of the problems of collective wisdom is that nobody knows how it is formed. This is because collective wisdom is basically non discursive, meaning that no formal agreement between participants is necessary to create it. It is therefore taken from granted. But as it happens with other trivial phenomena, the real wisdom of groups emerges precisely when it is not possible to take this wisdom for granted, when it ceases to exist.

The way in which configurational knowledge operates and gains “presence” seems to follow this pattern. Configurational knowledge is ultimately an understanding that is “there” most of the time in a silent, non discursive manner, but that emerges when spatial systems are dissonant, when the *natural order of things* is altered. How and when does this order emerges? Who forms it?

One interesting clue to respond to these questions might lie in Maturana and Varela`s idea of autopoiesis, which contents that living systems are circular machines that can be described as units of interactions; they exist in a constant negotiation with their environments. In order to maintain their circularity, the authors sustain, living systems should maintain *certain types of interactions* with their environments, otherwise they will collapse. This means that interactions are to some extent predictable, although these predictions are not about particular events but about kind of interactions. Thus, livings systems are cognitive structures, in the sense that their domain of interactions define them as such; *"living systems are cognitive systems and living as a process is a process of cognition"* (Maturana and Varela 1980:13).

These ideas seems to be coincident with that of Lakoff`s (1999), who declared that any mental operation, either conscious or unconscious is cognitive, and that human reasoning is fundamentally categorical. *“Living systems must categorize. Since we are neural beings, our categories are formed through our embodiment. What that means is that categories are part of our experience. They are structures that differentiate aspects of our experience into discernible kinds"* (Lakoff and Johnson 1999:19).

But not all categories are identical, said Lakoff. For example, the category furniture includes, among other elements, sofas, tables, chairs and desks, whereas the category table regards one specific type of furniture. The latter are called basic-level categories, that is, categories where a prototype (Rosch 1975), or an element representing the quintessential nature of its group, is more likely to be found. Basic-level categories have four properties: they are easily imaginable (persons can rapidly access a mental representation of them), they have similar shapes, they involve the same type of interaction (most persons interact with such category in similar ways), and finally they are the level at which knowledge is organized in our minds.

Interestingly, Lakoff affirms that humans interact more unanimously and efficiently with basic-level categories. They are *“the basic level is that level at which people interact optimally with their environments, given the kind of bodies and brains they have and the kind of environments they inhabit"* (Lakoff and Johnson 1999:28).

Here it will be argued that the concept of spatial hierarchy is in fact one of these basic-level categories, one that involves the convergence of metric and configurational aspects of networks. It is, in other words, an idea with which people *think with, rather than an idea with which people think of* (Hillier and Hanson 1984). *“Ideas we think with are everywhere, but we do not experience them: they structure out thought and actions, but we have forgotten the existence. The trick of out culture it might be observed, lies in the way the artificial appear natural”* (Hillier and Hanson 1984:193). But why do people arrive at this understanding?

A suggestive line of thought suggested that spatial reasoning is ultimately embodied (Varela, Thompson et al. 1993; Kövecses, 2000; Edelman 2006; Clark 2007), that is, that a person’s perceptual apparatus is somehow shaped by his or her bodily capacities. It follows then that to move in the world is a cognitive *and* a physical act, and that to reason about the environment would be equally shaped by some physical constrains. “*By using the term embodied we mean highlight two points; first, that cognition depends upon the kinds of experience that come from having a body with various sensorimotor capacities, and second, that these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological and cultural context”* (Varela, Thompson et al. 1993:173)

Two main consequences, one emergent and one enactive (Varela, Thompson et al. 1993), results from this idea. First, that Hillier`s idea that cities have a generic structure (the deformed wheel), which permits the encounter of visitors and inhabitants in the public realm and, at the same time, facilitates the movement of people and goods, makes perfect sense. After all, the deformed wheel capitalizes a basic human behavior consisting in moving linearly. Second, that movement is basically linear, as demonstrated by Conroy-Dalton (2003), could be understood as an elementary cognitive operation, one that would permit people to understand their worlds, for long streets tend to be well-connected ones. In short, it is argued that the fact that most people are more effective in identifying a street as important if the metric and configurational properties are concurrent, is not arbitrary but belongs to the most profound part of their cognitive capacities, one that considers spatial hierarchies as a basic-level category. Seeing it this way, the compelling question that in the first chapter asked Is there a syntax in our minds? could be responded here with an enthusiastic YES!, but rather than being a competition between metric an configurational factors, it is a coordination of them (see figure 8.2).

From a cognitive point of view, the ideas proposed here are concordant with recent investigations in neuroscience (Kelso 1995, Ibañez, 2008; Thomson 2007). Kelso, for example, has suggested that people`s cognitive apparatus is intrinsically unstable and dynamic, meaning that a given behavioral pattern (as per the identification of a main street in a map) depends on the coordination of two or more parameters. Once these parameters are reached, Kelso argued, a new behavioral pattern emerges. Furthermore, Kelso suggested that cognition is, above all, a problem of coordination between different processes, *"There is a fundamental need to understand the most complex systems of all, ourselves. Even the most ardent reductionists now admit that the brain cannot be understood solely on the basis of the chemistry and biophysics of single cells, But there is a huge void in out knowledge of what single cells do versus many of them do when they cooperate. That's why is crucial to discover the laws and principles of coordination of living things. It is coordination that lies at the root of understanding ourselves and the world we live in"* (Kelso 1995:288).

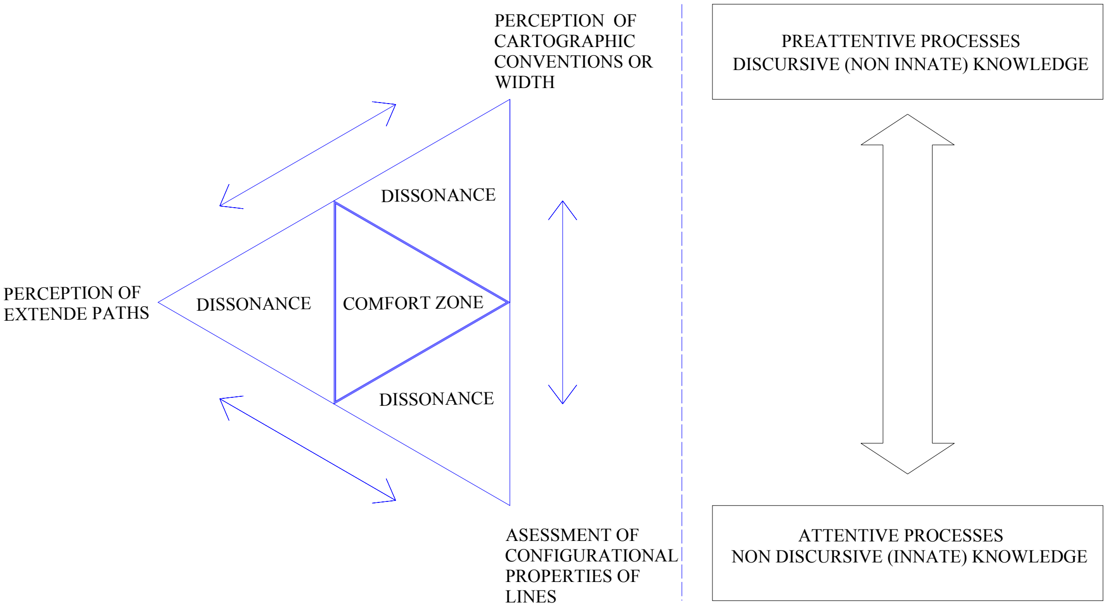

Figure 8.1: the heuristics proposed in this thesis

8.4.- Some implications of this research

Without doubt, the heuristics presented here might be of interest of cartographic theorists, especially of those theories that consider that map understanding is a resultant of the operation of cognitive, visual and lexical processes (MacEachren 1995). According to this view, a map is not a device that has to transmit a given message to its users (Robinson 1952), but rather, a complex artifact whose role is to trigger cognitive operations in people. So far, these operations have been mainly focused on visual (Gestalt principles or Marr`s 2,5 primal sketch), and semantic aspects of mapping (coloring, lettering, style, cloropeth distinctions), with scarce, or no attention paid to the role of configurational information. In that respect, this thesis then could be read as an attempt to insert configurational issues directly into the core of cartographic theory.

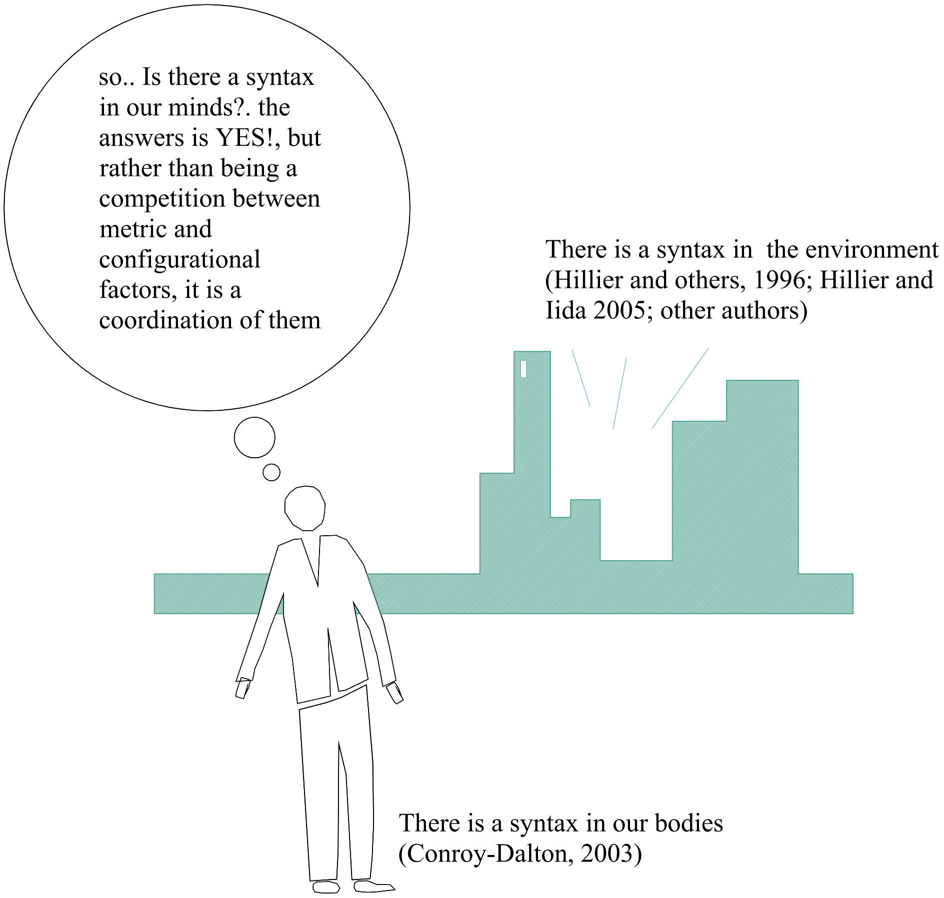

Figure 8.2: this thesis’ fundamental question

From a practical point of view, this thesis’ findings could also serve to improve existing guidelines for map design, especially those that require individuals to infer qualitative information from spatial networks. Furthermore, the fact that this thesis demonstrated that the retrieval of hierarchies is a dynamic process that needs the participation of metric, configurational and cultural aspects, might serve to improve automatic navigational devices, in terms of refining the verbal or pictorial representations they provide to users.

But this thesis also hopes to enrich space syntax theory. To date, space syntax has mantained that spatial understanding operates in a similar way to speech, that is, that humans silently absorb the “laws” that permit them to create meaningful sentences and, in the meantime, to discard meaningless phases. Reminiscent of Chomsky`s universal grammar (Chomsky 1966), this view assumes that if a common spatial language has to exist, it must be innate, given that for a discrete number of spaces there is always a large a number of possibilities to arrange them, but a far more stringent way to make these combinations meaningful. Hence, humans have to learn how to make spatial statements meaningful in the same way that they learn how to make phrases comprehensible. Hillier`s words *"the set of combinatorial principles is the syntax. Syntax is the most important property of morphic languages"* (Hillier and Hanson 1984:48)

Here it has been argued that meaningful morphemes are a product of a circular mechanism in which some combinatorial arrangements are perceived as unambiguous and logical, whereas others are perceived as equivocal and unfocused. What ultimately determines if a morpheme like the term main street would be, or would not be, perceived as a meaningful statement, is the interaction between this morpheme`s metric and configurational factors. To be more specific: what determines if people perceive the spatial morpheme *main street* as a meaningful morpheme, will be determined by this morpheme's degree of alignment between metric and configurational aspects.

8.5.- Ideas for future research and applications

Since this thesis is coming to an end, it seems logical to look back to what was done and propose some methodological and conceptual improvements, as well as possible lines of research for future investigations.

First, it should be said that the methodology developed and progressively refined in each chapter proved to be a reliable, simple and economical technique for revealing how people retrieve hierarchical information from networks. Proof of that is the fact that more than seven-hundred participants took part in this research.

A straightforward improvement of this technique would be nonetheless to use web-based platforms for experiments, rather than paper-based questionnaires. This could increase both number of participants and type of scenarios to be tested, thus improving the understanding of how cartographic, visual and configurational aspects of space interact in forming a person's spatial hierarchies. An additional advantage of web-based experiments is that they could analyze behavioral data automatically, thus freeing future researchers of a time-consuming, painstaking transcription. Also, these methods could expand the scope of analysis, incorporating a wide rage of angles of aggregation, and not only the ones employed in this thesis, to explore how people retrieve spatial hierarchies in networks.

But while asking people to outline the "main street" of a map, seemed to be an effective method to know how hierarchical information of networks is retrieved by people, the same cannot be said of the question that asked individuals to outline important junctions in maps. As it was shown, judging the relative importance of junctions is a process not only shaped by metric and configurational factors, but also, by some visual ones, which operate simultaneously with the principle of Good Continuation. Future efforts could then investigate the issue in a deeper way, making use of sophisticated techniques, like eye-tracking, or immersive scanning (Spiers and Maguire 2006), to reveal such phenomena.

But if investigating how subjects retrieve hierarchical information from maps seems to be an interesting but still relatively unexplored field, to know how these representations are employed by subjects in their daily lives (or in other words, how they are translated to reality), is likely to bring even more fascinating results. As Hillier put it: *"how far do these cognitive realities intervene in the functioning of the urban system?* (Hillier 2001:02.27).

Based on the results observed in this thesis, several questions can be formulated:

- How do movement patterns take form in dissonant spatial systems?
- What is the effect of such dissonance on a city`s land uses?
- How does the convergence of metric and configurational factors in cities relate to the idea of urban buzz?
- How do people experience minor deviations occurring in grids? When does a person start perceiving that slightly misaligned street is a continuous one? Does this ever occur?

- How do unfamiliar subjects internalize such discontinuations in real cities?
- How would metric and configurational information of spatial networks interact in order to permit persons to retrieve hierarchical information of more regular spatial networks?

Here it will be argued that results found in this thesis might serve to understand some recursive but puzzling behaviors observed in real life. For example, it is often the case that when persons had to travel the same route several times, they are unaware minor discontinuations of streets as those shown in chapter Seven, and move forward as if they were moving linearly. The same can be said of many taxi drivers (Peruch, Giraudo et al. 1989), who seem to be more inclined then the general public to prioritize metric, over topological, aspects of space. Results observed indicate that minor discontinuations do involve a *cognitive cost* in most persons, but that this cost might be ignored depending on some circumstances.

Another application of this thesis results` is city planning. As it demonstrated, subjects can identify more confidently and unanimously a main street in a map if such road is extended and connected than if any of these requirements is not achieved. Planning agencies might wish to take into account how people understand spatial systems when designing cities, so as to help citizens to apprehend their urban structures as much as possible. Moreover, some authors (Marshall 2004) have argued that so far no clear, unambiguous guidelines exist in urban theory about the ultimate properties of hierarchical streets. This, according to Marshall, has produced a theoretical vacuum in the discipline that has impeded the definition of guidelines for the construction of more pedestrian-centered streets. Future research could explore the issue in depth, attempting to link some of the results obtained in this thesis with necessities of planning agencies.

Lastly, it is expected that the methodological and conceptual improvements outlined in this research contribute to the fruitful and promising dialogue between space syntax and spatial cognition in order to discover the cognitive roots of space syntax.

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