The Impact of Urban Geometry on Cognitive Maps

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Submitted to the Department of Architecture
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ABSTRACT

This thesis investigates the relationship between urban geometry and cognitive maps. It is focused on the question of how human cognition of the built environment is affected by urban geometry. Building on the foundations of Kevin Lynch's studies of environmental perception (Lynch, 1960) and recent configurational measurement techniques of the built environment, it addresses an important question that Lynch has left unresolved: Why do people have more complete recollections of some parts of the urban environment, and not others?

This thesis proposes an analytical measurement framework based on graph theory to compare the results of cognitive maps with objective spatial properties of the corresponding built environment. In order to test our hypothesis, first I measure and define urban geometry based on graph theory in two selected areas with different geometries in Kenmore, Boston and Kendall Sq., Cambridge, MA I will then collect cognitive maps based on specifically designed map drawing surveys. Finally, I examine the relationship between graph results and cognitive maps in order to identify the ways that urban geometry affects human perception.

The findings inform urban designers and scholars of the city of how the configuration of the built environment can affect people's memory of a place, thus shaping one's experience of a city.

Keywords: configurational patterns, urban geometry, cognitive maps, graph theory.

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INTRODUCTION

The relationship between spatial structure of the built environment and social behavior has always been one of the central debates in urban planning. Researchers have studied the effects of the built environment on social indicators such as travel behavior, energy expenditure, and public health (Sevtsuk, 2010; Hillier, 1984; Forsyth, 2008). Among different aspects of the built environment, certain studies found that these social indicators are affected by urban configuration and its geometry; however, the relationship between street patterns and perception has not been much explored. Kevin Lynch studies people's perception based on certain characteristics of the city to explore how people remember paths, edges, districts, nodes and landmarks. Lynch's research focused on large neighborhood or whole districts of a city. This thesis takes a closer look at particular locations in Boston. Rather than focusing on a large set of two- and three dimensional attributes of urban form, it takes a more nuanced look at one attribute of city form- its street patterns.

In this thesis, I investigate whether and how the geometric pattern of street networks influence people's ability to remember the built environment they routinely use. Based on studies in Wayfinding and cognitive geography, I derived some hypotheses that suggest how different geometrical characteristics of street networks might interact with mental recollections of a place. For example, the first assumption is to test if continuous streets are more easily remembered than interrupted streets. To test different hypotheses, I chose two particular areas of Boston and due to their diverse street geometries, asked a sample of 15 residents in both areas to complete the street network in a specified area of a corresponding map that was left blank.

The literature in environmental perception and configurational studies has its root in Kevin Lynch's investigation into cognitive maps, Space Syntax theory in geometrical analysis and theories of cognitive geography. (Lynch, 1960; Hillier, 1996; Gell, 2009) (Figure 0-1) Kevin Lynch's legacy in studies of people's perception and certain characteristics of the built environment explained that some places had better images than others. For instance, he stated that New Jersey did not have as "good" image as Boston: "The evident low imageability of New Jersey was reflected in the image held even by its long-time residents, and was manifested in dissatis-

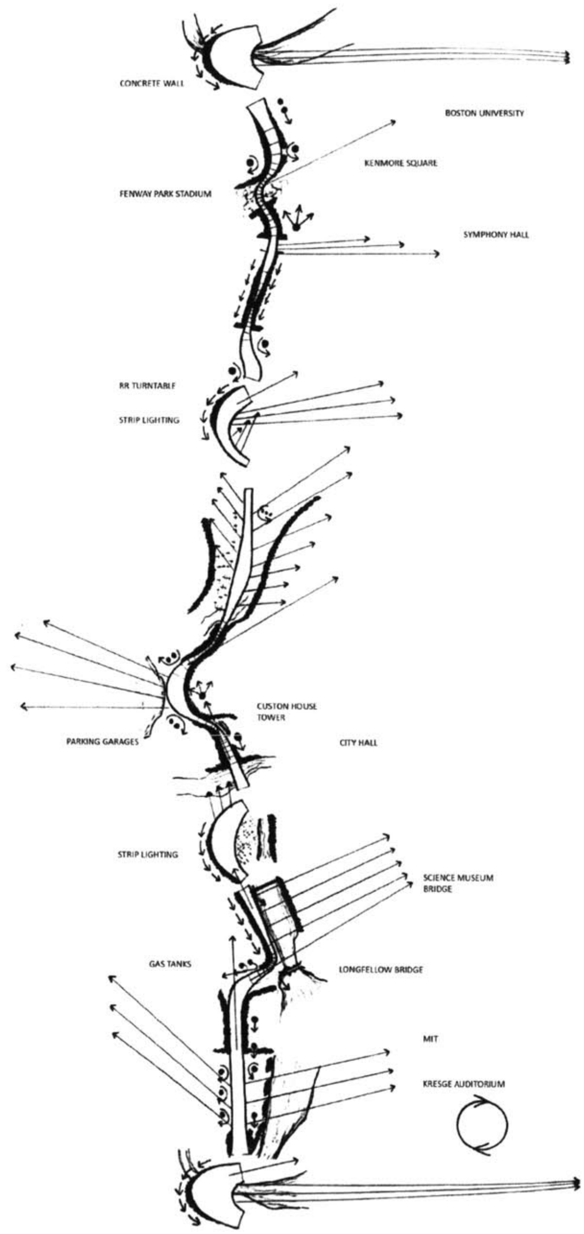


Figure 0-1. Cognitive map - View from the road (Appleyard, 1964, P. 38).

faction, poor orientation, and an inability to describe or differentiate its parts." (Lynch, 1960; 32) This brings in mind the question of what is a good image of a place? How can good be defined?

Rather than confronting this ambiguous question, this thesis focuses on the "completeness" of people's recollection of a place. I emphasize the completeness of cognitive maps and their relation to people's perception of street patterns. Completeness of maps does not necessarily imply better city designs. For instance, grid street pattern in Manhattan can be easily remembered, where it might not indicate a remarkable urban design project. The "completeness" of people's memory of a place, however, can be more readily articulated. It is relatively straight- forward to describe how thoroughly subjects were able to recall particular streets. The "completeness" of mental maps tells us the extent, to which certain street properties can influence people's perception of street networks.

Lynch has also grounded his studies on the scale of the city, investigating how people in different neighborhoods understand paths, edges, districts, nodes and landmarks (Lynch, 1960; 47). In "*Image of the City*", he argues that the environmental image is the most significant link to find one's way in a city. This image is the product both of sensation and of the memory of the past experience. He mentions legibility and imageability of the city as basic parameters, by which people perceive their environment (Lynch, 1960; 4, 9).

Thesis Framework

This thesis investigates how different streets patterns are related to different cognitive or mental maps, which represent how people encode and decode their built environment. In consequence, similar to Kevin Lynch's studies on cognitive maps, I ran surveys and asked residents of selected areas in Boston and Cambridge to draw street patterns based on their memory. I then examined the actual street patterns and evaluated the

Figure 0-2. The spatial structure of open space and its axial representation (Hillier, spacesyntax.com)

completeness of cognitive maps, testing hypotheses that I suspect could impact people's ability to remember geometric configuration of street networks.

The scope of this research relates to two bodies of literature: cognitive maps and street pattern analysis. The literature on people's perception of the built environment and the relationship of psychology in urban planning has its origin in the works of Downs and Stea, followed by Kevin Lynch, Appleyard, Gell and Golledge (Lynch, 1960; Appleyard, 1964; Gell, 1985; Golledge, 2003). "Research on human spatial orientation (wayfinding) has centered on two conflicting theories: the 'mental map,' whereby humans build abstract cognitive representations of the spatial relations between objects and 'practical mastery,' which rejects the idea that such abstract presentations exist and, in its most developed form, suggests that wayfinding is a process of moving from one recognized visual perspective to another." (Istomin and Dwyer, 2009)

Figure 0-3. Alternative paths - Hillier (Sevtsuk, lecture notes, 4.242J/11.331J).

The literature of street pattern analysis is grounded in various analytical tools to evaluate spatial networks such as Marshall's work on streets patterns (Marshall, 2005), Space Syntax tool to analyze axial lines (Hillier, 1984), and Porta's ideas to employ graph theory to evaluate street networks (Porta, 2009). For example, Space Syntax works on geometrical analysis of the built environment based on axial lines that can be traced back to graph theoretical studies of the built environment (Figure 0-2, 0-3). This analysis represents each street as a graph link and each node as a street junction.

This research, therefore, questions the relationship between cognitive maps and the geometry of street patterns to test how different geometrical characteristics can change people's perception of the built environment. This thesis will then test its hypothesis based on empirical experiment in two case study sites.

The following points are different assumptions based on geometric characters of street networks, which I am going to test by comparing them with cognitive map results, which will be completely described in chapter 3.

In the first chapter, I am going to describe and expand the notion of human perception of the built environment by means of cognitive maps. In this chapter, I will also explain the literature on human perception and Kevin Lynch's work on cognitive maps in more detail. The second chapter discusses urban geometry, street configuration and its relationship to different types of street patterns. As a result, this chapter is concerned with how the geometry of streets can be overlaid as graph links and nodes to describe their properties with certain rigor and precision.

The third chapter represents the methodology for the street analysis and empirical study comparing maps drawn by respondents to characteristics of actual streets. In the final chapter, I will compare the empirical results of the selected sites in Kenmore, Boston and Kendall Sq, Cambridge to test the correlation between street geometry and complied cognitive maps. To compare the cases, I set constraints on other factors affecting cognitive maps by selecting areas with a similar size, street pattern and land use distribution.

The results of this research suggest the importance of understanding the effect of street patterns on cognitive maps in planning and design of the built environment. Different urban geometries are shaped by size, spacing, angles of the physical infrastructure of cities, which influences people's perception of a city. The spatial form of the built environment is composed of configurational patterns of paths and street patterns in a city. For instance, Andres Sevtsuk in his PhD dissertation at MIT investigated the reach to the built environment in Cambridge, MA to explore the impact of the distribution of retail services on land values (Figure 0-5).

This configuration has an impact on people's perception of the built environment. Paraphrasing Leslie Martin, "The pattern of the city sets out the rules of the game, but players should have the opportunity to use

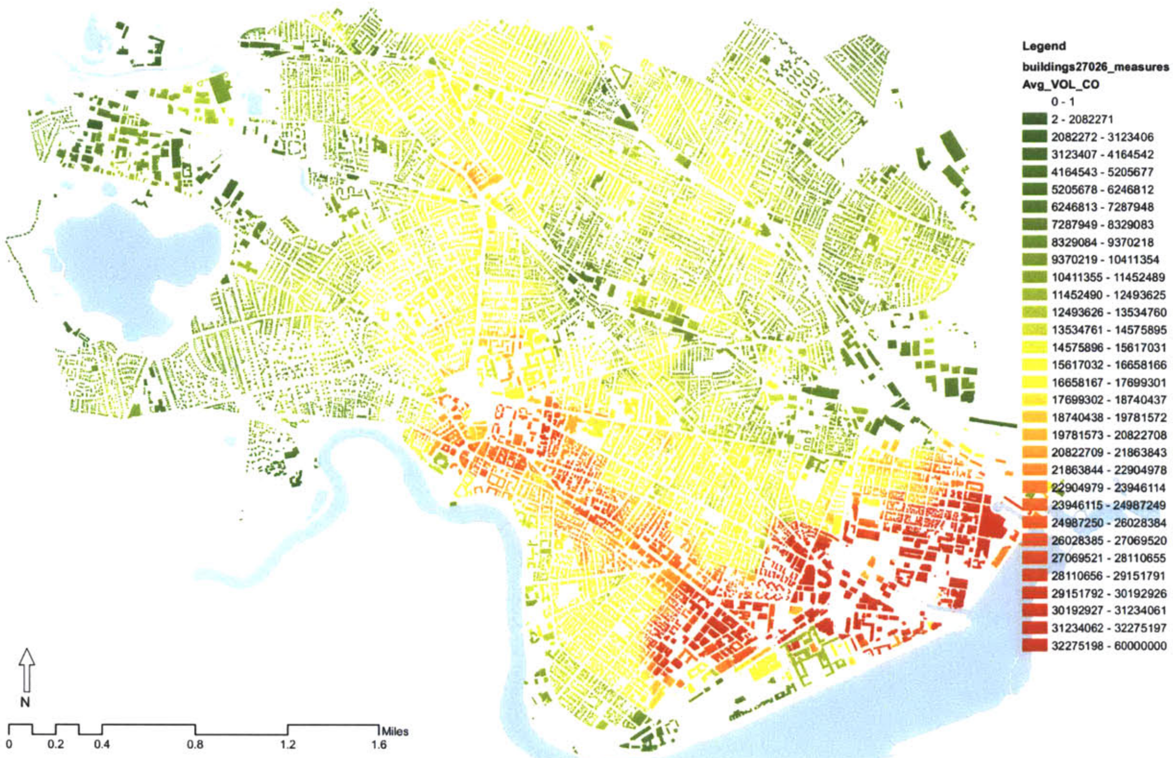


Figure 0-5. Reach to the built volume in Cambridge, MA - Andres Sevtsuk PhD dissertation (Sevtsuk, 2010, p. 85).

their individual skills whilst playing" (Martin, 1972). Yet despite extensive investigations, the relationship between legibility and physical characteristics of the built environment still remains poorly understood.

Addressing this gap, this study investigates the level of completeness of cognitive maps under variable street patterns. I assume that the geometry of street networks expresses the image of the built environment in people's minds, where its impact can be traced in people's cognitive maps from areas with different geometrical properties. Further research in this area can be focused on expanding the detailed survey in other districts in Boston and in other cities, with different street patterns.

CHAPTER 1

CHAPTER 1: COGNITIVE MAPS

1-1- Cognitive mapping

Downs and Stea (1977) explain cognitive mapping as a psychological process, by which individuals recall, code and decode their built environment. "This knowledge includes the knowledge of routes and the location of key environmental features." (Sanoff, 1991; 76)

Cognitive mapping is defined as an abstraction, which covers mental abilities to remember the built environment, whereas a cognitive map is a product to arrange this representation. Downs and Stea identify two main concepts of cognitive maps as *representation* and *environment*. A representation depicts a mental image, which is a simplified model of the environment. Environment by its own is a general term, which should be focused on one of its aspects such as the built environment or street geometry in this study. Cognitive maps give people the ability to understand where and how to reach their destination (Downs and Stea, 1977; 6). Cognitive maps can therefore, exert an important influence on spatial navigation and comprehension in the built environment. In this thesis, I am interested to test the impact of street patterns as an environmental property on people's perception.

Cognitive mapping is known as a spatial problem solving method, since it represents how people translate their environment into maps. This translation procedure includes two steps: First, people make the map in their minds (map-encoding); and in the second step they read it (map-decoding). To answer the question of how people make maps and reconstruct them in their minds, researchers found that people use sets of rules and regulations to program their minds to know:

- what to do,
- in what order, and
- how to combine them together. Downs and Stea believe that there are four mapmaking decisions that individuals consider: the representation purpose, the viewpoint or perspective, the scale and the symbolization method (Downs and Stea, 1977; 63). These mapmaking questions determine sets of rules to construct the map in mind. As a result, in this thesis, we controlled the purpose by focusing on street geometry, the viewpoint by asking about plans, the scale and symbolization by clarifying the drawing method in a scaled and bordered map. By controlling these decision making factors, cognitive representations can answer the question of how cognitive mapping responds to particular characteristics of the environment under study- street patterns in this case.

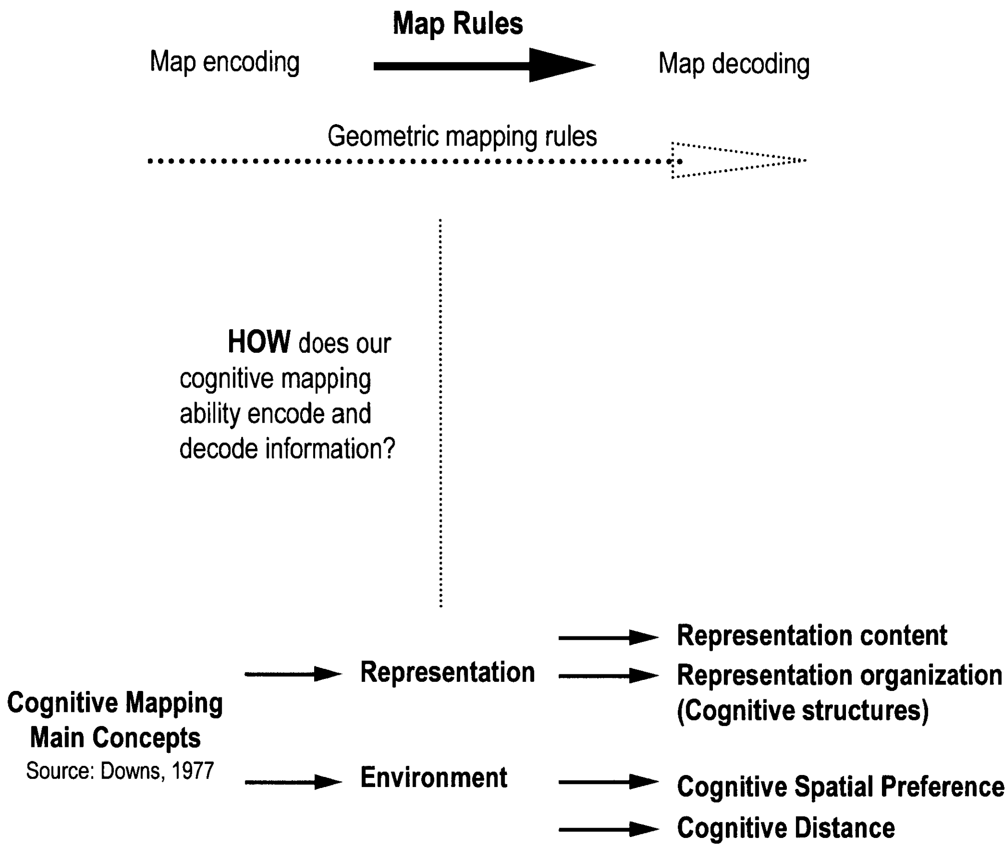


Figure 1-1. The descriptive representation of encoding and decoding cognitive maps (Sanoff, 1977)

1-2- Spatial Cognition

As mentioned in the first part of this chapter, two key concepts of cognitive mapping comprises cognitive representation and the environment. The term "environment" can be scrutinized by cognitive spatial preference and cognitive distance (Figure 1-1).

Cognitive spatial preference explains how humans encode the built environment using landmarks and spatial signs to remember the built environment. Peter Gould suggests how mental maps are expressed as a representation of human decisions:

"Many of the decisions that men make seem to be related, at least in part, to the way in which they perceive the space around them and to the differential evaluations they place upon various portions of it." (Downs and Stea, 1973; 183) Although some parts of human perception of the built environment is unique, there is another part which is shared with other people. Therefore, cognitive maps can represent general or shared information about spatial preferences (Downs and Stea, 1973; 185-186). This thesis explores if some of those shared aspects of environmental cognition are related to the geometric properties of street networks. For instance, I test whether certain street patterns such as grids or star-shapes are more commonly and more completely represented in cognitive maps than less structured paths of the street network.

Second, cognitive distance conjures up the idea of how people cognitively transform the distance in their minds by differentiating between "the world as we see it and as it really is." Downs and Stea argue that people use quantitative information as "part of the geometry of cognitive maps" in order to adapt themselves to the spatial environment. As a result, cognitive distance is defined as the estimate of distance based on people's memory (Downs and Stea, 1973; 317). I investigate whether we can measure certain geometric properties of streets using graph analysis and compare them with cognitive maps. For instance, how continuity of streets or the distance between street sight-lines can have an impact on people's perception.

Different researchers have different views on how people perceive cognitive distance. Lowrey suggests that people use "an interval-scale based metric," which allows people to find out distance between different points, while Lynch indicates that people use "the degree of removal from a fixed point." (Downs and Stea, 1973; 320)

Mental map theory vs. Practical-mastery theory

Advocates of mental map theory argue that humans find their way based on the spatial information that they receive and decode to recognize their built environment. Gell describes this decoding process as a conversion of "information" into "practical decisions." Thus, mental map theory explains wayfinding based on "plotting a route in relation to the objects and places encoded in a mental map", while people update their preference to mental maps when they want to move from one landmark to the other. This theory is further developed in studies of (Ingold, 2000), (Lynch, 1960), (Downs and Stea, 1973) and (Golledge, 1978) (Istomin and Dwyer, 2009; 30) For example, this theory clarifies that people can orient themselves and find their ways based on route properties and buildings or landmarks along it.

In contrast to mental map theories, there has been a long debate on whether people build abstract representations in their mind (cognitive map) or perceive their built environment based on the transition between different perspectives (practical-mastery theory). Gell proposed the idea that people do not build mental maps, but they remember the built environment based on habit and daily activities (Istomin and Dwyer, 2009;

30). For instance, in practical mastery theory people can find their way based on perspective and scenes of different streets, where they can distinguish between these perspectives.

In conclusion, researchers found that mental map theory and practical-mastery theory are both complementary, since human beings use both abstract representation and route perspectives in their wayfinding decisions (Istomin and Dwyer, 2009; 41). The following table shows how different researchers found diverse results about people's perception of landmarks, nodes, paths, edges and districts in different cities with various sample sizes. For example, Lynch's studies in Boston had a sample of 30 professionals, where he evaluated the city with clear districts and landmarks, while other studies in Chicago by Saarinen represent defined landmarks, paths and districts among 42 area workers. This interesting study shows different results when it is done among other samples. For instance, when the study was completed among 18 suburban students they could not recognize a clear district for Chicago, while a sample of 12 University students had the same results as area workers. As a result, in this thesis, I am going to balance my sample size mostly by university students with a controlled balance of the people who were grown up in suburban or urban environments. The last interesting example in this table reflects the study by Stea and Wood on Mexico city, which resulted in strong landmarks, paths and districts in Mexico city, where edges were almost entirely absent (Figure 1-2). To conclude, I am interested in pushing this research on configurational studies further by focusing on street patterns and investigating how perception is related to different street properties such as continuity, width, average length of street segments, street patterns and angles.

Principal investigator and year published	City	Interview Sample (Number and Predominant Type)	Land-marks	Nodes	Paths	Edges	Districts	Investigator's Comments
			Importance of Urban Elements					
K. Lynch (1960)	Boston (United States)	30 (Professional, managerial)	●	○	○	○	●	One strong edge; distinctive districts, confusing paths; understand structure.
	Jersey City (US)	15 (Professional, managerial)			○			Lack of character; formlessness; low imageability.
	Los Angeles (US)	15 (Professional, managerial)	○	○	●			Less sharp image, visually faceless, but active, ecologically ordered
D. Jonge (1962)	Amsterdam (Netherlands)	25 (Wives of skilled and while-collar workers)		●	●			A very strong image; strong predominance of main elements; spider web structure.
	Rotterdam (Netherlands)	22 (Wives of skilled and while-collar workers)	○	○	○			Over-all image weaker; buildings seen more clearly; no clear boundaries.
	The Hague (Netherlands)	25 (Wives of skilled and while-collar workers)	○		○		○	No wide straight path; separate elements and buildings; vague as to boundaries.
J. Gulick (1963)	Tripoli (Lebanon): entire city	35 (Students, upper middle class)		○	○		●	Stresses districts geographically distinctive or nodes; buildings not a major focus.
T.F. Saarinen (1969)	Chicago (US)	42 Area workers	●		●		●	Tightly defined areas with internal detail.
		18 Suburban students			●	○		Border areas.
		12 University students	●		●	○	●	Border areas and external landmarks.
H. Klein (1967)	Karlsruhe (Federal Republic of Germany)		●	●	○			Rational; striking landmarks; highly linear; imaged center moving westward.
D. Appleyard (a969)	Giudad Guayana (Venezuela): entire city			○			●	Little "common" urban knowledge of city; higher for local areas; higher for lower income population.
D. Stea and Wood (1970)	Mexico City: city and center		●	○	●		●	Edges almost entirely absent; strong domination by major paths; district landmarks.
	Puebla(Mexico): city and center		●	●				Streets extremely regular highly legible but uninteresting.
	Guanajuato (Mexico): city and center		●	●	○			Highly irregular; unstructured; bi-nodal.
	San Cristobal las Casas (Mexico): city adn center		●	○	○			Legible city; clear and strong pattern of spatial activity.

Figure 1-2. Cognitive mapping research from principal investigators (Source: Downs and Stea, 1979; 84-5)

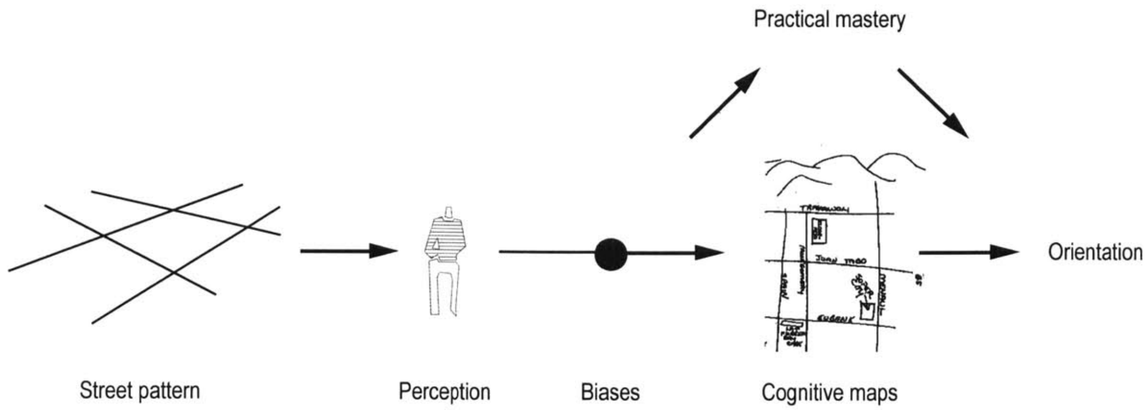


Figure 1-3. The descriptive idea of the relation between street pattern and people's perception

1-3- Spatial Orientation

The definition of orientation used by Downs and Stea, is excerpted from the book English and English as (1958): "*The discovery or knowledge of where one is and where one is going, either literally in space and time, or figuratively in relation to a confusing situation or a puzzling problem. The orientation is cognitive when it consists chiefly in knowing the situation.*" (Downs and Stea, 1973; 290)

As Kevin Lynch describes, orientation is one of the most significant features in wayfinding, which can be achieved by visual and other sensations (Lynch, 1960; 3). What Lynch argues as difficulties in the city image comprises confusion, floating points, weak boundaries, isolations, breaks in continuity, ambiguities, branching and lack of character or differentiation, which all support the notion of difficulties caused by the lack of spatial orientation (Lynch, 1960; 25).

In order to recognize spatial orientation, it is necessary to distinguish "the cognitive use of orientation" from perceptual orientation or awareness of bodily position in space." Downs and Stea argue that: "The ability to orient is a process which ties cognitive maps to the spatial environment." (Downs and Stea, 1973; 290) I argue along with Lynch that there could be an important intermediary step between actual street patterns and cognitive maps where the geometric characteristics of street networks affect cognitive maps, which in turn affect orientation. This thesis argues that people perceive their built environment based on some "Biases," while not all theories accept the impact of "Biases." This research tries to find out one of these "Biases" in the impact of street properties on people's perception (Figure 1-3).

The knowledge of understanding the cognitive use of orientation, which explains "where we are" is called "topographical orientation." The simplest type of topographical orientation forms based on following a path to recognize the way. So, in this case, wayfinding clues such as numbered highways or familiar crossroads leads to people's destination. When people are required to make a decision which path to chose, they are referring to this type of orientation schema or mental map to orient themselves in the built environment (Downs and Stea, 1973; 296). This schema can be represented by visual techniques of surveying. Downs and Stea state:

"*The better oriented a person is, the more closely his schema is likely to resemble a map. Not only are directions distorted in the topographical schemata of most people, but distances and the relative areas of various regions also reflect their importance to the individual rather than geographical reality.*" (Downs and Stea, 1973; 297-8)

1-4- Cognitive representations

Cognitive representation of nature and attributes of the built environment comprise cognitive maps, mental maps or spatial images." (Downs and Stea, 1973; 79) (Figure 1-4) Cognitive representation consists of the content of representation and its arrangements. The content of representation reflects how people identify a place in their mind. For example, orientation depends on matching an identity with the surrounding environment. This process of cognitive mapping will enable researchers to predict frameworks, in which they can suggest what will or might happen (Downs and Stea, 1977; 84-88).

As a result, I am interested to investigate if cognitive representations can help researchers to predict people's perception of street networks. To design this research project, we look at cognitive mapping and survey techniques in the next part to select the qualitative research method for this study.

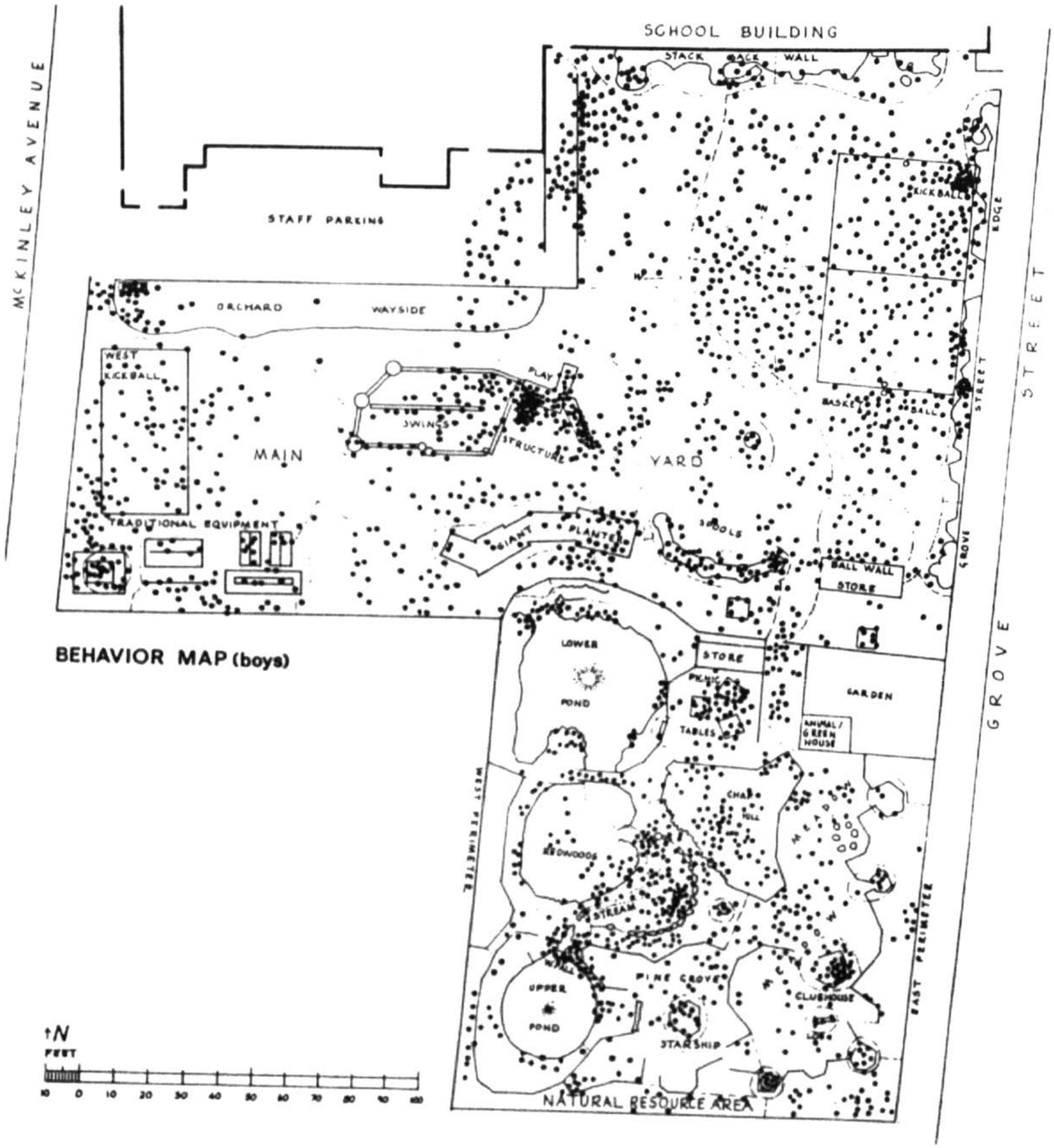


Figure 1-4. Behavior map aggregated from eighteen noontime recess observation periods (Drawing: Robin Moore) (Sanoff, 1977; 88).

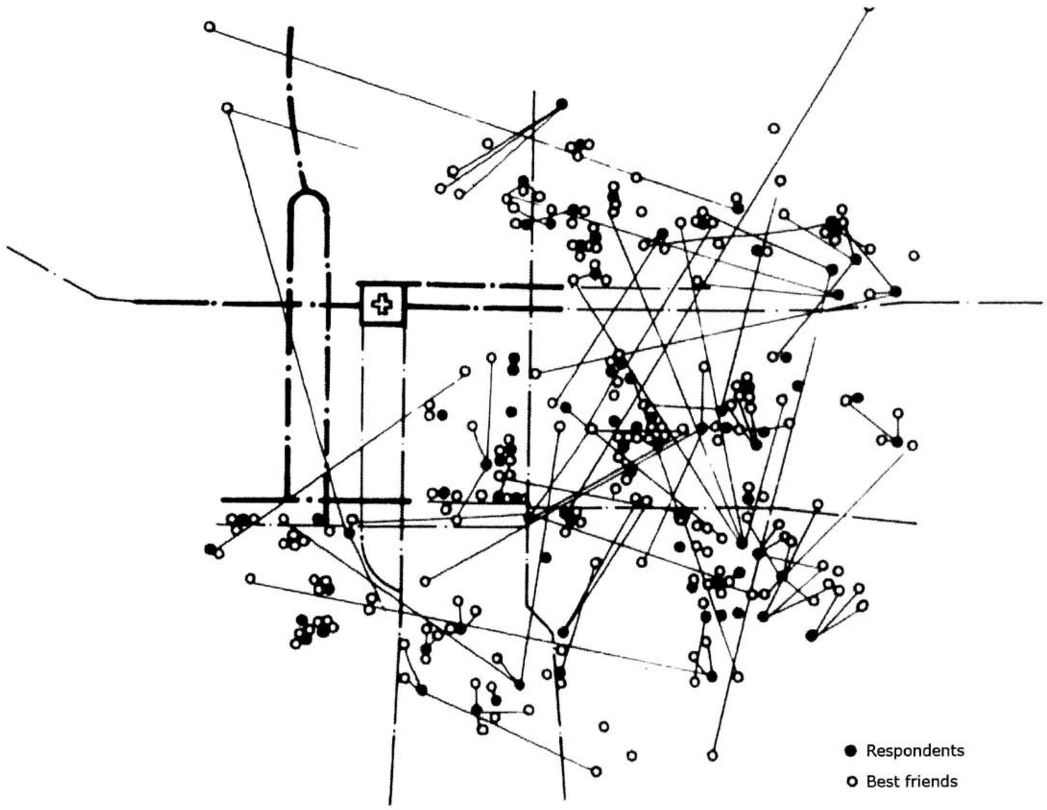


Figure 1-5. Map locating respondents and their best friends in a Raleigh, North Carolina neighborhood (Sanoff, 1977; 123).

1-5- Cognitive mapping techniques

Research methods to study cognitive mapping is intimately related to problems caused by the complexity of access to the information in people's minds. As a result, methodologies such as *Observation* and *Self-reports*, which extract mental images are known as the most significant methods to study cognitive mapping (Sanoff, 1977; 75).

Observation consists of verbal responses to questionnaires and tracking methods to observe how people behave in the built environment. Sometimes, additional information can bias the results, where this problem also remains unsolved in photo interviewing and other visual methods of observation. Self Reports create the second category to elicit cognitive information in form of verbal, written, or visual surveys. Therefore, cognitive maps, as visual self reports, are described as functional analogues. One of the techniques to represent how people encode and decode the environment is to ask a sample of people to explain their surroundings or map their activities through their experience of walking from one place to another (Sanoff, 1977; 75-77).

Other documentary techniques consists of photo-interviewing or sonic mapping, which addresses auditory information of the built environment. In this thesis, I used self reports and surveys as a research tool in form of map drawings.

To expand visual research methods, it is valuable to mention how Thiel (1961) developed a "sequence-experience notation system," which worked by recording the continuity of space experiences. Thiel argued that surfaces, screens, and objects can express all visual qualities and quantities of the built environment. In other words, he proposed the idea of encoding people's perception conveyed through signs and symbols. For instance, he proposed graphic codes for Lynch five elements of a city: paths, edges, districts, nodes, and landmarks. The trend to record people's perception also continued in recording movement (Halprin, 1965) or highway sequences (Appleyard) (Sanoff, 1977; 109-114)

Thiel's effort to encode the built environment, stimulated this research project to explore ways to test how people respond to street patterns and to what extent encode and decode them. There are different research methods to test this hypothesis, by running surveys, using tracking systems, field trips, etc. Between these methods, I have used "map drawing based on memory," for its ability to cover how people can remember street patterns in addition to the possibility of translating compiled visual surveys to graph analysis. For instance, Sanoff investigated an exploratory study to test the relationship between social characteristics of a neighborhood and its physical boundaries. In this study, he conducted a survey in Raleigh, NC to test activity patterns in order to understand how residents perceive the boundary of their neighborhoods (Figure 1-5). He assumed that this boundary is influenced by the "locality, in which social interaction occurs." As a result, he found that the physical boundaries of neighborhoods were in a direct relation to boundaries of their friendship networks (Sanoff, 1977; 122-124). This example shows how an efficient survey design could result in predicting the relationship between physical boundaries and friendship networks.

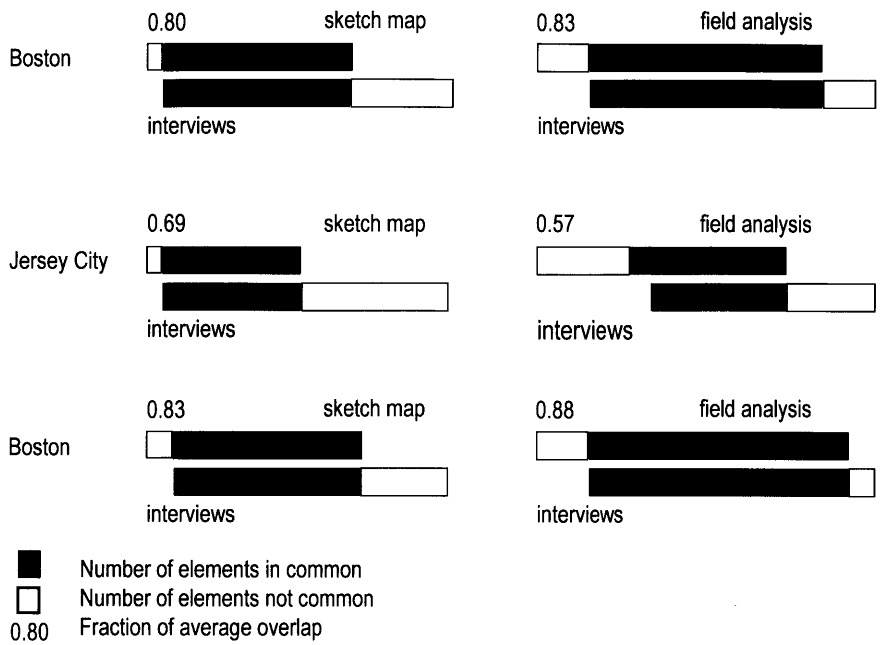


Figure 1-6. Overlap between interviews, sketch maps, and field analysis (Lynch, 1960; 152)

1-6- Cognitive mapping Interpretation

To understand and interpret the results of cognitive maps, researchers need to find ways to compile their collected qualitative data. Kevin Lynch cites a number of factors which result in a less sharp and clear image of a city as "decentralization of the metropolitan region," "the grid street pattern," and "shifted central activities." (Lynch, 1960; 33) This idea came from compiled or synthesis maps, which Lynch created in his study on three different urban environments in Boston, New Jersey and Los Angeles. Complied maps for each area are produced based on the percentage of recorded activities for the total number of surveys. Figures 1-6 to 1-8 show how some of these maps are compiled.

Lynch states that to produce visual maps, they have used two systematic methods to utilize a field connnaissance by a trained observer and a lengthy interview from passer-by in streets (interview and sketch maps) (Lynch, 1960; 15). Some of the interview questions consist of asking people about directions for the trips that they normally take going from home to work or questions to describe different parts of Boston and its particular elements (Lynch, 1960; 141).

The method that Lynch used in interviews was to ask subjects to classify photographs in groups, which made sense to them and were requested to identify as many pictures as possible with their reason to identify those images. For instance, in New Jersey, which did not have a clear image in resident's minds the field analysis predicted two third of the interview images.

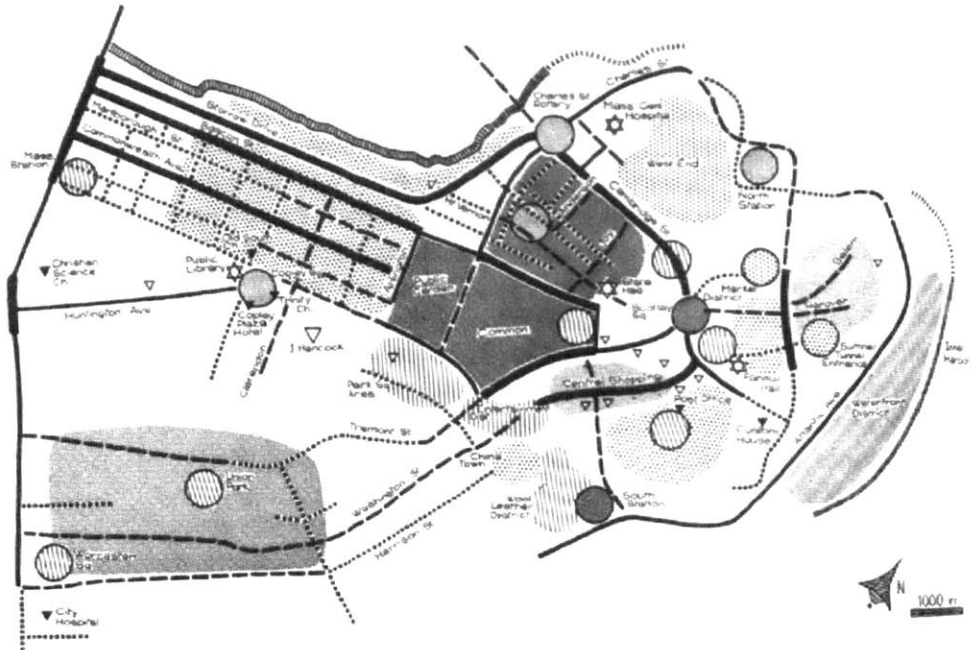


Figure 1-7. The Boston image as derived from verbal interviews (Lynch, 1960; 163)

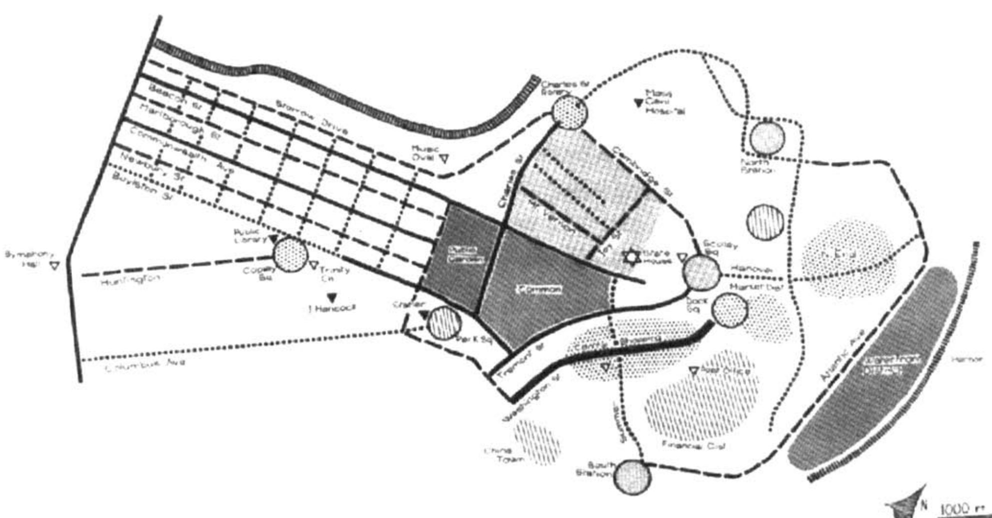


Figure 1-8. The Boston image as derived from sketch map (Lynch, 1960; 163)

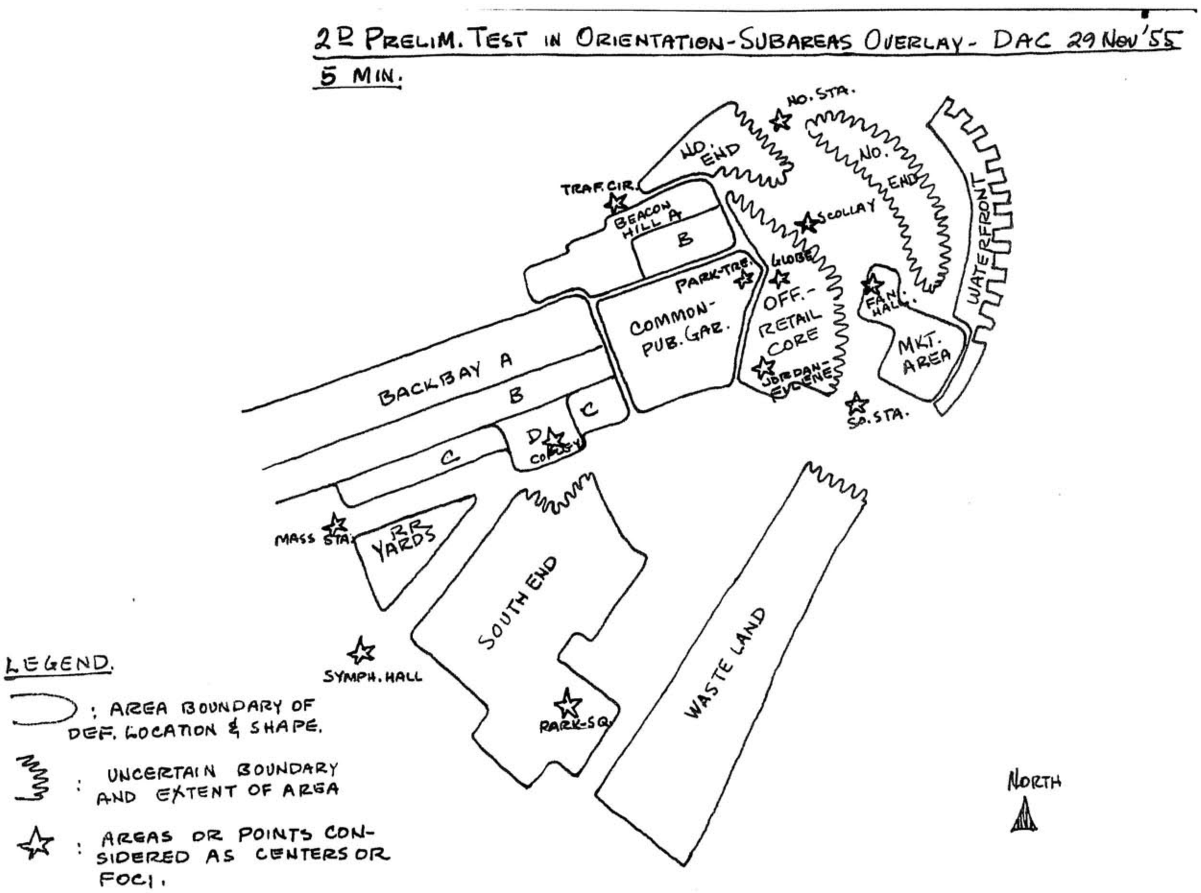


Figure 1-9. Third Preliminary Test in Orientation - Subarea Overlay, David Crane, 1955 (Source: Kevin Lynch Visual Collection. URL: http://hdl.handle.net/1721.3/36558) Courtesy of the MIT Libraries. Photographer Nishan Bichajian.

This study have also shown that photographic recognition confirmed the verbal interviews. For example, more than 90% of the people were able to recognize Commonwealth Avenue and the Charles River, where Tremont Street, Beacon Hill, and Cambridge Street were also well recognized (Lynch, 1960; 142-152).

In Lynch's compiled maps, the legend and notes represent how paths and edges are shown with different line-weights based on the percentage of recognition in the interview results (Figure 1-7, 1-8). The method that Lynch used to compare all results of interviews, field works and sketch maps is shown in the comparison diagram in Figure 1-6, which represents how close were the result of these three different methods. I have also taken the advantage of this analysis, stating that people's cognitive maps can be a visual measurement method to be compared with actual street pattern analysis. As a result, I intend to design a visual survey to collect cognitive maps.

One of the interpretation results and conclusions made in "The image of the city" is formed on the basis of the lack of character based on what the majority of people were able to draw. For example, he concludes that since maps of New Jersey lack recognizable districts and landmarks, there is a paucity of character in this city (Lynch, 1960; 26-29). The other interpretation from compiled maps shows major difficulties in Boston as confusions, floating points, weak boundaries, isola-

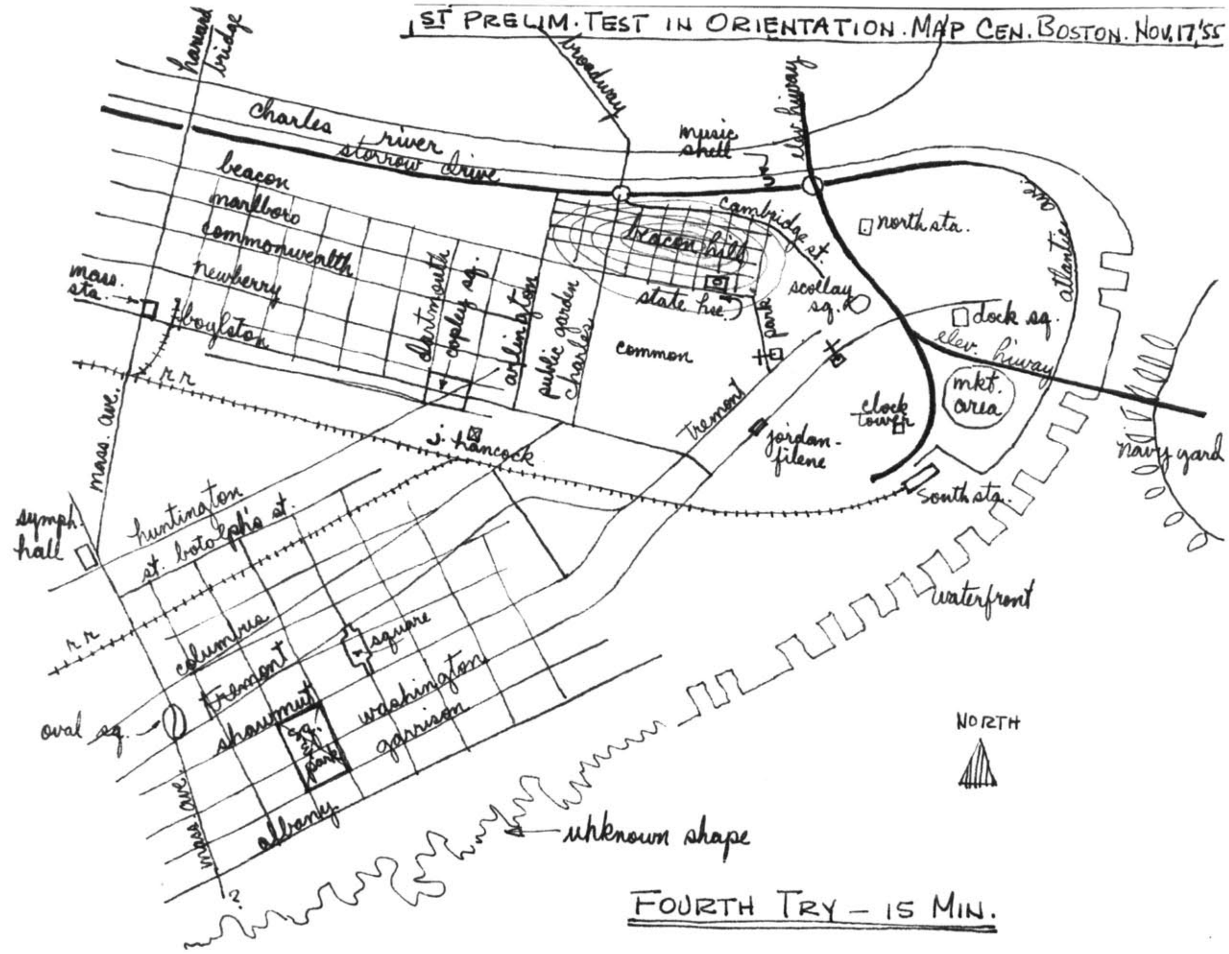


Figure 1-10. First Preliminary Test in Orientation - Map Central Boston, David Crane, 1955 (Source: Kevin Lynch Visual Collection. URL: http://hdl.handle.net/1721.3/36559) Courtesy of the MIT Libraries. Photographer Nishan Bichajian.

tion, breaks in continuity, ambiguities, branchings, lacks of character or differentiation (Lynch, 1960; 25).

The third interpretation from compiled maps that I would like to address relies on analyzing different characteristics of each city element:

- **Paths:** To measure the strength of paths, Lynch investigated to what extent people could recognize the width of streets. For example, Cambridge Street, Commonwealth Avenue, and Atlantic Avenue are well-recognized paths in Boston. Moreover, special facade characteristics, proximity to certain features, continuity and alignment of paths are evaluated based on compiled maps in Lynch studies. For instance, he argues that perpendicular intersections are easier to remember or he also concludes that crossings of more than four intersections were difficult to remember (Lynch, 1960; 50-58). Therefore, to complete tested features for paths, it's valuable to quote Lynch about his thoughts on path networks: "The Los Angeles grid is a good example. Almost every subject could easily put down some twenty major paths in correct relationship to each other. At the same time, this very regularity made it difficult for them to distinguish one path from the other, while in Back Bay, parallel streets have their own individual character." (Lynch, 1960; 61)

Edges: Lynch evaluates that edges are strong in Boston and New Jersey, but weaker in Los Angeles. He interpreted this data based on the percentage of recognized edges such as rivers, artery roads and other water edges (Lynch, 1960; 62-3).

Districts: "In some Boston interviews, the districts were the basic elements of the city image." Lynch have recognized and interpreted districts based on variable boundaries that people drew (Figure 1-9). For instance, in Boston, the West End and North End were not differentiated internally, where Beacon Hill was the highest structured district in Boston (Lynch, 1960; 67). The idea of representing the image of a city emerged in recognition of different districts made a valuable progress in understanding urban environments, inspired me to investigate the concept of people's perception of street patterns.

Nodes: Nodes as strategic foci, junctions of paths or concentrations of some characteristics, are evaluated in Lynch's study based on the majority of recognized nodes in people's interviews. Sometimes nodes are thematic concentrations, while subway stations can also create strategic junctions. In addition, Lynch argues that recognition of a node does not necessarily require a strong physical form (Lynch, 1960; 72-6). In this thesis, I am interested in investigating nodes as the intersection of different streets and evaluate them based on the angles that they make with each other to test its effect on people's perception.

Landmarks: Lynch defines landmarks as simple physical references which help people to orient themselves and find their way in decision points. Lynch evaluates landmarks by minor and major points by asking people to mark landmarks that they can remember. (Lynch, 1960; 78), which we did not address in this study.

Kevin Lynch design projections

There are certain characteristics, which Kevin Lynch proposed as a result of his cognitive research to be applied on paths and other city element designs (Figure 1-10). Some of these principles can be summarized in applying visual hierarchy in paths, clarity of direction, and simplicity in the topology of joints and right-angled crossings. He also defined the districts based on the definiteness of their boundaries. Design projections that Lynch suggested, therefore, emphasize on simplicity and clarity of forms, continuity of paths and edges, dominance of one part over another, clarity of joints, and directional differentiation (Lynch, 1960; 95-97, 104-7). There is a normative statement in this, which argues that a clear image of a place is 'good' or desirable, and that we should design places that produce clear images.

Lynch implicitly assumes that some places have a more coherent image than others. Yet he doesn't explain what determines these differences, and what form characteristics lead to better images. We are avoiding the question of "Good | Bad" image by looking at the completeness of maps. Lynch also investigated general elements of a city (paths, edges, districts, nodes and landmarks) through general drawings, while this thesis looked at a concrete relationship between street properties and people's cognition.

1-7- Conclusion

Based on the procedure of cognitive mapping, I investigate if people not only record spatial preferences and cognitive distance, but also encode and decode geometries of street patterns. The great research done by Kevin Lynch and other projects in way-finding, motivated me to investigate people's perception of streets in a smaller scale. I explore whether people update their way-finding information based on certain geometrical properties of street patterns. Hence, in the next chapter, I will explain the theory behind street patterns and their relation to graph theory to bring out the hypothesis of this research. I will then test my hypothesis in Kenmore, Boston and Kendall Sq., Cambridge by comparing street patterns with compiled results of cognitive maps.

CHAPTER 2

CHAPTER 2: STREET PATTERNS

2-1- History of street cognition

Street scenes have experienced myriad of changes during the history from industrial revolution in England and political revolution in France. Interpreting scenes from Renaissance cities, streets gave birth to the idea of bringing activities into public places and transforming them to a stage for social interactions. In Italy, long straight streets were formed to join basilicas and provide access to the countryside, which provided a way to orient residents in a city. As a result, streets transformed from corridors to outdoor activity passages and provided broader perspectives (vistas). Furthermore, during the enlightenment, street patterns were more influenced by paradigmatic utopian ideas and the use of natural geometry in designing street networks (Figure 2-1). "*They believed in the power of environment over the mind, where changes in the environment could change the state of the mind.*" (Anderson, 1979; 29-34)

The rationalist ideas of enlightenment in the last decades of the eighteenth century were presented in *Basilidade* and the *Code de la Nature*, constructed to reflect all geometrical excellence of the nature. The Renaissance principals based on the image of man, followed by symmetry in art reintroduced natural imitation in urban design as a means of a pathology of a city to treat street patterns as blood vessels in the body (Figure 2-1). This was heavily influenced by the printing of "De Motu Cordis" as Sennett describes in his "*Flesh and Stone*" book (Sennett, 1943). The evolution of people's perception of streets continued in ideas of Fourier in "Gallery-Streets," which proposed that voids and courts can create communal relationships in different neighborhoods. Afterwards, during 1853-1867, Haussmann's ideas to create grand boulevards and avenues provided new perceptive characters for streets in Paris, based on changes in street lengths, widths, junctions, and facades (Anderson, 1979; 34, 86-93).

Structure of Streets

"*Present-day western cities are predominantly a combination of two generalized physical conceptions. Rather than starting off as distinct types, they evolved into such over time. One could be described as a city that appears to have had its streets and open spaces carved from the solid mass; however, the other conception is a city that appears to be open land, into which buildings have been introduced as objects.*" The forces that led to spaces carved from the solid mass have resulted from "growth by infill rather than by expansion" as a need for efficient communication. An alternative response against the traditional city other than technological reasons created structures, in which buildings are the "generated" elements (Anderson, 1979; 115).

William Ellis introduces two elemental types of streets: The first configuration is called "continuous development," which explains the ordinary meaning of a route that proceeds along and terminates by buildings. The idea of Haussmann's boulevards, which transforms the streets to a continuous channel of space is an ideal example of this type. Second idea represents streets as "elongated courtyards" portray enclosed spaces with characteristics of interior spaces, courtyards or piazzas. The narrow courtyard between the Uffizi's two wings in Florence, Italy represents a good example for this type of streets.

Other than the evolutions in the structure of open

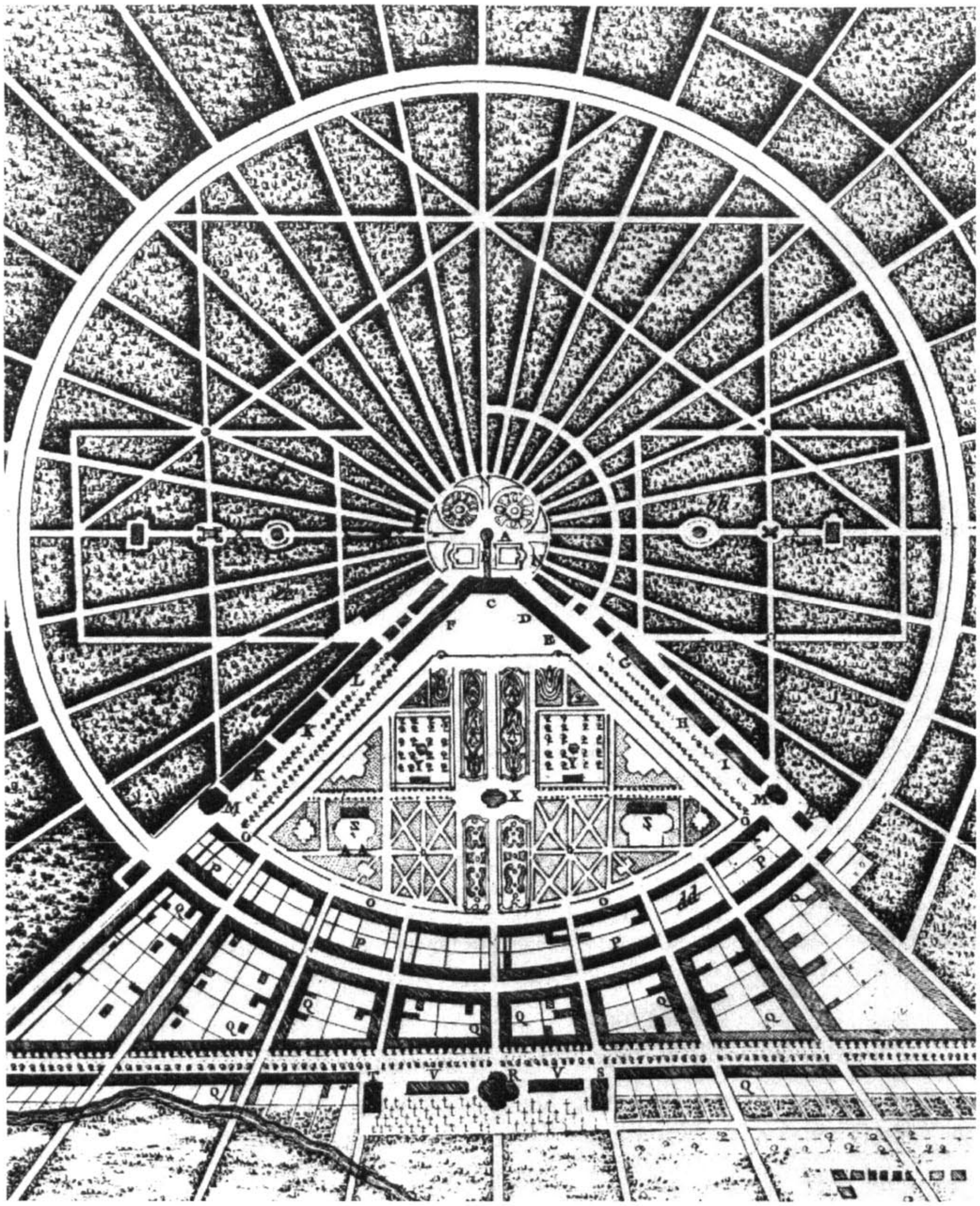


Figure 2-1. Plan of Karlsruhe, built in 1715 as a hunting retreat for Karl Wilhelm (Anderson, 1979; 33).

A. Tower from which the Prince views the 32 routes, 9 of which from the streets of the town
B. Gallery
C. Chateau
D. Opera
E. Tennis court
F. The Prince's quarters
G. I, P, Stables
H. Riding school
K. Orangeries
L. Gentlemen's quarters
M. Salons
N. Menagerie
O. Hotels
Q. Houses
R. Lutheran Church
S. Calvinist Church
T. Catholic Church
V. Schools
W. Pumps
X. Reservoirs
Y. Orangeries
Z. Greenhouses

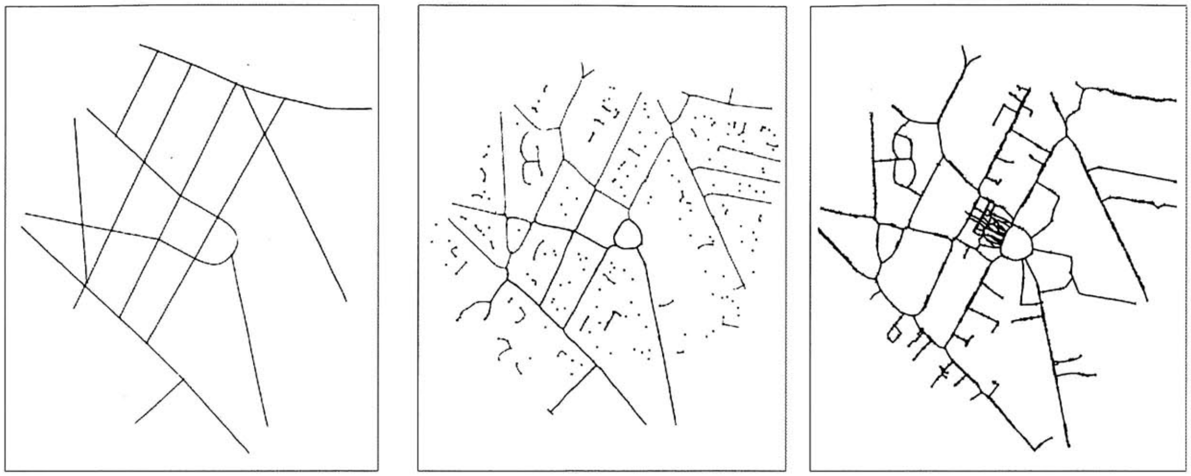


Figure 2-2. Public claim (Anderson, 1979; 285)

and built spaces during time, changes in American life-style that transformed public activities into private activities have resulted in different perception of the built environment. Thomas Schumacher states that the perception of the environment will be broken in a hierarchy of relation between street to house or at the level of district to city (Anderson, 1979; 146). This note explains how the hierarchy of street network can change people's perceptions and preferences. To address different street patterns, street uses are categorized in three types of "residential streets," "mixed residential and commercial streets," and "commercial streets", each imposing a different formal characteristic and a spatial perception, each with different cognitive characteristics (Anderson, 1979; 152). The key differences between street types upper discussed here result from the way buildings enclose the streets, not the two-dimensional configuration of streets themselves, which is later analyzed in this thesis. In this thesis, I have chosen two districts with the same ratio of residential to commercial streets, so as to control for this factor. There are various models to interpret cognitive results of street patterns during the history. In the following part, one of these models, which represents streets as graphs will be introduced.

A Model for the Study of Urban Structure (Stanford Anderson)

The idea of representing streets as graphs dates back to Euler in the early 18th century. In an attempt to move from descriptive studies to projections of street patterns, Stanford Anderson at MIT proposed a model to use graphs for the study of urban structures. These graphs, drawn for several parts of Paris and Cambridge, MA include the graph of pedestrian circulations, the base graph, the graph of open spaces and the graph of public claim to represent street patterns. The simplest concept to start the analysis implies a base graph, which is generated by "tracing center lines of streets and projecting them to their meeting points." (Anderson, 1979; 277-80) (Figure 2-2)

The first analysis graph is represented to indicate pedestrian circulations, where vertices and edges of this graph are routes, explaining the idea of street hierarchy. The second graph illustrates open spaces by tracing points and small sub-graphs of courtyards. Third, graphs of communal spaces can represent spaces of public claim, spaces of dwelling claim and spaces of occupational claim (work places). Graphs of public claim, which represent publicly accessible spaces of the city, depict various types of accessibility information (Anderson, 1979; 284-86). "For instance, white surfaces represent spaces that are totally inaccessible, without privilege. At the other extreme, crosshatchings denotes the spaces that are available to the public with the least degree of constraints and the remaining dots record spaces that are visually but not physically available to the public." (Anderson, 1979; 281-81) As a result, these graph representations of streets outline the model, by which planners can investigate inquiries about different subsystems of a city, which are related to the cognition of the built environment.

One of the obstacles with modern urban planning is that planners rarely design open spaces between buildings. The conversion of the total composition of nineteenth century planning to the utilitarian design for separate buildings resulted in a change in street patterns from a more condensed natural pattern to a more straightforward one. For example, there is a difference between the contemporary grid pattern, in which streets separate buildings, and the street network of the nineteenth century, where buildings and open spaces reinforce each other (Anderson, 1979; 341). The above graph analysis illustrates how the combination of built and open spaces can result in different public claims.

The idea of street graph analysis was pushed further by Bill Hillier studies in space syntax, 1970-80, which formed based on axial geometry of streets. Although the method that Anderson proposed in his study shares the idea of using graphs to represent and dissect street pattern, space syntax provides another axial method to analyze networks of streets.

In the next part, we are looking at other literature on street patterns and applications of graph theory index in the built environment to propose the idea of how to measure and produce graphs in this study to analyze street networks and to compare them with cognitive evaluations collected from surveys.

2-2- From Streets to Patterns

Streets have various geometrical characteristics or properties such as width, length, continuity and the pattern of networks. Investigation through these characteristics requires mathematical abstraction to transform actual street networks to graphs and to their hierarchical patterns, where the hierarchy of streets directly relates to street types. Stephen Marshall provides the following table to describe the road hierarchy of transport in the urban environment (Marshall, 2005; 15, 25).

Road Type	Predominant activities
Primary distributor	Fast moving long distance through traffic
District distributor	Medium distance traffic
Local distributor	Vehicle movements near beginning or end of all journeys
Access road	Walking
Pedestrian street	Walking, meeting, trading
Pedestrian route	Walking, cycling
Cycle route	Cycling

Source: (Marshall, 2005; 25)

While the recognition of street types in transportation research is more focused on the function of roads, urban design categories often tend to focus on the physical form of streets. The literature on desired street patterns from Lynch's coherent system of sequences to interconnected network of streets in the Charter of New Urbanism permeates in urban design guidelines (Marshall, 2005; 26-33). I used a graph analysis measurement method in this study to evaluate the extent, to which different street properties related to cognitive maps.

To distinguish between street patterns, I have based my assumptions on Ray Brindle's work, who classified street patterns in two main types of grid and the tributary; however, there are different hypothesis among theoreticians. For instance, Stephen Marshall suggests that there are four broad categories of street patterns as linear, tree, radial and cellular types (Figure. 2-3), where Kevin Lynch in "Good city form" categorizes street patterns to Axial network, Capillary, Kidney, Radio-concentric, and Rectangular grid (Marshall, 2005; .77-78). I believe that each radial and cellular street type can be generalized into the category of a tree in Marshall's classification. Furthermore, in Kevin Lynch's classification, I argue that axial networks and angular grids both represent a grid system, where capillary, kidney and radio-centric embody various forms of a tree-shape or tributary type. In figure 2-3, there is a classification taxonomy of streets that Marshall proposes, where I argue that we can describe curvature properties of street patterns separately and purely distinguish between street patterns. In addition, we can also recognize radial patterns as a sub-category of a tree, since each tree has its own radial junctions.

I am inspired by Marshall's effort to classify street patterns (Figure 2-3), to quantify geometries to describe the properties of graphs and to convert Hillier's axial maps into graphs. First, to quantify geometrical properties of street patterns, Marshall denotes T-ratio and X-ratio as the ratio of T-junctions or cross-roads and X-junctions to the total number of junctions respectively. In consequence, he evaluates a street network as grid-like when it has more cells or as tree-like when the number of crossroads decrease (Marshall, 2005; 96-101). For instance, the idea of measuring the T-ratio and X-ratio leads to test how different numbers of perpendicular and non-perpendicular junctions in graphs influence cognitive maps.

To expand the second inspiration source, it re-

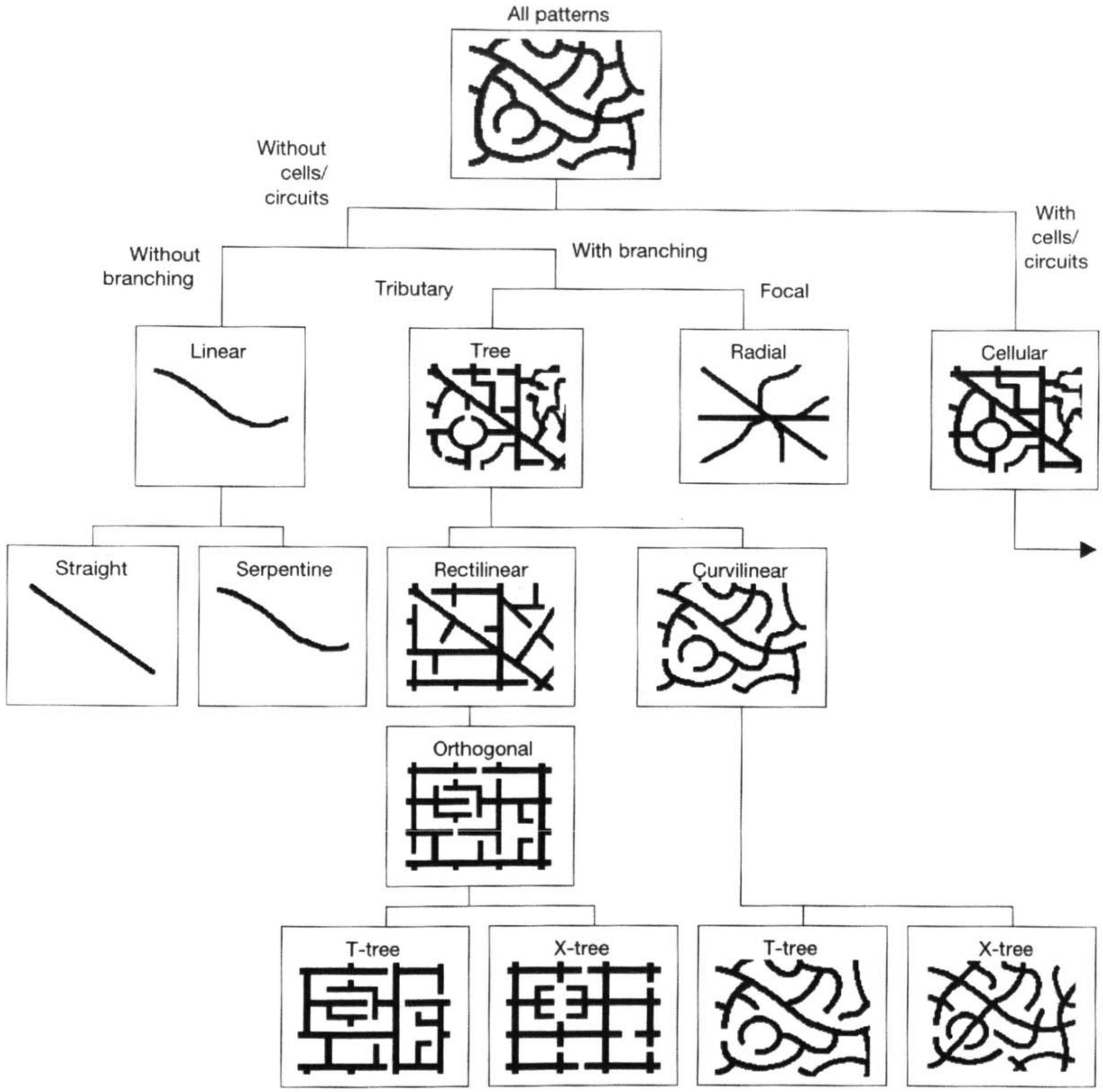


Figure 2-3. Stephen Marshall's elaborated taxonomy of patterns (Marshall, 2005; 93)

quires to focus on how Marshall converted axial maps to graphs. To interpret axial maps. Marshall transforms lines of movement to vertices of a graph, while the axial intersections become the edges. Then, he asserts how to measure the "value of connectivity" of a graph that relates to the number of intersections along each line. The next geometric property, which is introduced in Marshall's work is the measure of "distance," which resembles to what Bill Hillier called the depth of a graph (Marshall, 2005; 112-113). In my opinion, there are similarities in Hillier's measure of "depth", Marshall's notion of "distance" and Porta's opinion about "closeness, which is explained in the next part. In this thesis, I have coupled these concepts with the definition of "continuity" based on the sight-line.

Figure 2-4 demonstrates the distinction between continuity, connectivity and depth. Marshall defines

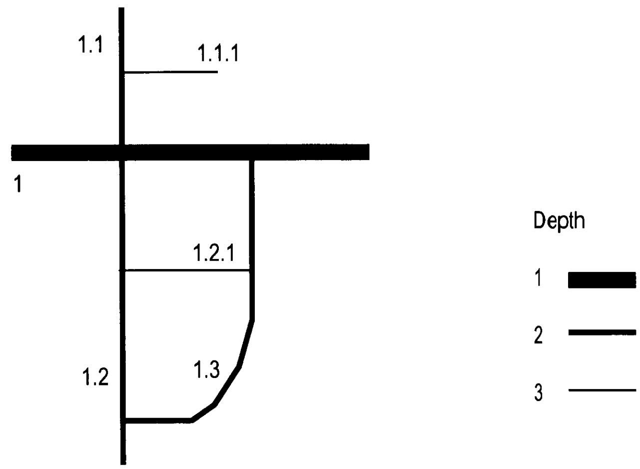


Figure 2-4. Example illustrating continuity, connectivity and depth of routes (Marshall, 2005; 120)

continuity as "the length of a route measured in links," while he represents connectivity as "the number of routes, with which a given route connects," and depth as a measurement tool to check "how distant a route is from a particular datum." For example, in this figure route 1.1 is more continuous than route 1.2.1, because of its continuity through a junction. This route is also more connective than 1.2.1, since it has four intersections, while route 1.2.1 connects to two routes. Marshall measures the depth by allocating the depth of 1 to the datum route and 2 to routes which are directly connected to the datum. For instance, figure 2-6 illustrates how labelling can represent the depth of routes. Route 1.1 shows that it branches out from route 1 and route 1.1.1 indicates that it ramifies from 1.1. As a result, the length of the label denotes the depth of the route (Marshall, 2005; 120). The idea of connectivity can be compared to counting the number of intersections for a route or finding out the mean of segment length for each route. I have used these principles to define our analytical tool in this thesis.

In conclusion, by looking through different geometrical properties of graphs, I am going to use the basics of mentioned literature in graph theory and define a measurement tool to use in this thesis. I am going to measure other geometrical properties of streets such as continuity, street width, average length of street segments, street patterns and angles, which will be completely defined and discussed in the next chapter.

CHAPTER 3

CHAPTER 3: METHODOLOGY AND RESULTS

3-1- Site selection

In this thesis, I was inspired by looking at places where Kevin Lynch investigated in Boston and I started to find two areas with diverse geometrical properties, while they introduce an area of two neighborhoods. Hence, I have selected Kenmore and West BackBay compared to Kendall Sq. with diverse geometric characteristics, the same boundary size and the same land use systems. To be more specific, in Kenmore-West BackBay and in Kendall Sq., there is a variety of continuous streets versus interrupted ones, different average length of street segments, and street patterns with various types of angles, which provided a convenient research context. For instance, Kenmore consists of a star-shape pattern and a grid-type in West-BackBay, where Kendall Sq. also contains a radial pattern in Kendall Sq. and a grid along First and 5th streets. As a result, geometric characteristics such as street continuity, width, average length of street segments, street patterns and angles

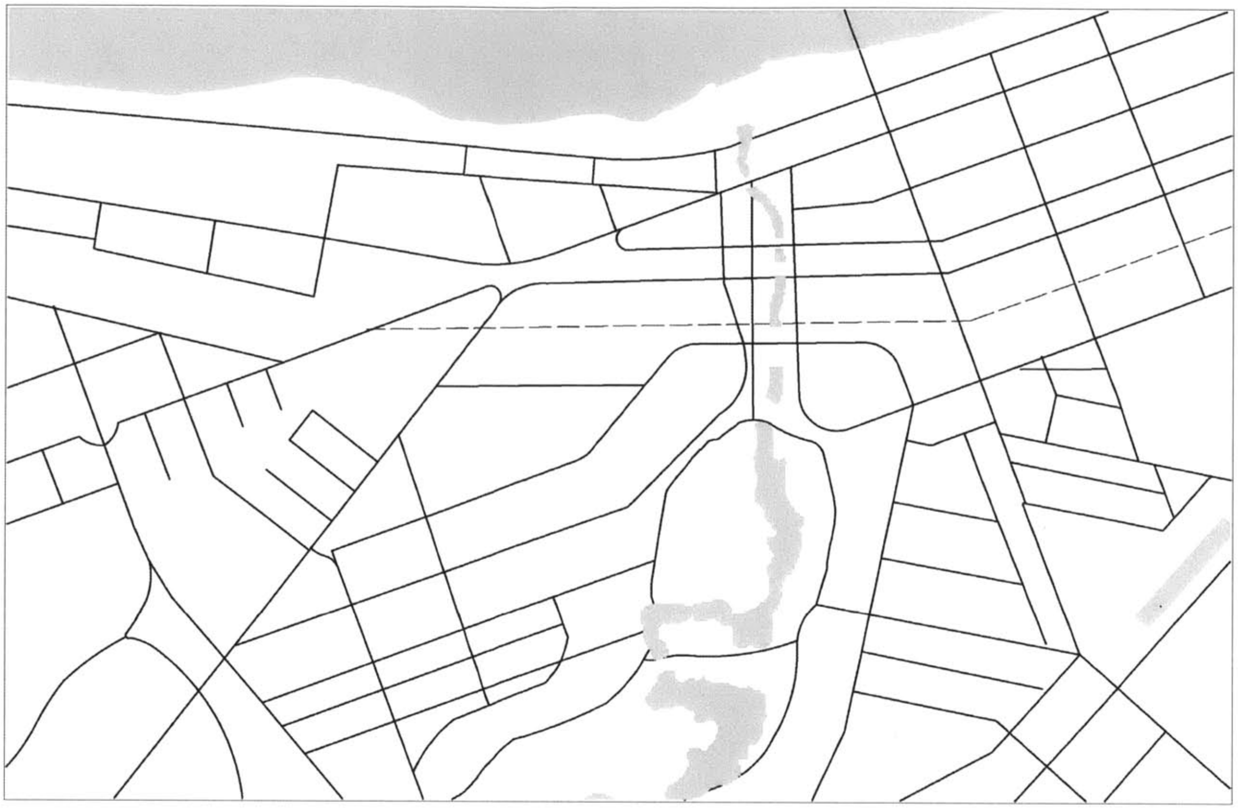


Figure 3-1. Kenmore and West BackBay street patterns, Boston, MA (GIS)

can be compared to street networks in Kendall Sq., Cambridge, which has geometric features in common with Kenmore-West BackBay (Figure 3-1 and 3-2).

Both of the selected sites contain an equal area of approximately 535,000 square meters, which provides a convenient size of two neighborhoods. The selected size is good for this comparison, because people can remember street patterns within their walking distance of two neighborhoods. This boundary size also gives us the opportunity to test street's geometric properties, which might not be discernible within one neighborhood.

3-2- Methodology and Hypothesis

The methodology in this study is based on the comparison between the completeness of cognitive maps with objective properties of the environment in order to see if particular properties of the environment are remembered more completely. To test the completeness of mental maps, compiled maps are produced as the result of cognitive map surveys, which asked people to fill in a boundary with streets based on their memory. The method used to compile cognitive maps formed on the basis of completeness of drawn streets. To be more specific, I have measured the percentage of drawn and accurately drawn streets among the total sample size of 15 in each area.

Figures 3-3 and 3-4 illustrates the visual survey

Figure 3-2. Kendall Sq. street patterns, Cambridge, MA (GIS)

sheet given to the people, who participated in this research. The first reason that we decided to draw surrounding streets in this project was according to various definitions of urban areas in people's minds. For example, in a pilot study to ask people to draw Kenmore or BackBay, they have started to draw the whole Boston and some parts of the streets in each requested area. Second, since in this project we have focused on streets, surrounding streets could illustrate the example of a requested drawing. Finally, provided surrounding streets and names were designed as a guide, so that people could better recognize and recall the area to orient themselves.

Admittedly, this research gained certain benefits from using visual survey methods in form of self-reports as cognitive maps within a snowball sample. I have found my interviewees by e-mail through private networks and after receiving replies from the people who were willing to participate in my survey, I have fixed a 15 minute meeting to complete the map after their oral consent. The following written text shows my research survey question.

Age: ---

Gender: F | M

Before age of 18, did you spend most of your adolescent years in a rural area or an urban environment? Rural | Urban

How long have you lived in Kenmore | West-BackBay?

1- Please fill in a schematic map of streets in Kenmore | West-BackBay within the red area on the map, and

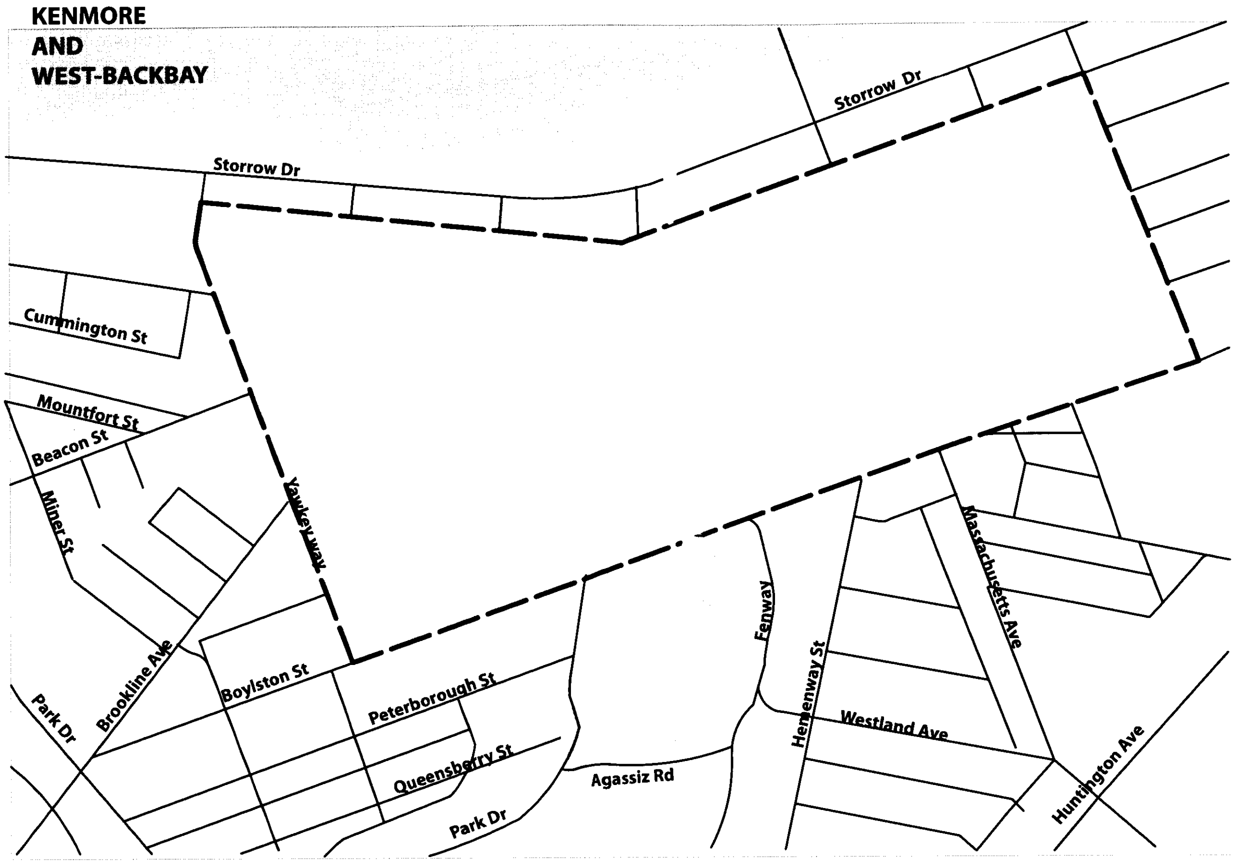


Figure 3-3. Kenmore and West BackBay survey sheet

name each of the streets you draw to the extent you can remember. You have up to 15 minutes to complete your drawing. This survey is to test how people remember the street geometry; so, please do NOT use any external clues such as maps, GPS or smart phones to draw the map.

2- Please mark the closest intersection to your home in Kenmore | West-BackBay.

To control the effect of other factors, I have chosen selected survey samples with homogenous distribution of people who participated in this survey both in Kenmore and Kendall Sq. (Figure 3-5, 3-6) The average of age among the selected sample is 25-30 years with an equal distribution of female and male genders. Approximately 60 percent of the total sample of 30 were grown up in urban environments and reside in the boundary for an average of one year in Kenmore and 2.2 years in Kendall Sq.

Another control factor in these two selected sites is related to the similarity in the distribution of land use systems. The distribution of land use systems can directly affect on people's perception of street patterns, since land use system is directly related to the number

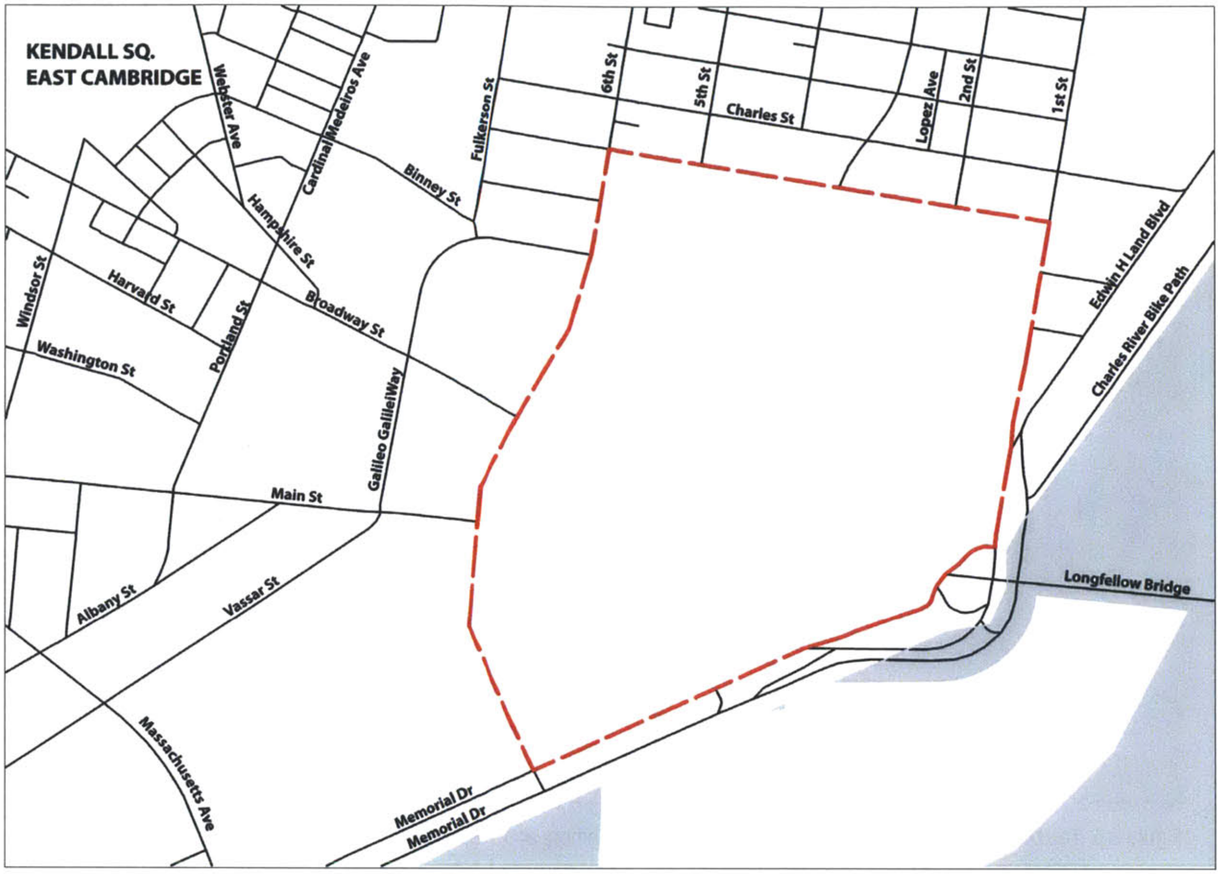


Figure 3-4. Kendall Sq. survey sheet

of commutes that people make in their daily travels. Both sites have approximately the same ratio of residential to office areas, which are similarly distributed. This similarity provides a control test to reduce the impact of other influential factors in people's perception of street properties. (Figure 3-7, 3-8)

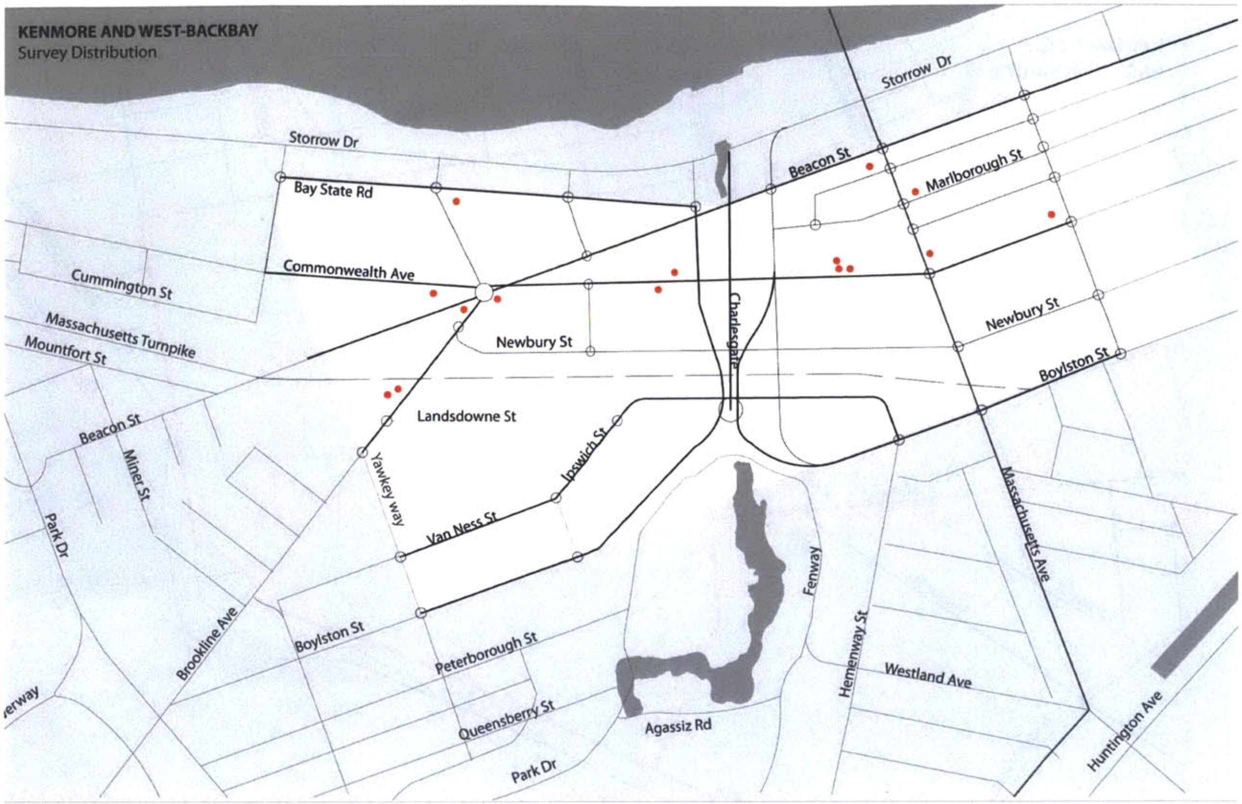


Figure 3-5. The homogeneous distribution of survey samples in Kenmore and West BackBay

Hypotheses

This thesis investigated different assumptions about the relationship between street properties and people's perception and tried to test them within a comparison of the actual measurement and the empirical results. The following points describe the evolution of tested hypothesis in this research.

Hypothesis 1- People will remember continuous paths more clearly than interrupted paths. Looking at previous studies about street continuity by Kevin Lynch (Lynch, 1960; 106) and the use of axial lines by space syntax (Hillier, 1996; 132) brought up this hypothesis. Continuity is defined based on the sight-line for streets not being interrupted by buildings and not having an angular change of more than 20 degrees (Hillier). People's mind will lose its sense of orientation after a certain number of directional changes on the path. As a result, people can remember continuous paths more easily, since they can better orient themselves with limited number of orientation changes. The second reason to support this argument relies on the fact that continuous streets consist of several short paths. People thus use them a lot, and therefore remember them well.

Hypothesis 2- People will remember wider streets more easily than narrow streets. My first reason to support the idea of a more clear image of wider streets comes from the fact that the width of streets is designed in regard to its frequency of use and as a result, people can remember them easier. The second reason to support this idea relies in better street perspectives that

Figure 3-6. The homogeneous distribution of survey samples in Kendall Sq.

people can encode in their minds from wider streets, as they have a broader image of their surroundings. It might be argued that continuity and street width are correlated. While I will test this correlation, I claim street width as a separate hypothesis influencing people's perception, because wider streets are not necessarily the most continuous ones and we can test their impact separately.

Hypothesis 3- People will remember streets with more number of intersections (density of intersection). The density of intersection is defined as the number of intersections along the total length of a street. Lynch's idea about nodes as decision points inspires me to test this hypothesis as a street property. First, I argue that the number of junctions influences the quality of access to other nodes, which can result in more frequency of use. Second, streets with more number of junctions will be better remembered, because every junction is a decision point, which makes people think about their options and as a result can be better remembered.

Hypothesis 4- Well-defined street patterns are remembered much easier than non-defined patterns. Based on studies of Gell, Istomin on way-finding and the genesis of Marshall's studies in street patterns, I argue that people encode the geometric structure of the built environment in their mind in places with well-defined patterns. For instance, streets designed with a clear pattern such as a grid or a star-shape can be better perceived compared to non-defined patterns.

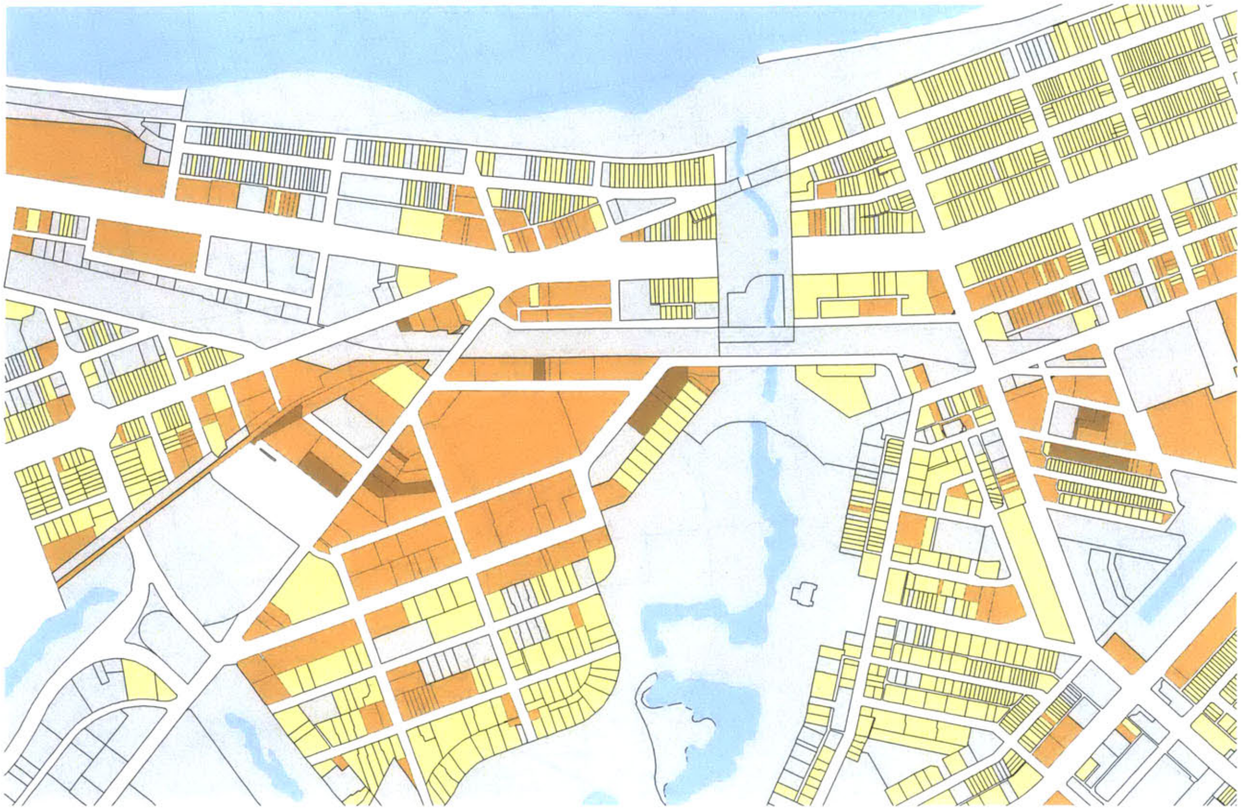


Figure 3-7. Kenmore and West BackBay land use systems (GIS)

Residential
Commercial
Industrial
Exempt ownership

Hypothesis 5- People will better remember junctions with less angular deviation from perpendicular angles. Since people are more often used to perpendicular angles, which give them a more clear sense of orientation, they can encode these angles more easily than non-perpendicular angles. As a result, people can recall angles based on the nearest perpendicular angle. For instance, if angle between two streets is 80 degree, people can recall it as it is near 90 degree, while remembering a deviation of 45 degree is more challenging.

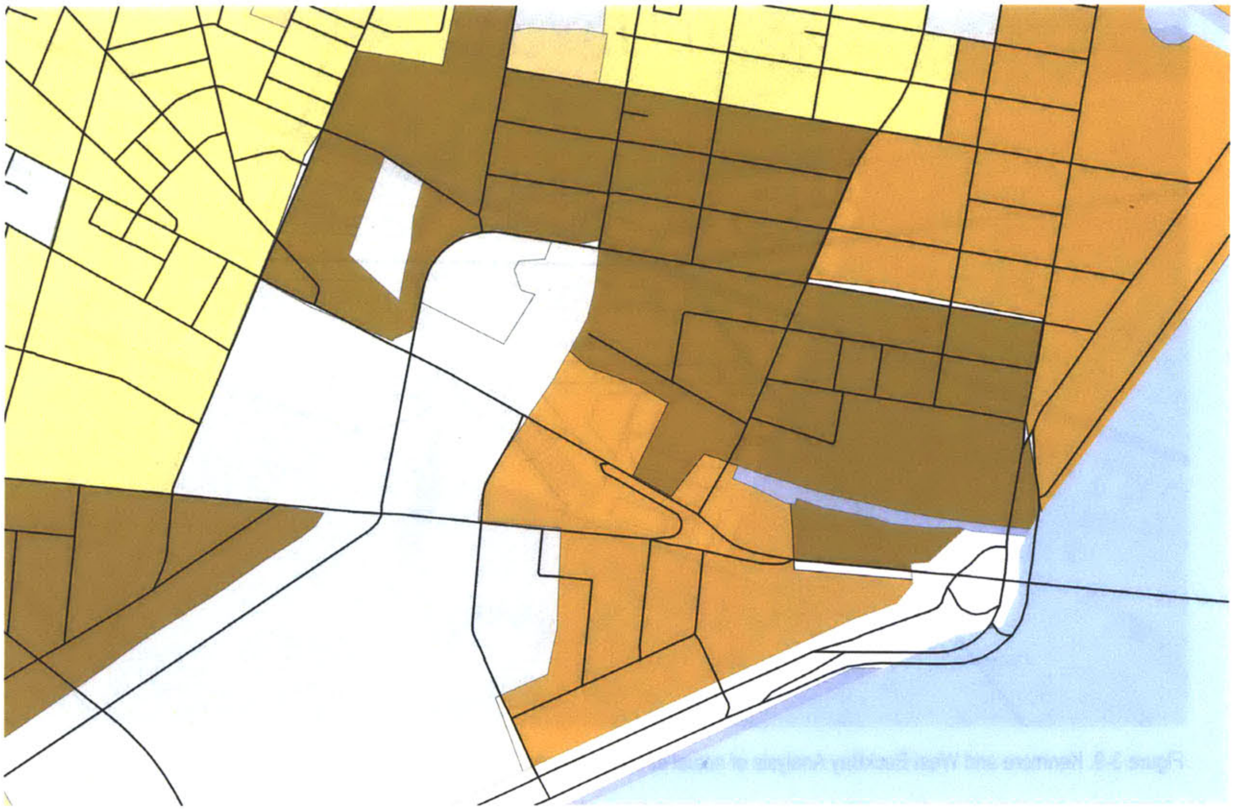


Figure 3-8. Kendall Sq. land use systems (GIS)

Residential
Commercial
Industrial
Exempt ownership
Sport and recreation

3-2-1- How to measure the hypothesis and compare the results with cognitive maps?

The key question to this thesis methodology is to understand how to measure each hypothesis to then compare it with empirical results. To measure this research hypothesis about street properties, it is significant that each hypothesis be measured exactly and unambiguously through mathematical representation of street properties, since each hypothesis explores geometric properties of streets. Moreover, as this thesis explores the relationship between street properties and people's perception, the comparison of actual measured data from streets should be precise to provide reliable evaluations based on the geometric analysis and survey results.

Continuity

The first hypothesis claims that people will remember continuous paths more clearly than interrupted streets. Bill hillier have measured continuity based on axial lines representing the sight-line for each street (Hillier, 1984; 95-97). We argue that sight-line cannot measure

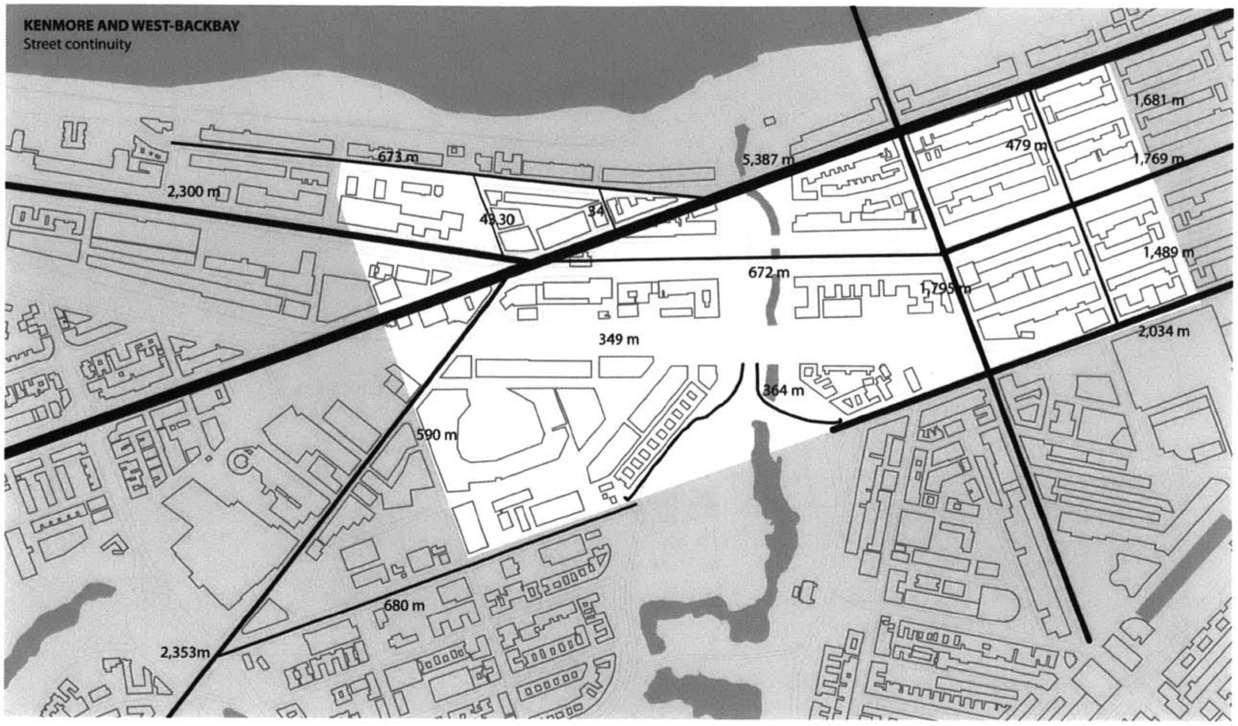


Figure 3-9. Kenmore and West BackBay Analysis of actual street continuity

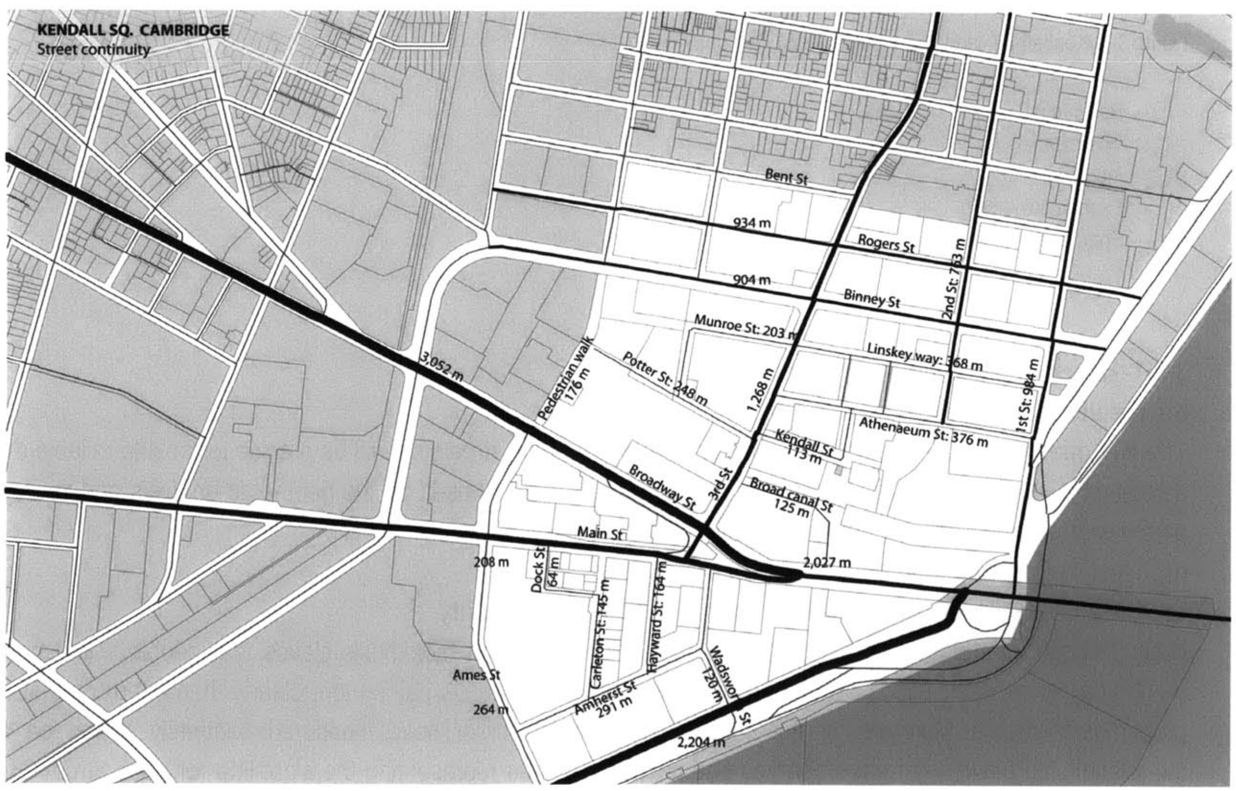


Figure 3-10. Kendall Sq. Analysis of actual street continuity

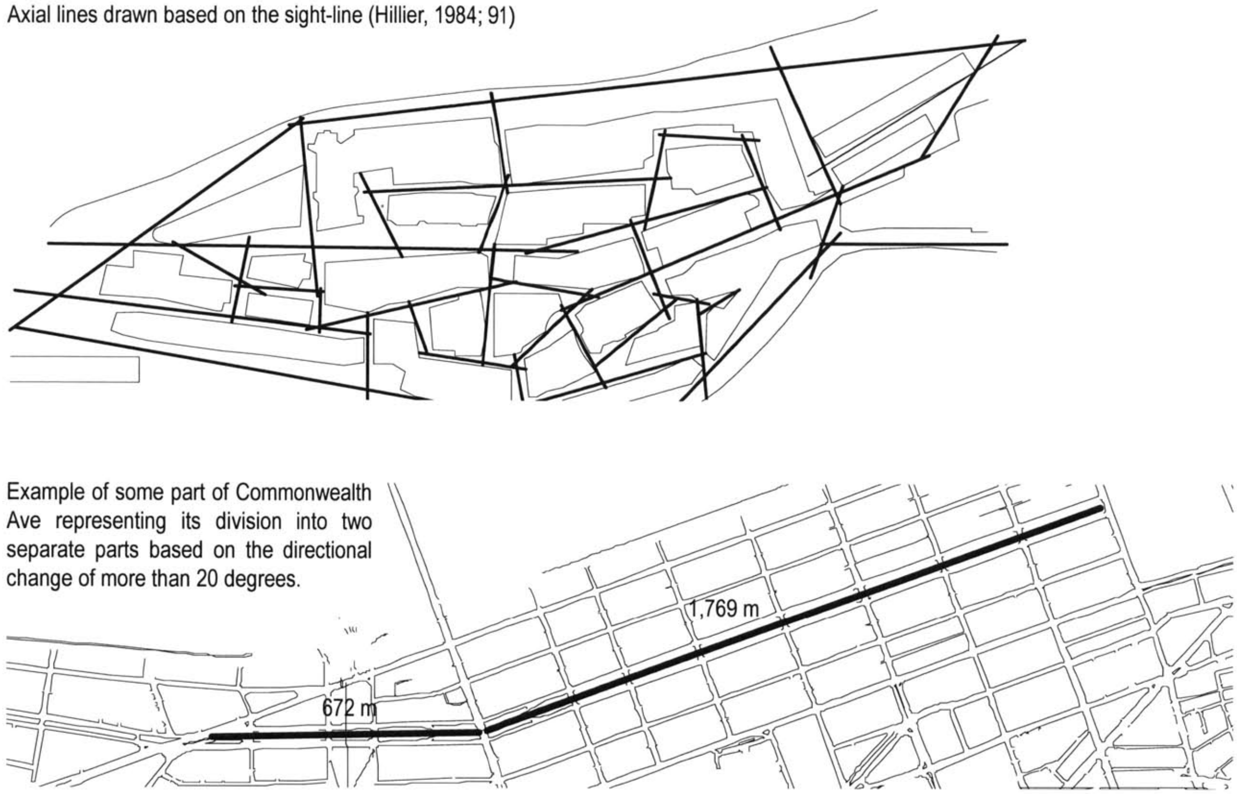


Figure 3-11. Examples of axial lines and the method that this research used to measure continuity

continuity in this study, because the sight-vision has its shortcomings, while people can perceive a street as a continuous line more intuitively. As a result, in this research, I have measured the length of the street, where it neither is interrupted by any buildings nor has a turn of more than 20 degrees (Figure 3-11). I have shown results by different line-weights, in which the line-weight increases based on its level of continuity. I have then compared continuity analysis with a complied map of collected cognitive survey results.

To create cognitive maps based on survey results, two compiled maps are created based on the percentage of "drawn" streets and "accurate" drawn streets from 15 samples in each area of Kenmore and Kendall Sq. I defined accuracy in drawings based on the location of the drawn street and correct curvature without mixing up street names. For example, if 100% of the respondents drew Beacon Street in Kenmore, 53.3% could draw it exactly on its accurate location. To evaluate continuity, therefore, I have compared where streets have more line-weights in both actual street network analysis and in the compiled map from surveys (Figure 3-9, 3-10). I have also tested the quantitative data of continuity and perceived streets using the linear correlation to test if they are correlated.

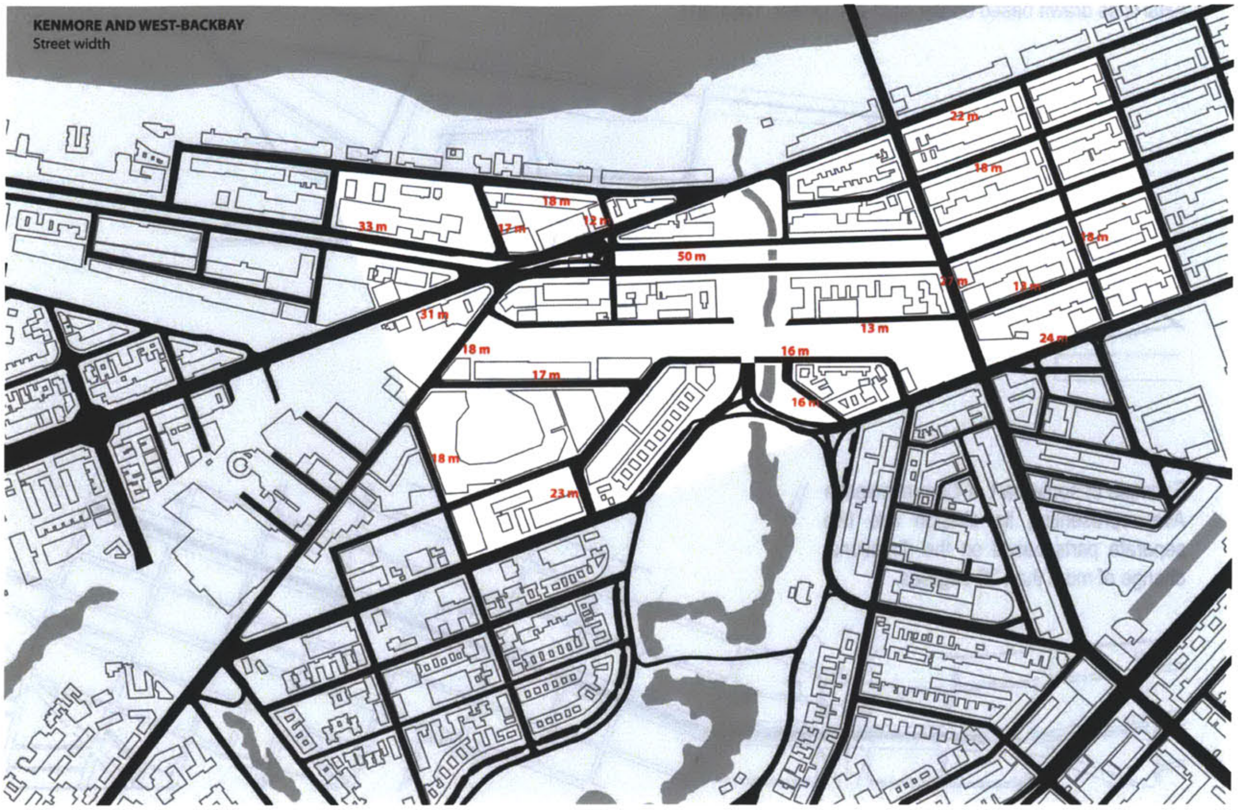


Figure 3-12. Kenmore and West BackBay Analysis of actual street width

Street width

The second hypothesis suggests that people will remember wider streets more easily than narrow streets. To evaluate this hypothesis on actual street representation, I have measured each street width through reading the distance between buildings and have shown wider streets with a thicker line-weight. To measure the percentage of people's perception, I have used the same number of cognitive maps, in which each street was drawn and was drawn accurately. As a result, I could compare the width map showing the location of wider streets with compiled cognitive maps to see if a correlation exists.

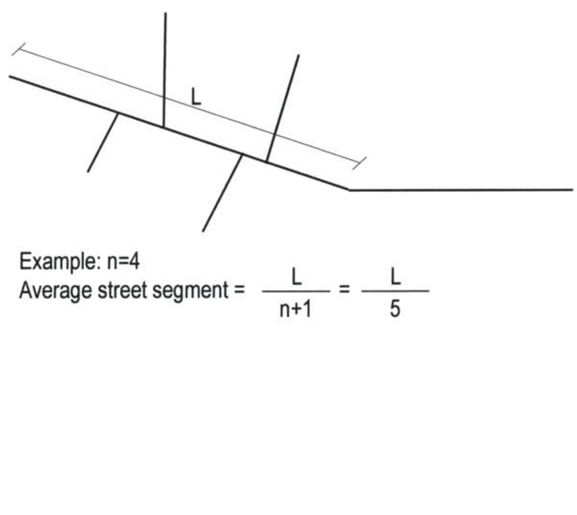
In general, we know that there is a relation between continuity and street width, since continuous streets are often designed wider with regard to the number of daily commutes (Marshall, 2005). Thus, I have run a correlation test to check if I can investigate this hypothesis as a separate assumption from continuity. The correlation test between street continuity and width resulted in a low relation and I decided to check this hypothesis separately (Figure 3-12, 3-13).

Figure 3-13. Kendall Sq. Analysis of actual street width

Average length of street segments

The third hypothesis suggested that people will remember streets with more number of intersections (density of intersection).

To measure this hypothesis and to find a comparable tool for each street, I have measured the number of intersections within the length of the street, which shows the average length of street segments. I have measured the average length of street segments for each street by dividing the length of the street by "n+1". In this measurement method, the length of the street addresses the length based on the definition of continuity for the street, which is neither interrupted by buildings nor have a directional change of more than 20 degrees. In this measurement, "n" represents the number of intersections in that street (Figure 3-14). I have measured the average



Example: n=4

$$\text{Average street segment} = \frac{L}{n+1} = \frac{L}{5}$$

Figure 3-14. Example of this research measurement method for street width

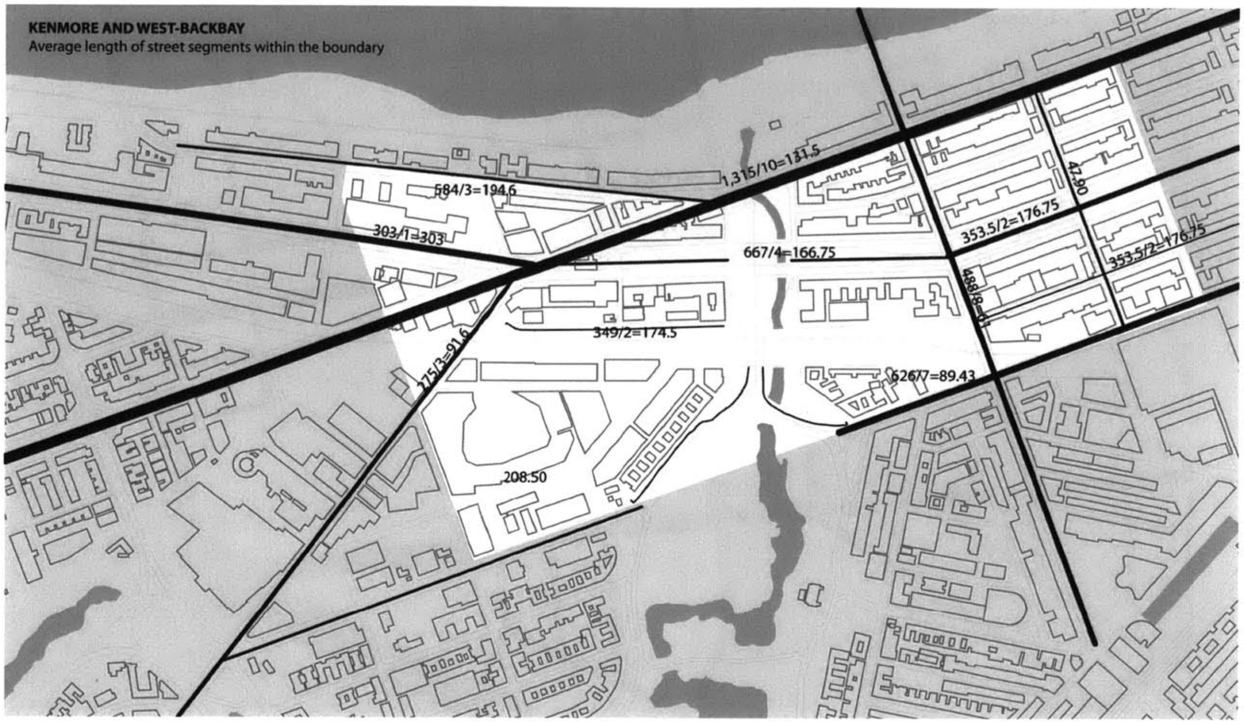


Figure 3-15. Kenmore and West BackBay Analysis of actual average length of street segments

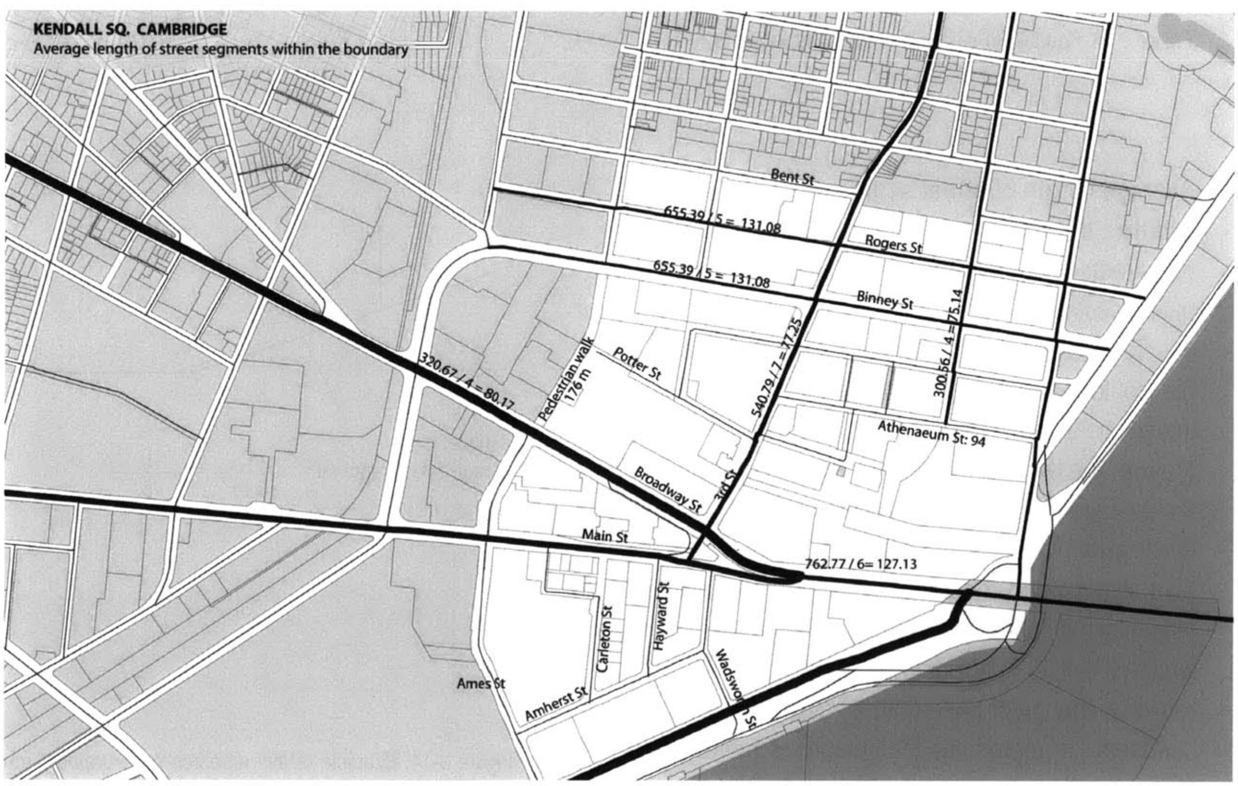


Figure 3-16. Kendall Sq. Analysis of actual average length of street segments

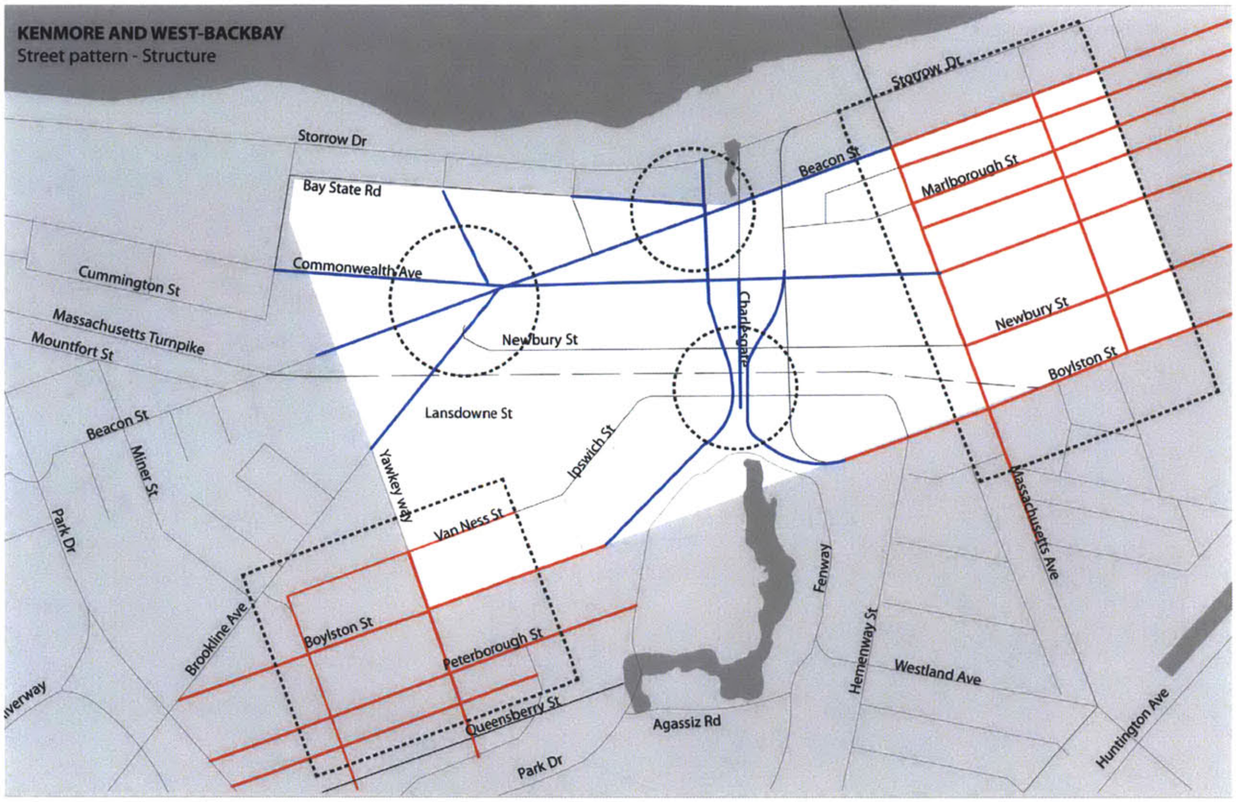


Figure 3-17. Kenmore and West BackBay Analysis of actual street patterns

length of street segments within the total length of the street and within the boundary of this study, where finally I have chosen the data for total length of the street, since they could represent more precise numbers for the average length of street segments. Then, I have visualized the data using the thickness of lines and my assumption was to test if streets with smaller average length of segments are remembered more frequently in cognitive maps. In this case also, I have used the same cognitive map results, indicating the percentage of drawn and accurate drawn streets, as a comparison (Figure 3-15, 3-16).

Street Patterns

Measuring street structures is one of the most challenging analysis in this study, since it is difficult to define what street patterns are. Based on street taxonomies that Stephen Marshall provides in categories of linear, tree, radial and cellular (Marshall, 2005; 93), I have determined two types of street patterns in both Kenmore and Kendall as non-pattern and well-defined pattern. Well-defined patterns can be generated by applying rules to street segments, where we cannot generate specific rules for non-defined street patterns. Well-defined patterns in these two areas consists of grid and star-shape patterns. In this study, grids are defined as street networks with two rules to add parallel or perpendicular streets. Star-shape patterns use the rule, in which streets diverge from the same point as a radial

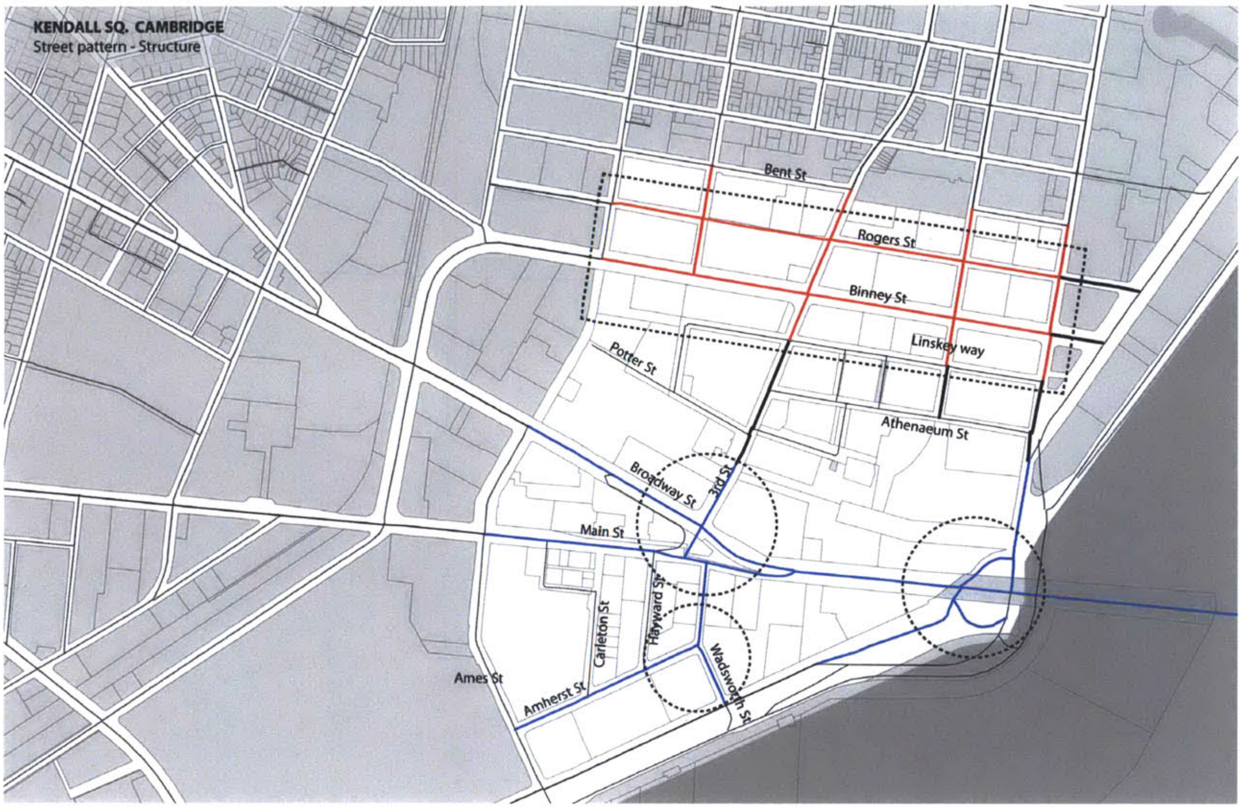


Figure 3-18. Kendall Sq. Analysis of actual street patterns

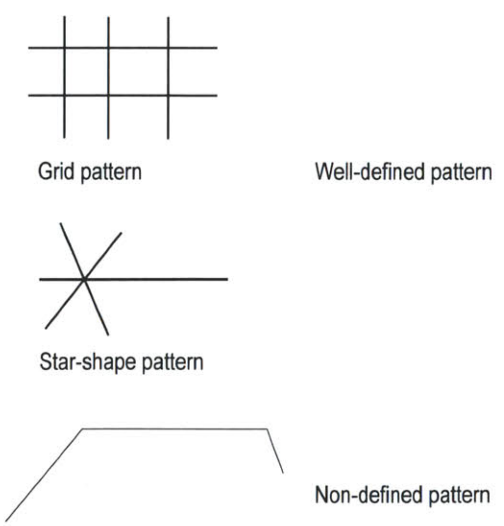


Figure 3-19. Examples of well-defined and non-defined street patterns

configuration (Figure 3-19). The reason that people remember well-defined patterns much easier is related to the recognition of certain rules, whereas non-defined patterns require more information to be remembered as they do not follow geometric rules. Then, I have evaluated each compiled map based on the percentage of recognized well-defined patterns and non-patterns in Kenmore and Kendall sq. from all surveys (Figure 3-17, 3-18). To compare the actual patterns with compiled survey maps, I have tested the linear correlation between well-defined and non-defined patterns with the percentage of perceived street patterns.

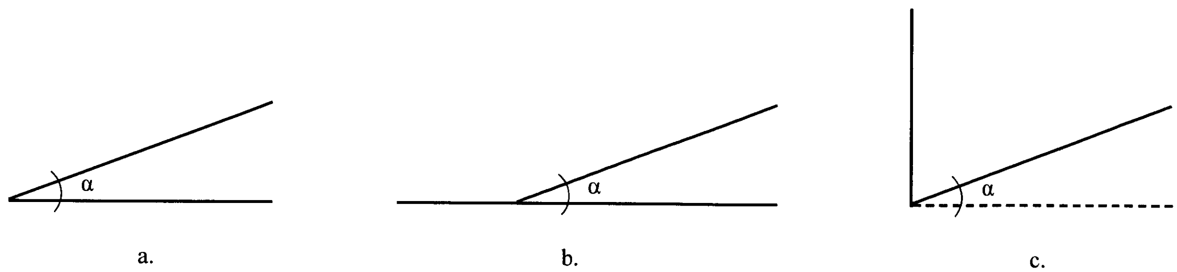


Figure 3-20. Examples representing the logic of angle measurement
a, b. α measures the angle between two streets
c. α measures how much the streets deviates from the perpendicular angle

Street Angles

The last hypothesis suggests that people will better remember junctions with less angular deviation from perpendicular angles. Previous research have found that perpendicular angles are more easily remembered. This measurement basically captures how much street angles deviate from perpendicular angles. I am going to measure angles by defining a continuous variable of the degree between streets for each node. When this degree is more than half of a perpendicular angle, we consider it as the subtraction of the angle between two streets from a perpendicular angle, since people can easily remember angles which are closer to a perpendicular angle. Moreover in junctions with more that one street intersection, we set a street as the base and calculate the deviation between the base and other streets from the perpendicular angle and then, sum the deviations up to designate a number to each node (Figure 3-20). This method is in a direct relation with people's perception by indicating how far an angle between two streets deviates from its nearest perpendicular angle. The less the deviation from a perpendicular angle is, the better people can remember it. As a result, by using this method, my hypothesis can be tested as if nodes with smaller angular deviations are the most perceived ones. (Figure 3-21, 3-22)

The method used to evaluate surveys and compile cognitive maps counts such surveys as perceived results for each node, when people could accurately recognize if the angle was perpendicular or non-perpendicular.

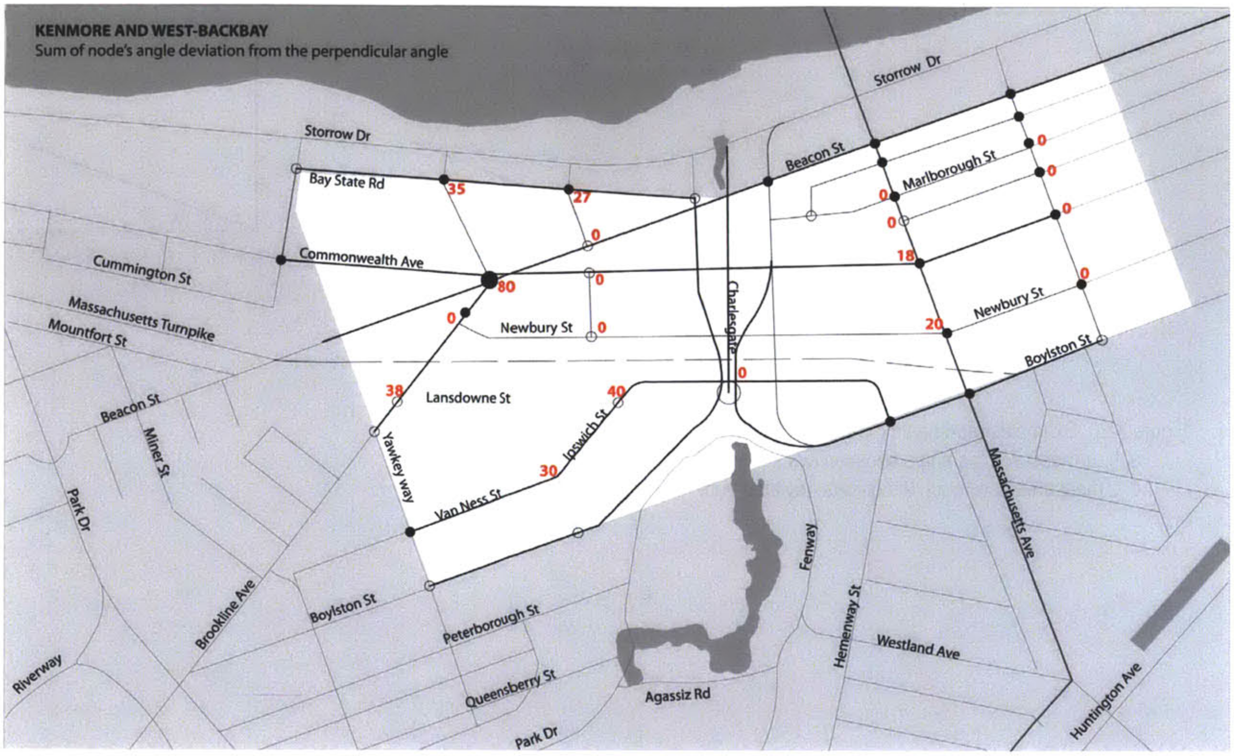


Figure 3-21. Kenmore and West BackBay Analysis of actual street angular deviations

Figure 3-22. Kendall Sq. Analysis of actual street angular deviations

	Average age	Gender		Grown-up Place		Average number of years to reside in the area
		F	M	Urban	Suburb	
Kenmore	25-30 years	46.7%	53.3%	66.7%	33.3%	1 year
Kendall Sq.	25-30 years	46.7%	53.3%	60%	40%	2.2 years

Table 3-1. Kenmore and Kendall Sq. survey respondents statistics

3-2-2- How to compare cognitive maps with graph analysis

The method that this research used is to check if there is a correlation between each geometric property of streets and people's cognitive maps. To be more specific, we can compare each street property map with the compiled perceived map to test how their line-weights are related to each other. For instance, the comparison between the continuity map and perceived streets shows that more continuous maps are better perceived. We have also used collected quantitative data from each street property and perceived streets shown in tables 3-2 to 3-7 for Kenmore and Kendall Sq. respectively. Then, to test the hypothesis, we checked the correlation between each street property and perceived streets for both selected sites using scattered charts.

3-3- Results

3-3-1- Empirical research in Kenmore and Kendall Sq.

The empirical research was basically the results of compiling the data collected from 15 visual surveys in Kenmore and Kendall Sq. (Samples of survey results are shown in the appendix.) In survey samples, I have considered residents within the boundaries, with the same dispersion of age, gender and a balance in the number of years that they reside in that area (Table 3-1). In consequence, I have evaluated cognitive maps of surveys in two criteria of perceived streets and "accurate" perceived streets (Figure 3-23 to 3-26). The results showed a stronger comparison factor between actual street properties and the percentage of perceived streets, and as a result, in scattered charts I have only used the empirical results of the perceived streets.

Kenmore - West Back Bay, Boston
Street Properties

Attribute	Continuity (meters)	Street Width (meters)	Average length of street segments within the boundary (meters)	Street Pattern (0=Non-defined) (1=Defined)	Percentage of perceived streets	Percentage of accurate perceived streets
Beacon St	5,387	22	131.5	1	100%	53.3%
Comm Ave-East Centre West	1,769 672 2,300	50 50 33	176.75 166.75 303	1 1 1	86.7% 86.7% 93.3%	80% 40% 93.3%
Brookline St	2,353	18	91.60	1	100%	93.3%
Massachusetts Ave	1,795	27	61.00	1	100%	100%
Newbury St	1,489 349	13 13	176.75 174.5	1 0	93.3% 33.3%	86.7% 0%
Marlborough St	1,681	18	176.75	1	100%	60%
Ipswich St	633	16	316.5	0	13.3%	13.3%
Hereford St	479	18	47.9	1	25%	25%
Lansdowne St	343	17	343	0	13.3%	13.3%
Van Ness St	417	16	208.50	1	13.3%	13.3%
Charlesgate	388	18	77.60	1	60%	53.3%
Boylston St	364	16	72.80	1	20%	20%
Deerfield Street	145	17	43.30	1	26.6%	13.3%
Raleigh Street	68	12	34	0	20%	20%

Table 3-2. Kenmore and West BackBay table of street continuity, width and average length of street segments compared to empirical results

Kenmore - West Back Bay, Boston
Angles

Attribute	Sum of angle's deviation from the perpendicular angle	Percentage of perceived Perpendicular | Non-P angles
Marlboorough-Mass Ave	0	66.70%
Marlborough-Hereford	0	33.30%
Comm Ave-Mass Ave	18	26.7%
Comme Ave-Hereford	0	33.30%
Newbury-Mass Ave	20	13.30%
Newbury-Hereford	0	0.00%
Ipswich-Lansdowne	40	6.70%
Ipswich-Van Ness	30	6.70%
Brookline-Lansdowne	38	6.70%
Kenmore Node	80	33.30%
Bay State-Deerfield	35	0.00%
Bay State-Raleigh	27	0.00%

Table 3-3. Kenmore and West BackBay table of street angles compared to empirical results

Kendall Square, Cambridge
Street Properties

Attribute	Continuity (meters)	Street Width (meters)	Average length of street segments within the boundary (meters)	Street Pattern (0=Non-defined) (1=Defined)	Percentage of perceived streets	Percentage of accurate perceived streets
Broadway Street	3,052	30	80.17	1	100%	100%
Main Street	2,027	26	127.13	1	100%	100%
3rd Street	1,268	18	77.25	1	93.3%	73.3%
Rogers Street	934	15	131.08	1	60%	60%
Binney Street	904	30	131.08	1	80%	80%
2nd Street	763	15	75.14	1	87%	33.3%
Athenaeum Street	376	9	94	1	40%	40%
Linskey Way	368	9	122.7	1	26.7%	20%
Amherst Street	291	15	97	1	93.3%	60%
Potter Street	248	12	82.7	0	33.3%	20%
Pedestrian Walk	176	3	176	0	20%	20%
Hayward Street	164	9	164	0	66.7%	33.3%
Munroe Street	203	9	101.5	0	13.3%	13.3%
Carleton Street	145	12	145	0	33.3%	26.7%
Broad Canal Street	125	9	125	0	13.3%	13.3%
Wadsworth Street	120	9	120	1	100%	40%
Kendall Street	113	8	113	0	13.3%	13.3%
Dock Street	64	7	64	0	33.3%	33.3%

Table 3-4. Kendall Sq. table of street continuity, width and average length of street segments compared to empirical results

Kendall Square, Cambridge
Angles

Attribute	Sum of angle's deviation from the perpendicular angle	Percentage of perceived Perpendicular | Non-P angles
Rogers-2nd	0	60.00%
Rogers-3rd	26	20.00%
Rogers-5th	0	60.00%
Binney-2nd	0	73.30%
Binney-3rd	26	20.00%
Binney-5th	0	60.00%
Linskey-2nd	0	26.70%
Linskey-3rd	26	6.70%
Athenaeum-2nd	0	26.60%
Athenaeum-3rd	26	6.70%
Broadway-Main	24	100%
Main-Carleton	0	33.30%
Main-Hayward	0	33.30%
Main-Wadsworth	0	46.60%
Amherst-Carleton	32	0.00%
Amherst-Hayward	32	6.70%
Wadsworth-Amherst	32	26.70%

Table 3-5. Kendall Sq. table of street angles compared to empirical results

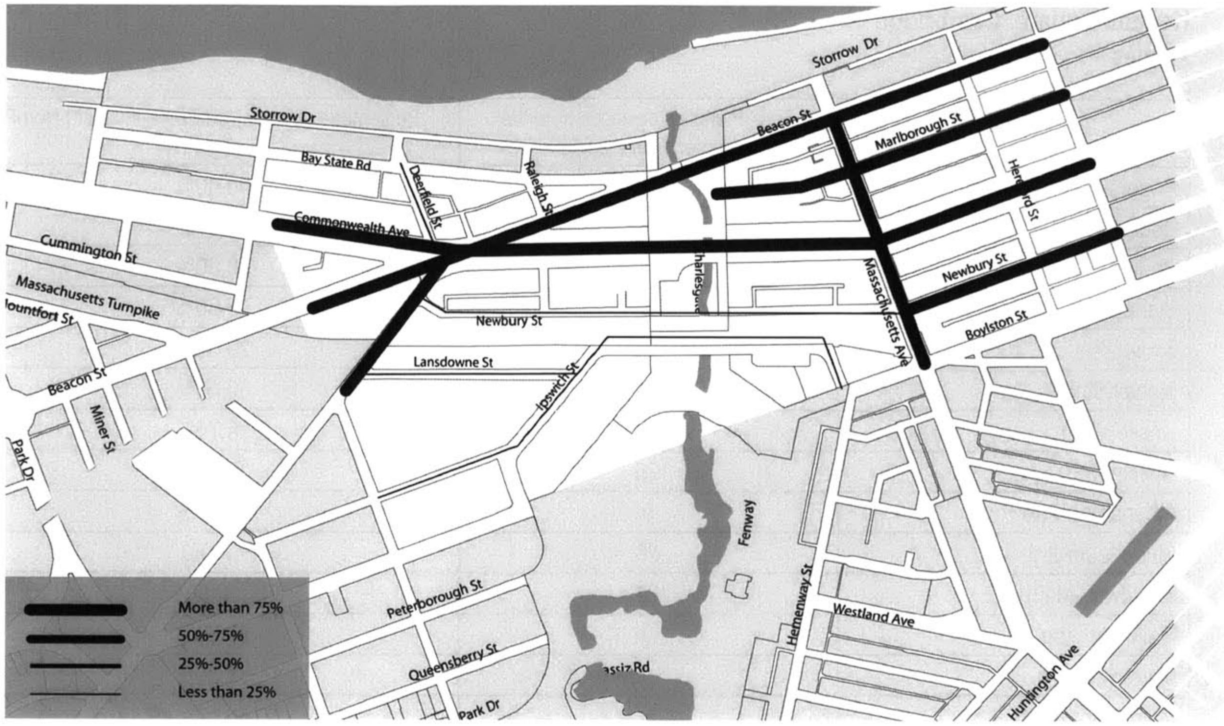


Figure 3-23. Kenmore and West-BackBay compiled map of perceived streets based on surveys

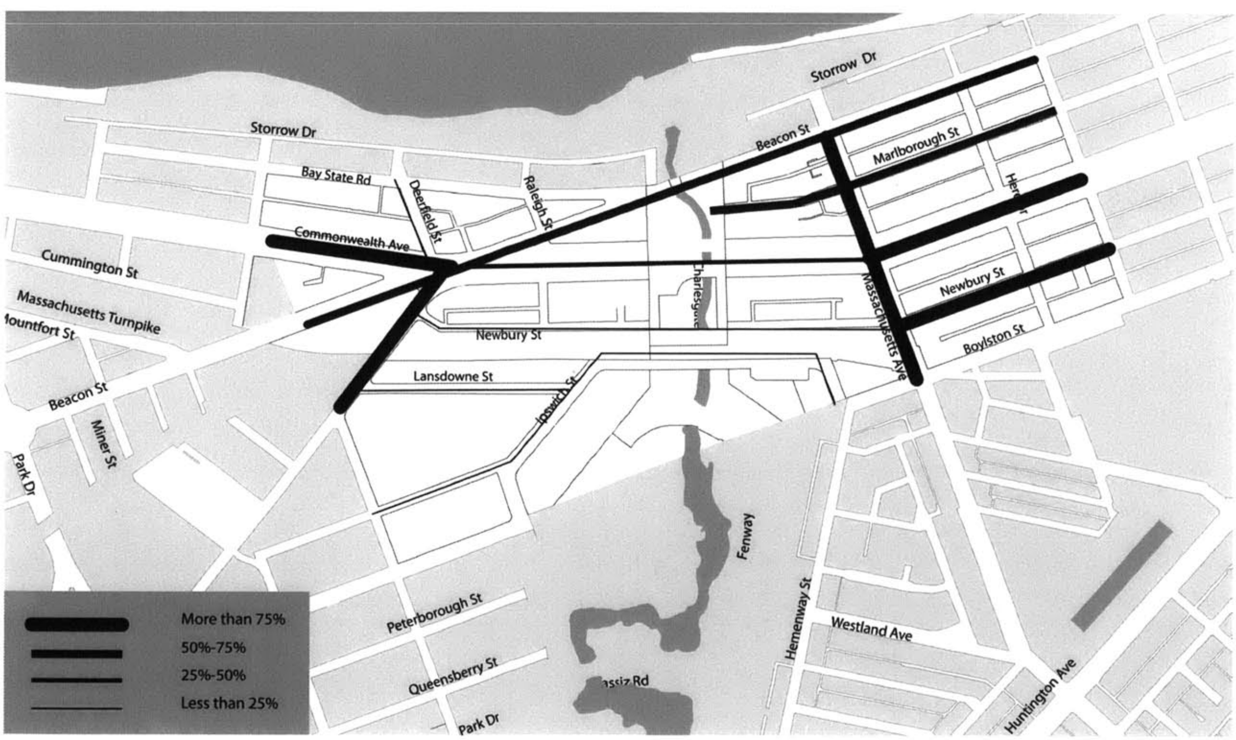


Figure 3-24. Kenmore and West-BackBay compiled map of accurate perceived streets based on surveys

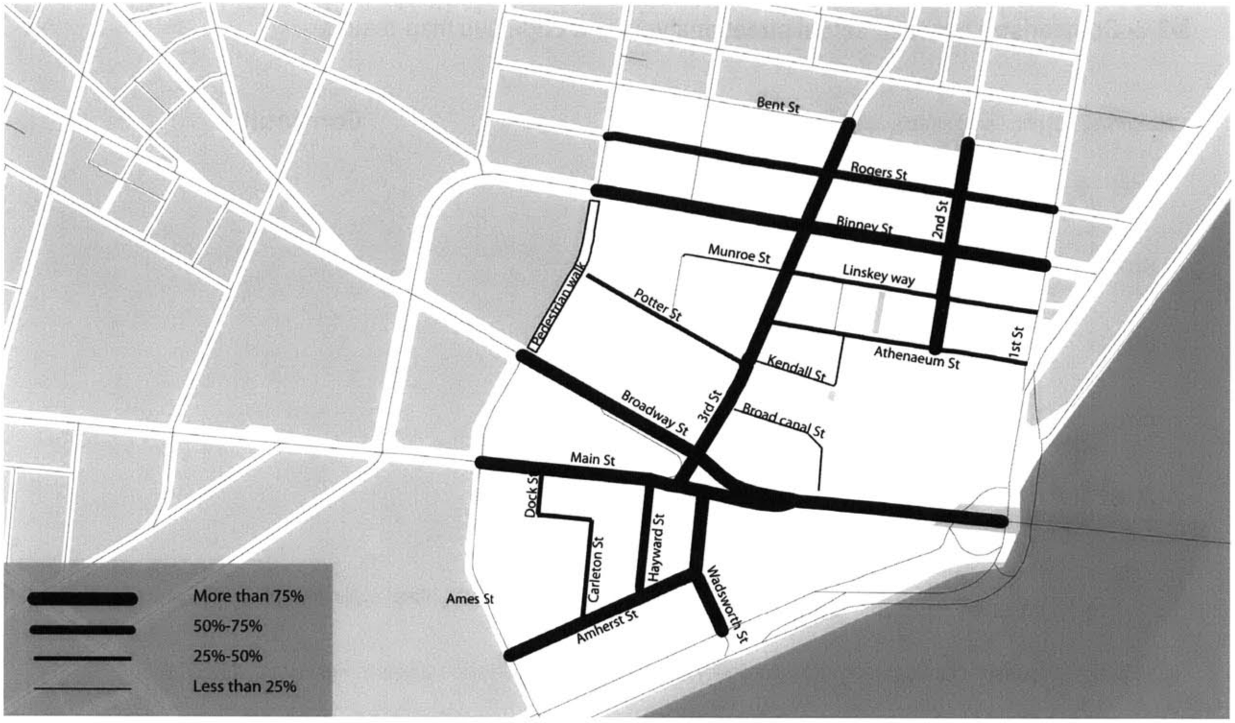


Figure 3-25. Kendall Sq. compiled map of perceived streets based on surveys

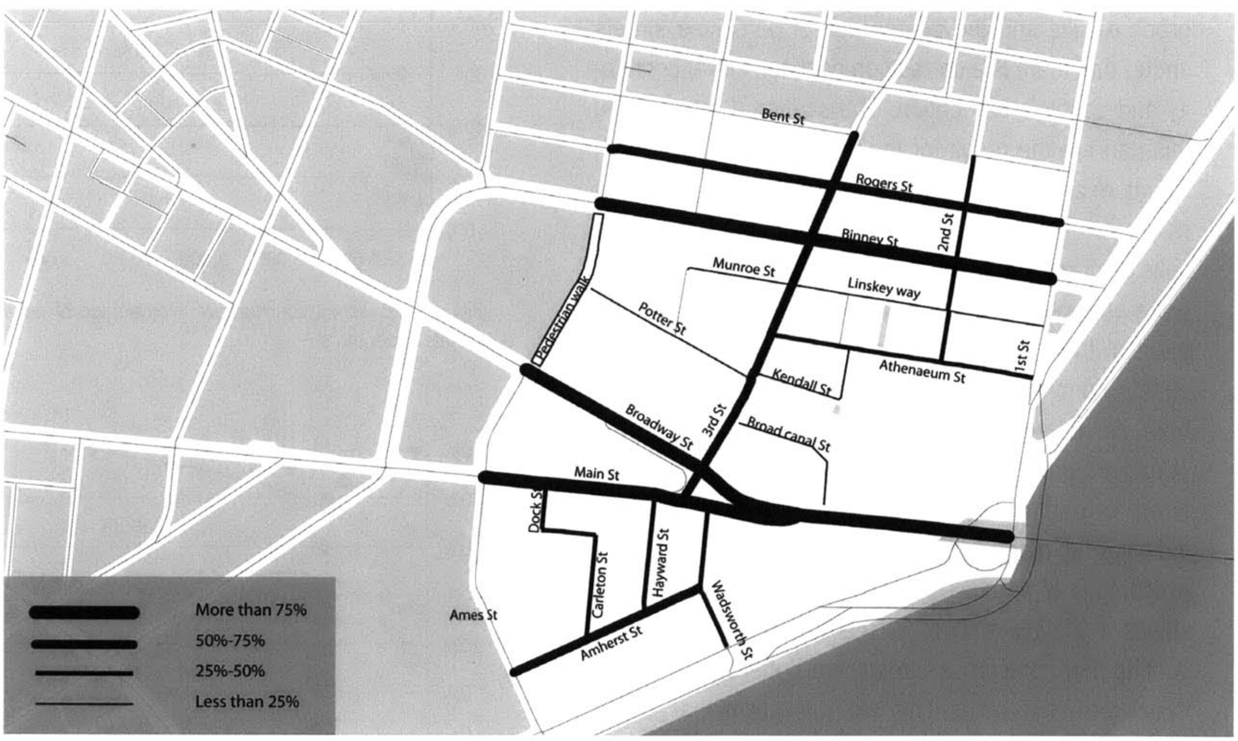


Figure 3-26. Kendall Sq. compiled map of accurate perceived streets based on surveys

3-3-2- Comparison between actual street analysis and cognitive map results

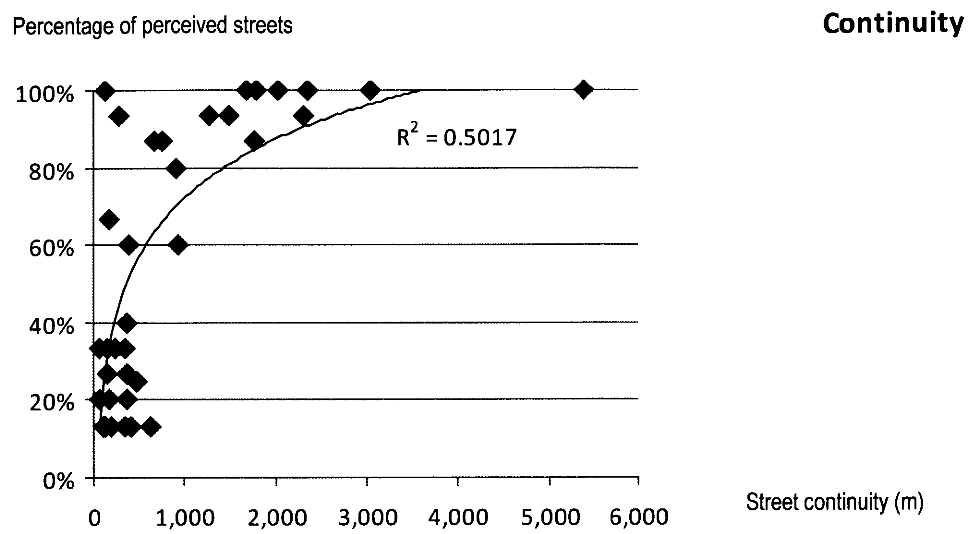


Figure 3-27. Comparison chart between street continuity and percentage of perceived streets in Kenmore and Kendall Sq.

Continuity comparison results

The comparison between the data set for continuity graph results and the percentage of perceived streets shows that there is a correlation between street continuity and people's perception. The scattered diagrams in this part are the result for the compiled data from both Kenmore and Kendall square, which gives us a sample size of 30. Figures 3-28 and 3-29 shows separate results of street continuity and people's perception in Kenmore and Kendall Sq. respectively. I would also like to mention that I have used the percentage of perceived streets compared to each geometrical property, since both percentages of perceived streets and accurate perceived streets are very close to each other. The scattered diagram above represents the R^2 of 0.5, which indicates a high correlation between continuity and percentage of perceived streets. As a result, this study shows a positive answer for the first hypothesis investigating that continuous streets are better remembered than interrupted routes. This finding explains that people in this study area appear to recall continuous streets more completely (Figure 3-27).

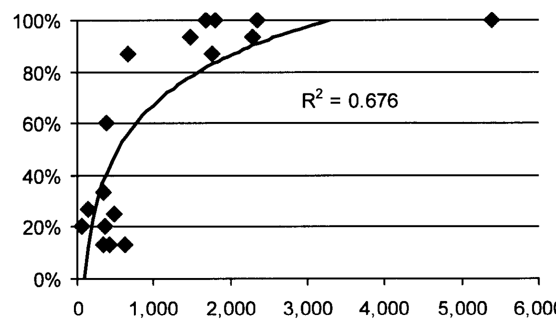


Figure 3-28. Street continuity vs. Percentage of perceived streets in Kenmore

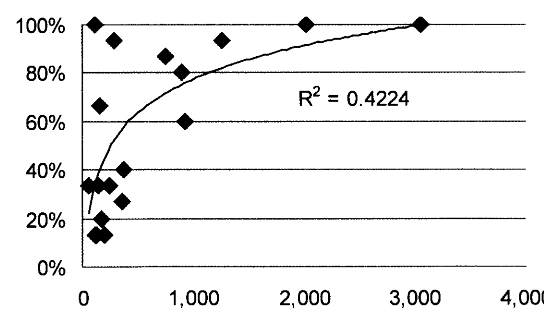


Figure 3-29. Street continuity vs. Percentage of perceived streets in Kendall

Street width

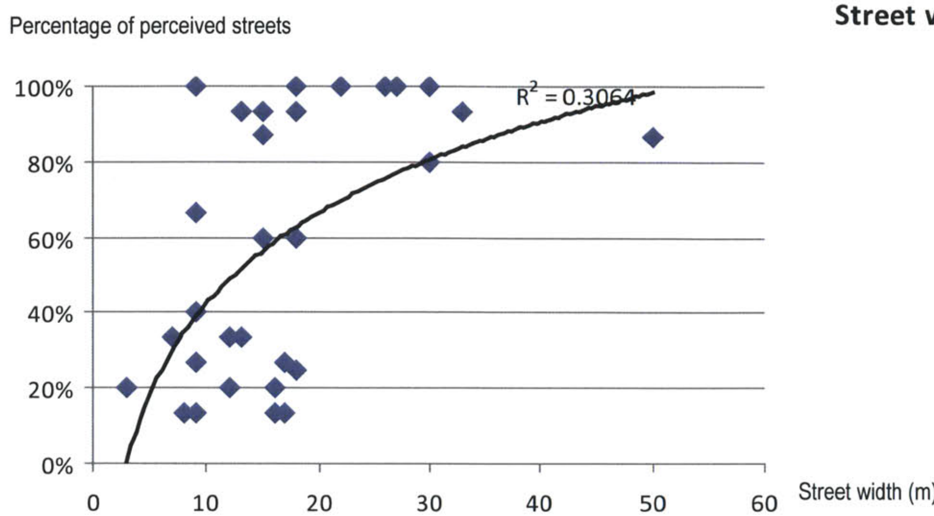


Figure 3-30. Comparison chart between street width and percentage of perceived streets in Kenmore and Kendall Sq.

Street width comparison results

The comparison between the street width and percentage of perceived streets shows that these variables are also correlated, since the R^2 of more than 0.3 indicates a considerable relation between the factors. Figures 3-31 and 3-32 illustrate the correlation between street width and people's perception in Kenmore and Kendall Sq. respectively. These plots suggests a higher correlation between street width and people's perception in Kendall Sq, probably because of the higher distribution of street widths in Kendall. Graphic representation of streets widths and compiled maps for each area also represents that where streets are wider, the percentage of drawn and accurately drawn streets are higher. Width and continuity are probably related to each other, but as it was discussed in the methodology part, we decided to compare them separately because of the trivial correlation between continuity and width. Thus, I conclude that street width is also directly correlated to people's perception, since people use wider routes more frequently (Figure 3-30).

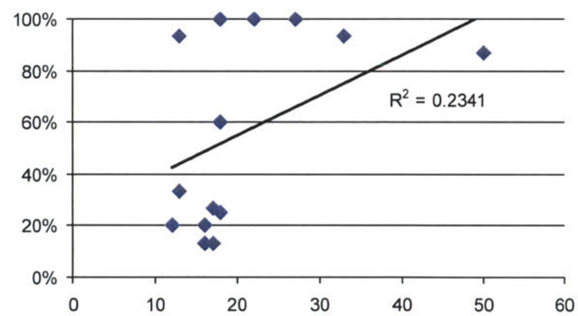


Figure 3-31. Street width vs. Percentage of perceived streets in Kenmore

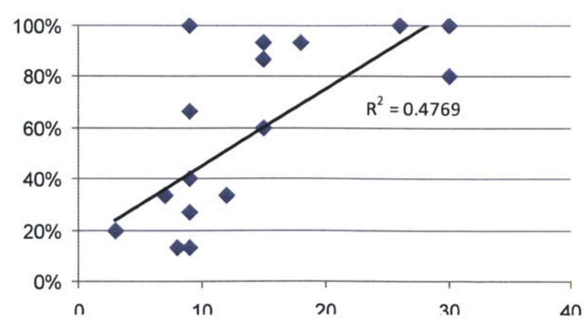


Figure 3-32. Street width vs. Percentage of perceived streets in Kendall

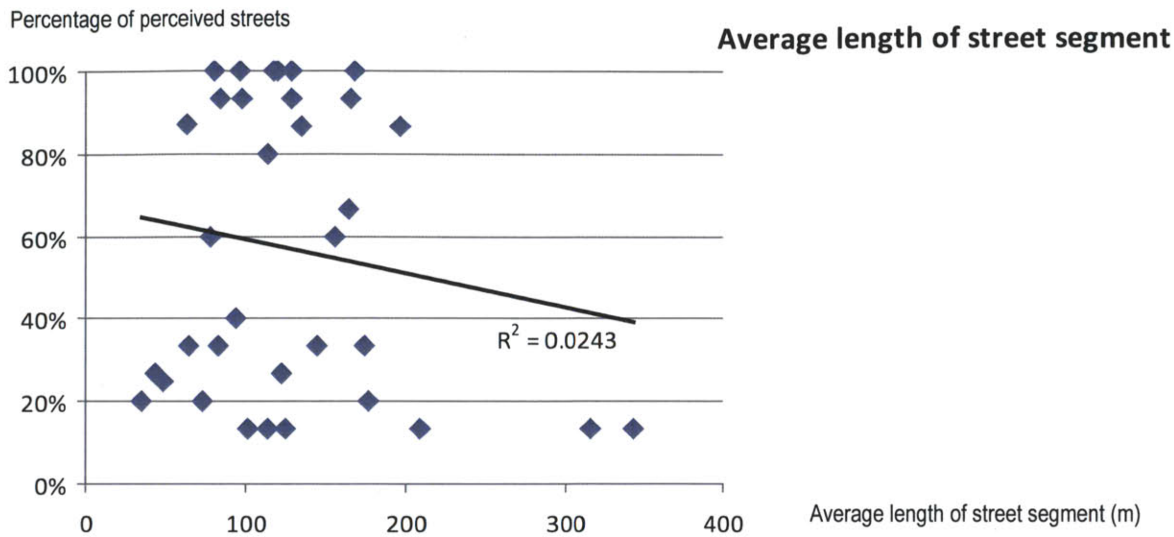


Figure 3-33. Comparison chart between average length of street segments and percentage of perceived streets in Kenmore and Kendall Sq.

Average length of street segments comparison results

I have analyzed this comparison based on the correlation between average length of street segments within each boundary and both the percentage of drawn streets and accurate drawn streets. The scattered diagram shows a low and negative relation between them with a R^2 of 0.02. As a result, my evidence does not suggest that average length of street segments on a given street affect people's perception (Figure 3-33). Moreover, because of a small sample size of 30, we cannot also reject this hypothesis. Thus, further studies can explore if people's perception are dependent from number of intersections. Alan Jacob's work on streets suggested that two-dimensional urban maps provide the possibility to measure street properties such as number of intersections and the distance between intersections, to know how far people may travel before making choices. On the one hand, he mentions that fewer number of intersections means diminishing choices and perhaps freedom, since each intersection represents an available route choice. On the other hand, if the street and block patterns are extremely small and complicated, large number of choices may result in confusion (Jacobs, 1993; 260-266).

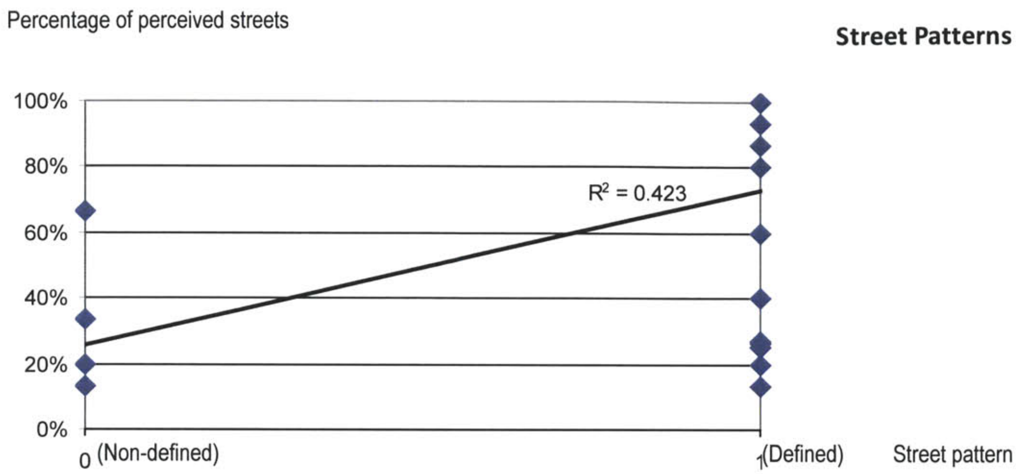


Figure 3-34. Comparison chart between street patterns and percentage of perceived streets in Kenmore and Kendall Sq.

Street Pattern comparison results

Street pattern comparison results show that in both Kenmore and Kendall square people could draw and recognize grid type and star-shape patterns with an average of 86.65% and 93.3% respectively; however, the number of perceived non-patterns streets decreases in both areas. To test if there is a correlation between street patterns and percentage of perceived streets, we assigned 0 to "Non-defined streets" and 1 to "Defined streets." The scattered diagram also indicates a correlation between street patterns and the percentage of perceived streets with the correlation of 0.42, which shows how well-defined street patterns were better perceived. This study, therefore, provided positive results for the fourth hypothesis investigating if people can better remember well-defined street patterns than non-defined structures (Figure 3-34).

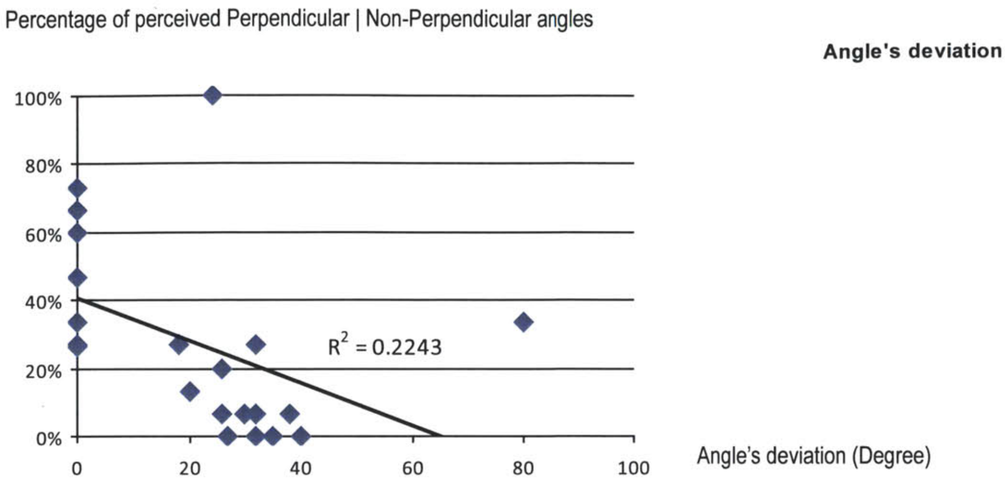


Figure 3-35. Comparison chart between angle's deviation and percentage of perceived Perpendicular | Non-Perpendicular angles in Kenmore and Kendall Sq.

Street angles comparison results

The correlation of street intersections' angular deviation from perpendicular corners appears negative, suggesting that more complex angles are less remembered. This experiment shows that smaller deviations from the perpendicular angles can result in better perceptions, while angles which are far from complete angles or junctions with various angular deviations can cause misinterpretations in people's minds. The scattered diagram also represents that deviations more than 45 degrees, which we assumed is difficult to perceive, does not show more than 40% in people's perception. As a result, the data suggests that this hypothesis about the impact of street angles on people's perception, holds (Figure 3-35). The correlation plot also addresses another point about the nodes with more number of intersections. As we see, there is a rise in perception axis for two points of Kenmore (80 degrees) and Kendall Sq. (26 degrees). I argue that nodes with more number of intersections can be better remembered, as they provide more choices. Since nodes with more number of intersections create star-shape patterns, we have also tested this hypothesis in the perception of street patterns. Thus, the results showed that larger deviations from perpendicular angles are less remembered, whereas nodes with more number of intersections are better remembered.

CHAPTER 4

CHAPTER 4: CONCLUSION

This study made an effort to evaluate how different geometric properties of street patterns impact people's memory and perception of those streets. Kevin Lynch in 1960 argued that paths, edges, districts, nodes and landmarks are the basic elements that formed an environmental image in people's mind, and using these elements evaluated if a city had a better or worse image. Other studies by Jonge in Amsterdam, Appleyard, Stea and Wood (Downs and Stea, 1979; 84-5) also followed the same approach to evaluate people's perception based on Lynch's city elements. These pioneering studies initiated a relationship between urban planning and people's perception of a city. In this study I have focused on different impacts of street properties on people's perception. The methodology that we used to test our hypothesis was formed based on the level of completeness of cognitive maps, not based on a good or bad image. I have argued that the completeness of the memory of a place demonstrates the extent to which physical patterns of the built environment lend themselves to cognitive representation and therefore explain whether certain types of streets and street patterns are systematically more completely remembered than others. If this is the case, then urban planners might need to develop a much better understanding of how environmental geometry is perceived by its users. I argue that completeness of maps can reflect the extent, to which an urban area can spatially be recognized. I conclude that an urban area, which is completely perceived can show that it was spatially recognizable. This sense of recognition of the environment can result in the sense of identity.

Kevin Lynch also investigated the relation between the memory of a place and one's sense of identity, which results in a more comfortable feeling of a place. He argued that a clear sense of urban environments that people inhabit, is intricately related to their self-identity and place in society (Lynch, 1960; 6) A comfortable environment, of which people have a more complete memory, could thus improve these qualities of identity and belonging. The more people feel that they belong to an area, the safer they feel. Designers, therefore, should pay more attention to attributes of places that create stronger images.

However, Lynch was short in proposing the ways that allow planners to create environments with a stronger image. Other studies in environmental perception have only looked at the relation between spatial concepts and people's perception. For instance, Piaget's study on the development of spatial topology in children argues that children can learn concepts of a generalized geometry such as proximity, separation, spatial succession and enclosure (Hillier, 1984; 47); while he does not contend which environmental changes can augment people's perception and spatial learning. Hence, this study was an attempt to scrutinize particular geometric properties of streets and street patterns which could affect people's perception. In this chapter, I discuss the ways that this study can lead to design implications to provide stronger images of the environment.

In order to make the comparison between street properties and people's perception operational, this thesis looked at the literature in how cognitive maps and street properties were defined and made an attempt to connect them. In chapter 1, the concepts of cognitive mapping and spatial cognition were uncovered. Chapter 2 looked at street properties through examining the literature in street patterns and different measurement methods of the built environment. Having extracted street properties influencing people's perception. I then selected two sites in Boston and proposed research methodology based on comparing actual street analysis with the completeness of perceived cognitive maps. To select different geometric characteristics of street networks, I looked at street properties such as continuity, width, average length of street segments, street patterns and angles in different intersections. As a result, to evaluate geometric properties of streets, I have measured actual street properties and compared them with the empirical surveys where residents of corresponding areas were asked to draw their street patterns from memory.

The results showed that continuity, street width and pattern had a strong effect on people's perception. We did not find enough evidence to suggest a relationship between average length of street segments and people's perception. Moreover, this study represented that among recognized streets, less deviation from perpendicular angles resulted in better understanding and a more clear memory of that intersection. There are, therefore, certain design projections that suggest how to design streets such that they can be more completely remembered.

Implications in design

Urban development strategies and design disciplines for new urban areas can be affected by guidelines, provided based on configurational studies to create places with more complete images in people's mind. Although, there are certain different environmental characteristics other than street network geometry which can improve the level of completeness of cognitive maps, this study tried to control some of them by selecting the same size and land use patterns in each area. First, the results in continuity indicate that more continuous streets provide stronger images in people's minds. Thus, designers can take into account the idea to employ continuous streets, since continuous paths are more used as they provide more links to connect shorter paths. There should also be a hierarchy to have a combination of continuous streets versus interrupted paths.

This brings me to my next argument about the ways that designers can consider street width. Often, the width of streets is interwoven with their length; however, this street property can solely create a sense of hierarchy and memory, since people's ability to encode and decode the environment differs based on the width of perspectives that they perceive. As a result, this study suggests that street widths could be used as a guideline to create hierarchies in neighborhoods. Street patterns, the next street property investigated in this study, indicated that people had a more complete memory of well-defined patterns than non-defined street networks. Places with clear street patterns, such as "grids" and "stars", were more completely remembered. This finding could also suggest a design guideline for newly developed urban fabric.

Street angles, the last street property investigated in this thesis might also suggest design guidelines. For instance, having nodes with different number of intersections can create a hierarchy in nodes and as a result, people can distinguish them much easier. On the one hand, important nodes where an unusually high number of streets intersect can be remembered easily. On the other hand, such intersections form angles which deviate from easy to remember perpendicular angles do not generate a clear orientation in people's minds. Design strategies, therefore, find it instructive to create important nodes, but at the same time be aware of the confusion that complicated street angles could generate in people's minds. We emphasize, however, that our sample sizes in this study have been far too small to suggest a strong relationship in all these cases and argue that more studies are needed to confirm these effects.

Research Limitations

This research came across several limitations, since it has only dealt with one feature of the built environment as street properties. Hence, this study was short to provide other influential factors such as the impact of land use systems, environmental topography, etc. This research was also limited to five street properties, while other street characteristics can be explored in different areas. For instance, in this research street patterns were limited to two types of grids and star-shapes, while these two types do not cover all types of street patterns. The sample size in this study was small and did not distinguish between the respondents who owed a car or pedestrians, who walked everyday. This study, as a result, was limited to suggest design guidelines, where further research in this criteria can result in proposing design guidelines for urban designers and planners.

Future research

Future steps can be made to push configurational studies further to investigate the relationship between street properties and people's perception. First, there are possible effective ways to test other street properties, which this study was short to provide. For example, the level of curvature of streets can be further explored. Second, future directions can uncover and control the impact of land use systems on people's perception of streets. For instance, one of the interesting questions in this area can address how the dispersion of retail services affects people's perception along different streets. Moreover, this study can also be extended by comparing other sites with more geometrical diversification in Boston or other cities and by comparing urban and suburban areas to test the way that people perceive them. Next steps can investigate attaining larger survey samples in order to test the significance of the results using regression methods. In each of these future directions, researchers should take into account differences in land use, population and size of their selected study areas to control other influential factors in people's perception of street networks. The results of such studies, therefore, can lead into design guidelines and projections.

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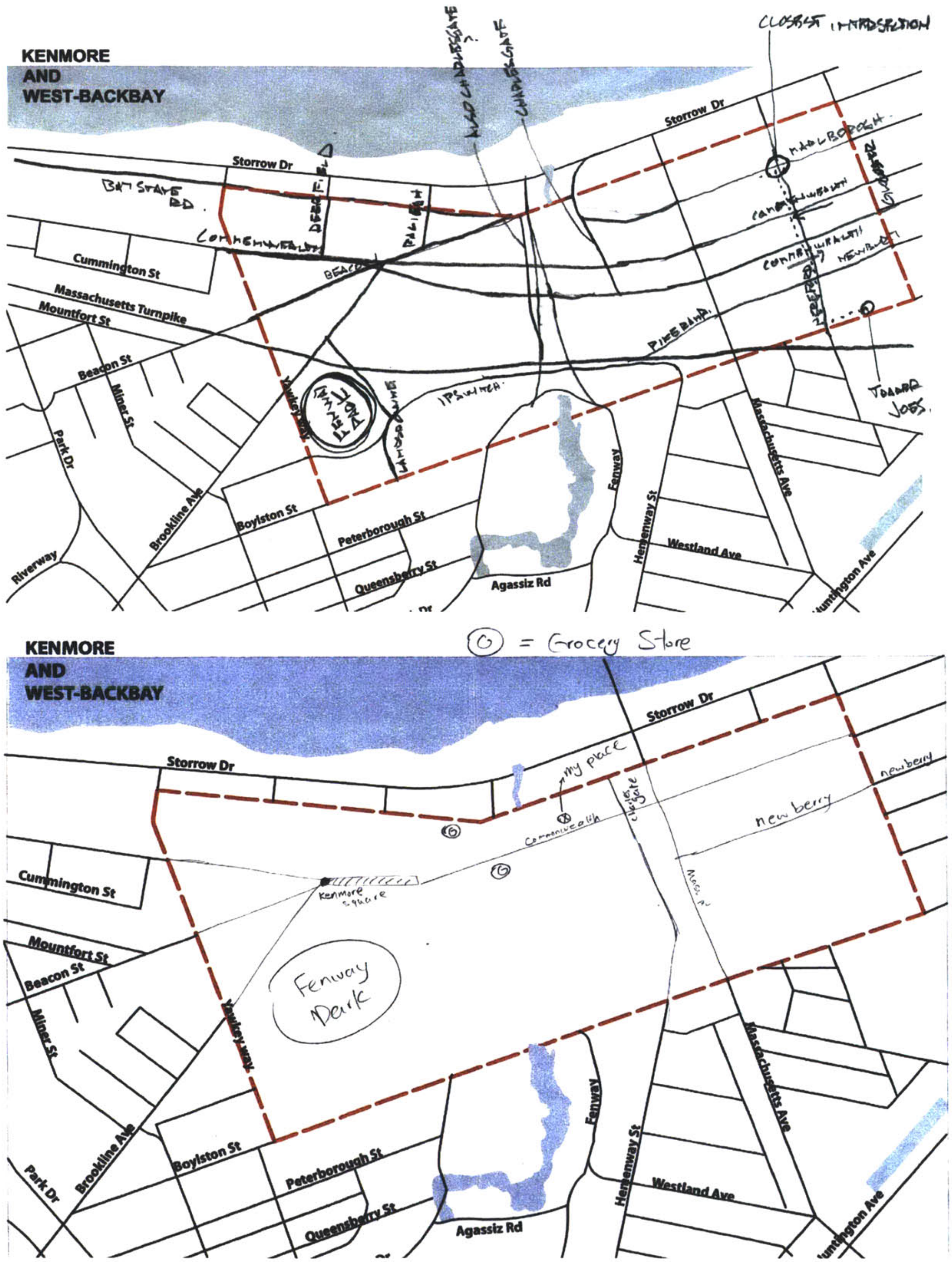
APPENDIX

The following cognitive maps show some survey results of this thesis. It illustrates how people responded to the drawing survey and how I collected data to compile maps in Kenmore and Kendall Sq.



Appendix Figure 1. Two samples of survey results in Kenmore and West-BackBay

Appendix Figure 2. Two samples of survey results in Kendall Sq.