How Human Schematization and Systematic Errors Take Effect on Sketch Map Formalizations

Master Thesis

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Submission Date: 2009-03-02

Abstract

Sketch map is an important way to represent spatial information used in many geospatial reasoning tasks (Forbus, K., Usher, J., & Chapman, V. 2004). Compared with verbal or textual language, sketch map is a more interactive mode that more directly supports human spatial thinking and thus is a more natural way to reflect how people perceive properties of spatial objects and their spatial relations. One challenging application of sketch maps is called Spatial-Query-by-Sketch proposed by Egenhofer. Being a design of query language for geographic information systems (GISs), it allows a user to formulate a spatial query by drawing the desired spatial configuration with a pen on a touch-sensitive computer screen and get it translated into a symbolic representation to be processed against a geographic database (Egenhofer, M. 1997).

During the period of sketch map drawing, errors due to human spatial cognition in mind may occur. A ready example is as follows: distance judgments for route are judged longer when the route has many turns or landmarks or intersections (Tversky, B. 2002). Direction get straightened up in memory. When Parisians were asked to sketch maps of their city, the Seine was drawn as a curve, but straighter than it actually is (Milgram, S. and Jodelet, D. 1976). Similarly, buildings and streets with different shapes are often simply depicted as schematic figures like blobs and lines. These errors are neither random nor due solely to ignorance; rather they appear to be a consequence of ordinary perceptual and cognitive processes (Tversky, 2003). Therefore, when processing sketch map analysis and representing it in a formal way, like Egenhofer's analysis approach for Spatial-Query-by-Sketch, the resulting formalization must necessarily be wrong if it does not account for the fact that some spatial information is distorted or omitted by humans. Therefore, when sketch map analysis is processed and represented in a formal way same as Egenhofer's analytical approach to Spatial-Query-by-Sketch, the resulting formalization is simply erroneous since it never takes into account the fact that some spatial information is distorted or neglected in human perceptions. Though Spatial-Query-by-Sketch overcomes the limitations of conventional spatial query language by taking into consideration those alternative interaction methods between users and data, it is still not always true that accuracy of its query results is reliable.

This thesis investigates the above issue by exploring the impact of human schematization and systematic errors on Egenhofer's approach for sketch map analysis. 10 experiment participants are asked to draw maps of two small areas with approximate space of $0.21km^2$. They are all familiar with the areas and able to finish their tasks with their inner eyes. The experiment gives the clue to how to modify Egenhofer's approach for sketch map analysis, that is, it will tell us which are cognitively important criteria of the sketch map and which are of less importance. There are two main steps in the experiment analysis: (1) to compare with the map of the reality and abstract inaccuracy or errors people made to find significant influential factors; and (2) to analyze these factors individually to see how they work in the framework of Egenhofer's approach to sketch analysis. As a wrap-up, modifications are suggested to improve so as to enhance Egenhofer's approach to sketch map analysis, especially its cardinal directions.

Acknowledgments

Technically, this thesis documents the study and research work I have completed in the Master Program in Geospatial Technologies[1]. On a personal note, as a foreign student new to Europe, the one year and a half study is an adventure of learning, friendship, maturation, and appreciation. All the people that have been part of this adventure deserve my gratitude.

Sincere thanks go to my supervisor Dr. Angela Schwering who guided me to the field of spatial cognition, encouraged me all the time, and helped to sharpen my research muscles and stay focussed on the present topic. I always obtained much valuable knowledge after discussions with her. Her advice, guidance, positive outlook and warm encouragement are invaluable.

My heartfelt thanks will also give to my other committee members, Prof. Dr. Werner Kuhn, Prof. Dr. Marco Painho and Dr. Pedro Cabral. Many thanks also to the staff from Universitat Jaume I and Insititue for Geoinformatics (IFGI). In addition, special thanks to all the experiment participants who are Jens Ortmann, Tanmoy Das, Rania Sabrah, Ledjo Seferkolli, Chunyuan Cai, Zhelu Ye, Song Li, Daniel Manso, Yikealo Hayelom, Massimiliano Livi, Denise Schlutow and Massimiliano Cecconi.

Thanks also go to my classmates and friends whom I met in Spain and Germany. It was the first time that I was so far away from home. Without your encouragements, support and friendship, I cannot imagine how helpless and bleak the life would be.

I will never forget to say thank you to the key Laboratory of Virtual Geographic Environment (VGE) so named by China Education commission and its director and my supervisor Prof. Dr. Guonian Lu. Thanks for his support and all the knowledge I earned during my 6-year study of GIS before 2007.

Last but not the least, I owe unaccountable debts to my loving parents who have been supporting and encouraging me incessantly when I began to know what support and encouragement were. Their broad-mindedness and vigorous endurance in life are what I always depend on in making my adventure in Europe a success with great interest.

1 Selected by Erasmus Mundus, project reference: 2007-0064/001 FRAME MUNB123.

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Chapter 1
Introduction

In order to extract useful information of objects properties and their spatial relationships from sketch maps, it is necessary to do the sketch analysis on the basis of internal sketch representations. Experiments in psychology and cartography show that topology is among the most critical information people refer to when they assess spatial relationships in geographic space, while metrical changes are frequently considered to be of less importance (Egenhofer, 1997). The sketch analysis approach by Egenhofer discussed in this thesis is based on such premises as *topology matters*, and *metric refines* (Egenhofer, M., Mark, D. 1995), so as to sustain the present study in this thesis. With participants being asked to draw specific spatial scenes, we investigate the existing computational model for sketch analysis from Egenhofer as well as the laws and theories in spatial cognition from psychology. The anticipated results of this study are: (1) an evaluation of the extent to which Egenhofer's approach can be applied to formalize sketch maps drawn by humans and; (2) the modification of Egenhofer's approach to account for schematization and systematic errors humans typically do while drawing sketch maps with their inner eyes.

1.1.Scope and Problem Statement

The challenge of sketch map analysis lies in the design of a computational model to describe the whole spatial scene on different levels of details and of successfully mapping them onto the reality, which means the information we get from this model is meaningful and applicable . A successful mapping requires a model to be flexible to maximize the applicable cases and, at the same time, minimize the influences of inevitable errors from human perceptions during their drawing. This thesis will evaluate and modify the model from Egenhofer of sketch map analysis. The writer will explore those influential factors from human schematization and systematic errors, and propose a modified formalization method of cardinal directions.

Only static sketches are of concern in this research. Static sketches are line drawings on paper that reveal no information about the drawing sequence of lines. In this paper, only patch and region will be discussed and processed as valid elements. They are defined as follows:

- A patch is an element in a partition of space. The interiors of any two patches are disjointed.
- A region is a perceived object in a sketch. A region can be a single patch or the union of two or more connected patches.
- The particular case that two parallel lines represent routes is also considered as a valid object in this thesis no matter whether they are closing geometry shape or not.

The study objects in this thesis are regions which represent features in the spatial scene. Spatial objects are always sketched according to their outlines or just simplified to schematic figures as blobs or lines. One patch would be a whole building or only part of the building, and patches are grouped into regions when they are perceived as the representation of one whole object. The groups can be either geographical or functional or conceptual depending on sketches and analysis requirement (Figure 1.1).

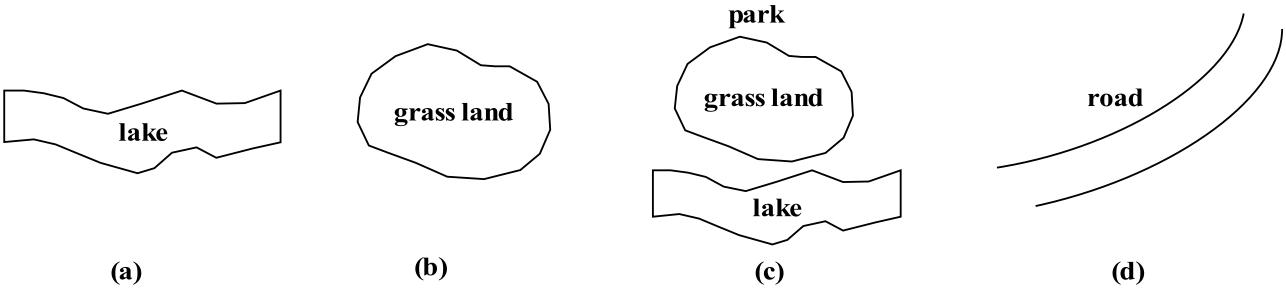


Figure 1.1: Valid objects in a sketch map for analysis. (a) and (b) are single patches representing geographic objects respectively. (c) is the grouping of patches (a) and (b) representing the region of a park. (d) are lines representing a road which are consider as valid.

A digital map provides an accurate snapshot of the real world and is easy to be interpreted. The same is not true in interpreting sketch maps which neglect details as objects, spatial and non-spatial properties and the most interesting part, spatial relations. Inevitable inaccuracies occur in human drawing and most of the errors are derived from human perceptions of the real world. They are cognitively natural and have a negative effect on sketch map representation. Traditional approaches without taking these errors into account will not bring forth satisfied feedbacks and thus interfere with such further sketch study as geospatial reasoning tasks.

1.2.Exploration and Modification

This thesis aims to explore how inaccuracy and errors people make when they draw sketch maps from their memories influence the accuracy of Egenhofer's approach to sketch map analysis, and then modify the existing approach and propose a new sketch map formalization. Sketch map analysis includes object properties and spatial relations among objects. The modification and formalization are mainly focused on spatial relations,which, in this thesis, are positional relations among spatial objects.

Approach. This thesis deals mainly with analysis of features of a paper sketch. In order to execute this task in a digital environment, sketches need to be digitized first as well as the maps of reality[2] for comparisons. This process includes two steps: (1)scanning, and (2)cleaning. Scanning can be accomplished with a common scanner that fits the desired paper sketch. Typically, sketches are drawn with the same pen or pencil for the entire sketching and, therefore, no distinction between colors is necessary (Wuersch, M. 2003). Unlike feature extraction from sketches which need to vectorizing and detect all the lines in the sketch, raster representation of sketch map as a binary image is kept unchanged in this thesis. It is assumed that the sketch only contains regions. The following step is to clean drawing errors as overshoots, undershoots and slivers. Due to the simplicity of sketches and research focus in this thesis, the detection of drawing errors and

2 Maps that are digitalized from satellite images.

their corrections are manually operated.

The following steps include: first, processing the comparisons between sketch map and map of reality and then listing the inaccuracy or errors people made. Second, Egenhofer's approach for sketch map analysis is applied to both maps. The outcomes of this step would be different spatial relations abstracted from sketch map and map of reality. Assumptions will be brought out on the basis of previous study findings to figure out how these inaccuracies and errors affect analysis accuracy in Egenhofer's, especially the accuracy in cardinal directions. In the end, modification and formalization are discussed on the basis of experiment outcomes from previous steps. The theories both from psychology and Egenhofer for sketch map representation and formalization are incorporated into the whole study. The main work flow in this thesis is illusrated as the following (Figure 1.2):

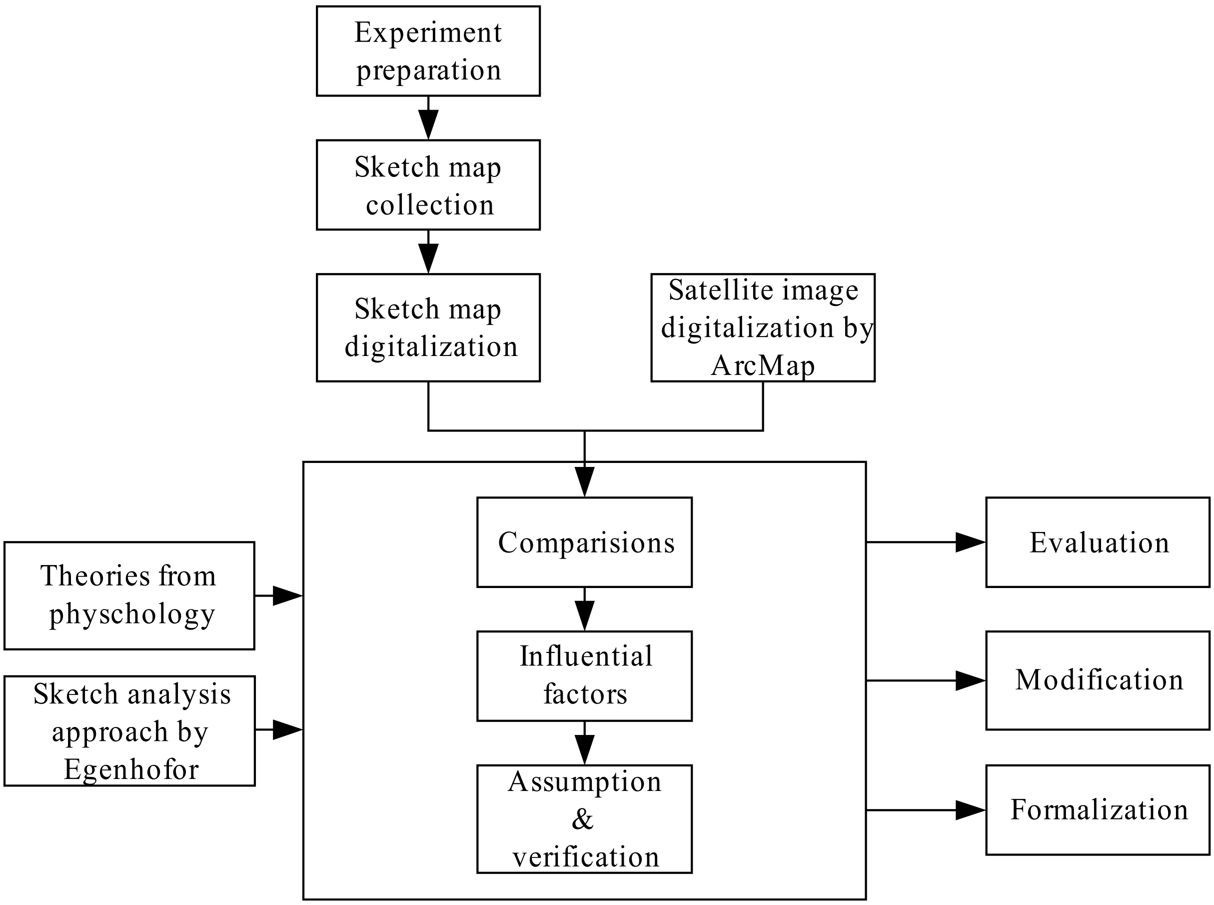


Figure 1.2: The main work flow of this thesis.

Hypothesis. It is quite common that people distort some spatial relations, or rather, what they draw indicates alternative topological relations that can not be obtained directly from sketches. As a result, among five types of spatial relations, we suppose only several of them are frequently effective when people are perceiving a map in their mind while others only take effect in specific situation or hardly appear or even are wrong.

Major Results. The major results of this thesis are listed as follows:

- Exploration of negative effects from human schematization and systematic errors on sketch map analysis and formalization.
- Evaluation of Egenhofer's approach to sketch map analysis.

- Proposal of a modified approach to calculating positional relations and discussion of its applicability and formalization.

1.3.Intended Audience

The intended audience of this thesis is those who have a research interest in cognition engineering, in building computational model for sketch representations. Software developers are also to be intended, since they may have huge interest in the design of methods for representing spatial relations from human sketches. This thesis may just well attract researchers of sketch-based interaction with computer and spatial query due to its relation to Spatial-Query-by-Sketch. A boarding audience including GIS professionals and geographers may also find this thesis helpful, because it aims to the future geographic information system, intelligent GISs.

1.4.Organization of Reminder of Thesis

The previous paragraphs make clear a motivation for the work throughout this study. A delineation is now entailed as to how the model and methods in the following chapters address the issues concerned. The remainder of this thesis is structured as follows:

Chapter 2 is a literature review of the existing study from psychology on spatial cognition of humans and related work of existing approaches to sketch map analysis from Egenhofer. The third chapter then describes the experiment design and implementation as the preprocessing for sketch analysis according to the theories we discussed in Chapter 2. New assumptions are proposed from the results of sketch map analysis and the following paragraph is engaged in the verification of these assumptions. Chapter 4 mainly proposes a modified approach, which naturally depends on the outcomes presented in chapter 3. The applicability and formalization of the modified approach are discussed at the end of this chapter. Chapter 5 summarizes findings of the thesis, draws conclusions, and shows for the interest of audience what is potential for further research related to this work.

Chapter 2
Related Work

Sketch map analysis is a board research topic involving psychology study of spatial cognition, sketch representation and machine intelligence. The most related work for this thesis is briefly reviewed here.

2.1.Related Study from Psychology

Within psychology, many researches like Tversky are focus on how do people think and communicate about the various spaces they inhabit and create. In sketch maps, people use space and spatial relations to represent abstract relations, temporal, quantitative, and preference, in stereotyped ways, suggesting that these mappings are cognitively natural. It has already been documented in psychology that, graphics as sketch maps reflect conceptions of reality, not reality. Consequently, it is inevitable that sketch maps omit information, they regularize, they use inconsistent scale and perspective, and they exaggerate, fantasize, and carry messages. These systematization of real world thereby produces errors. As below is a review of some documented errors people made in sketch maps.

Errors of Distance. Distance estimates in sketch maps are affected by irrelevant factors as hierarchical organizations, amount of information along the route and landmarks. For relative distance estimate in sketches, elements like buildings or water body are perceived as closer than those in different groups. In another situation, routes with many turns or intersections are always judged longer. Most remarkably, distance judgments are not necessarily symmetric. Distances to a landmark are judged shorter than distances from a landmark to an ordinary building.

Errors of Direction. Direction estimates are distorted as well in sketch maps. For example, people mentally rotate the directions of geographic entities around the axes created by themselves. Likewise, directions get straighted in memory. When people are asked to sketch a city map, curvatures are totally ignored or some routes may sketched as curves, but straighter than they actually are.

Schematic Structure. All sketch maps schematize. They include information important to their purposes, eliminating the irrelevant. Sketch maps often include depicted elements that are not present in reality, such as arrows and boundaries, and they also include symbolic elements such as names, distances. Besides, for sketch map representing routes, people always conceive them as sequences of start points, reorientations, progressions, and end points. These elements are sufficient to convey route structure for navigation, but insufficient to convey the exact configuration of the world. In fact, they may severely distort the configuration of the world.

Other Notable Errors. There are other errors of spatial memory and judgment which are not systematic but appear frequently during human sketches. For example, people make errors of quantity, shape, size, and angles of intersections, as well as errors due to perspective.

As Tversky emphasized in her paper, all the sketched errors are not random or due to solely to ignorance; rather they appear to be a consequence of ordinary perceptual and cognitive processes. The nature of sketches make them useful tools for checking and conveying ideas and being served as an external display to facilitate inference and discovery while inevitable errors lead to negative effect if sketches are used for extracting exact configurations of the reality.

2.2.Related Study from Egenhofer

By the use of sketches, Egenhofer proposed a new method for spatial querying which is named as Spatial-Query-by-Sketch. It is the design of a query language for GISs and it allows a user to formulate a spatial query by drawing the desired configuration with a pen on a touch-sensitive computer screen and translate this sketch into a symbolic representation that can the processed against a geographic database (Egenhofer, M. 1997). Compared with traditional methods for spatial querying, using sketching for query is a more interactive way. Since sketching supports human spatial thinking directly, it is more clear than verbal spatial descriptions which are frequently ambiguous and may easily lead to misinterpretations when several users have to work together.

Symbolic representation is the key process of Spatial-Query-by-Sketch. It allows to abstract away details of the sketch which it emphasizes its salient parts. Using this method, sketch is represented internally as a semantic network of spatial objects and their binary spatial relations. Spatial-Query-by-Sketch is founded on a solid mathematical model of spatial relations and its relaxations. There are five types of spatial relations are of the most importance for capturing the essence of a spatial scene and thus are the core of Egenhofer's approach for sketch analysis. In the following is Egenhofer's approach for analyzing five types of spatial relations.

Coarse Topological Relations. This spatial relation is on the basis of a comprehensive model called 9-intersection. It is applied for the analysis of the binary topological relations between two objects of type area, line and point (Egenhofer, M. & Herring, J. 1990). It characterizes the topological relation between two point sets, A and B, by the set intersections of A's interior, boundary and exterior with the interior, boundary, and exterior of B, called the *9-intersection*. For example, the coarse topological relations of two regions without holes in R^2 have eight distinct relations which are called *disjoint*, *meet*, *equal*, *overlap*, *inside*, *contains*, *covers*, and *coveredBy* (Figure 2.1).

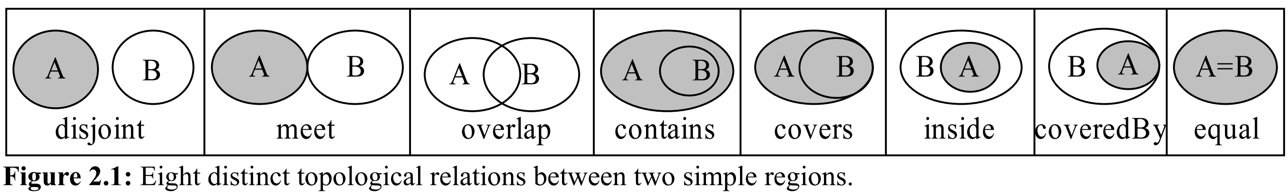


Figure 2.1: Eight distinct topological relations between two simple regions.

Detailed Topological Relations. If further criteria are employed to evaluate the non-empty intersections, detailed topological relations can be applied to pairs of objects. In the case of detailed topological relations of two regions, the necessary invariants are component sequences, component dimensions, types of boundary-boundary component intersections, crossing directions, boundedness and component relationships. For example, detailed topological relations can be expressed by *component invariant table* for non-empty boundary-boundary sequences, which lists the sequence of boundary-boundary components and each component's dimension, type, crossing direction, boundedness, and complement relationship (Egenhofer, M. & Franzosa, R. 1991).

Metric Refinements. As Egenhofer wrote, "occasionally, topological per se is insufficient to characterize the essence of spatial relations". To describe metrical details, measures about areas and lengths are applied as refinements of the topological properties and these measures are normalized values with respect to the areas or lengths of interiors and boundaries. As a result, these measures are scale-independent. Metric refinements are on the basis of non-empty intersections.

Coarse Cardinal Directions. Directions provide a basis for certain decisions about matching and similarity. For extended spatial objects as linear or areal features, Egenhofer proposed a new approach which adapt the projection-based method around the minimum bounding box of an object. Space around the bounding box is partitioned into nine regions for an areal object. These partitions are named north (N), northeast (NE), ease (E), southeast (SE), south (S), southwest (SW), west (W), northwest (NW), and at the same location (0). The positional relationships from an object to a target direction is described by recording the partitions into which at least some parts of the target object fall. (Figure 2.2) The experiments in this thesis are mainly focus on the analysis of cardinal directions among objects.

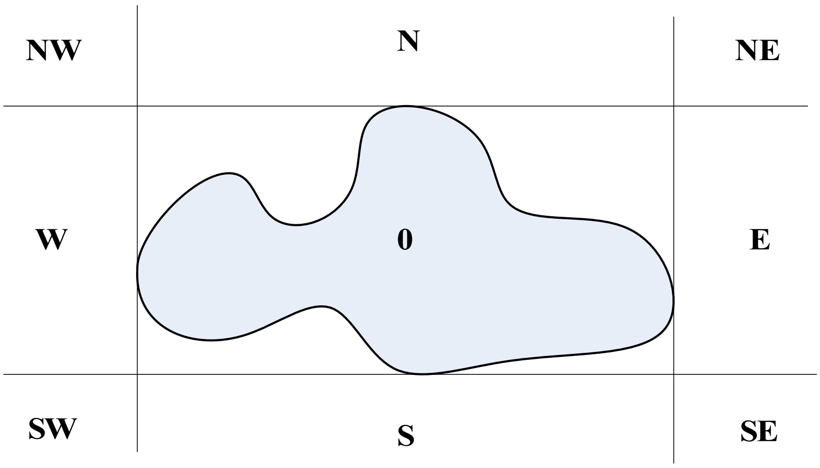


Figure 2.2: Projection-based cardinal directions for extended spatial objects.

Detailed Cardinal Directions. To provide more detail about directions among spatial objects, detailed cardinal directions are proposed by recording for each object that falls into more than one direction partition the percentage of the common intersection between a partition and the object. The range of each detailed cardinal directions x is $0<x<1.0$. The sum of all percentages of an object with respect to the partitions of another object must be 1.0.

The five types spatial relations plus spatial objects form the scene network which is the basis for processing a sketched query and for representing the query results in a prioritized order to the user. Because of the different levels of importance for capturing the semantics of a spatial scene, these five types of spatial relations are related to different query processing stages. Coarse topological relations are the key for pre-processing the sketched scene because by mapping the sketches relations onto 9-intersection model, we capture the most salient features of a sketch. Detailed topological relations capture complexity of topological relations so they are the key for analyzing the intentional complexity of the sketched relations. With the metrical refinements of the 9-intersection relations we formalize detailed geometric constraints about sketched spatial relations and cardinal directions are exploited for those queries in which the user explicitly states the importance of orientation relations or as a tie-breaker among sketched configurations with the same topology (Egenhofer, M. 1997). Finally detailed cardinal directions are used to rank the query results.

From above descriptions of related work from Egenhofer, we can conclude that the scene network including spatial objects and their spatial relations are the basis for Spatial-Query-by-Sketch. Moreover, five types of spatial relations capture the essence of spatial scenes people drew so they are the hard core in scene network for sketch interpretation and representation. Also these spatial relations are studied in this thesis as Egenhofer's approach for sketch map analysis.

2.3.Summary

In this chapter, two main achievements for a sketch map of a spatial scene are described: (1) What are the systematic and notable errors when people perceive a sketch map and (2) a symbolic representations of topological relationships proposed by Egenhofer for sketch analysis.

As already known from achievements in psychology, errors in sketches are inevitable and have their roots from human perceptions. If these errors are taken into account for sketch analysis, how do these errors influence the accuracy of representations of topological relations proposed by Egenhofer and among the common errors and inaccuracies people make, which are the main influential factors? The following experiment is mainly on the testing of sketch analysis approach proposed by Egenhofer and try to figure out the answers of these questions.

Chapter 3

Experiment and Assumptions

In this chapter, the present study explores the inaccuracy people made when they draw sketch maps of specified locations and analyzes these maps by comparing with the real two-dimensional maps. As the reflections of human conceptions of reality, sketch maps use inconsistent scale and perspective, and they omit some information, exaggerate, fantasize and carry messages. The experiment in this chapter is aimed at discovering human schematization and systematic errors which are stored in sketch maps and then apply sketch analysis approach from Egenhofer to sketch maps to figure out how these errors influence analysis accuracy .

3.1.Experiment Preparation

Drawing abilities are diverse among different participants and they may influence the goodness of spatial representations of the reality. As a consequence, it might happen that both two participants have almost the same cognitive maps of the same location but due to their drawing abilities, their final sketches may get completely different rankings on how well the map represent the real world. Moreover, a not well-drawn sketch map may increase the difficulties of recognition, analysis and formalization in the future. Consequently, a sample map is essential to show participants how a sketch map looks like so as to eliminate the adverse effect from participants drawing ability.

Likewise, the choice of spatial scale for sketches also has impact on the accuracy of final maps and the amount of information stored in sketches. Many spatial properties can not be described independently of scale. It is quite common that different geographic knowledge is captured from the same region but under different scales. Similar to geographic data with different scales, people draw maps with different levels of details according to the size of region. Only main streets but not all the street branches will be kept if people are asked to draw an overview of the whole city, whereas most of the street intersections will be depicted if the experiment instruction is describing the route from your home to the nearest supermarket.

Which pictorial elements are of the essence of a sample map? Which location scale is proper for the present study? In order to find out, an exploratory testing is held with 3 participants as an experiment preparation.

Participants. In this case, the precondition is that all the experiment participants must be familiar with the locations we chose. As a result, errors that come from participants' ignorance of areas can be eliminated. Three graduates, two males and one female, from university of Muenster participated individually and did the testing gratuitous and without agreements. They all answered affirmatively when asked if they were familiar with the provided locations. Data from all the participants were analyzed and reported below.

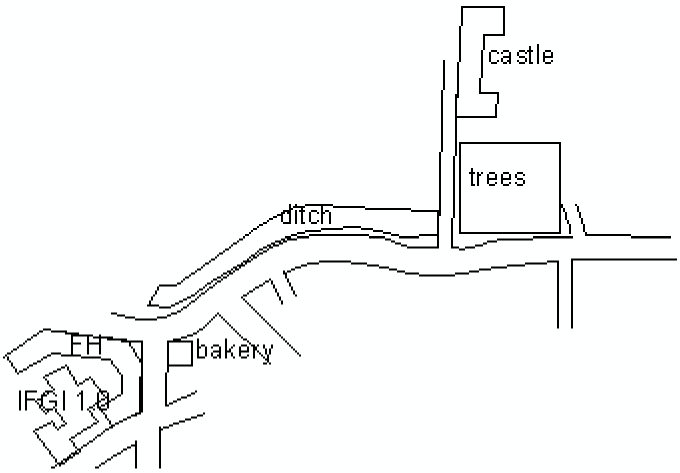
Locations. To find the most suitable locations for this thesis, three locations with different scales were chosen and participants were asked to draw them according to the given instructions. The first drawing task was describe a visitor the region around IFGI 2.0 which includes the bakery and segments of "Weseler-Str" and "Inselbogen". The second one was the drawing task covering the region from IFGI 2.0 to Mensa Aasee. The third one was depicting the region from castle to IFGI 1.0. After checking sketch outcomes, the first two locations were discarded. The small region around IFGI 2.0 does not have enough spatial objects and is too simple to be investigated whereas the region from IFGI 2.0 to Mensa Aasee has too many spatial objects and complex route information which is too difficult for participants to draw. All the participants spent more than 40 minutes on drawing and one of them even took more than one hour to finish the task. Finally the location from castle to IFGI 1.0 was chosen since it has a proper area of location, a suitable length of route and a certain amount of objects which are both suitable for analysis and easy for depicting.

Location I from castle to IFGI 1.0 (see Figure 3.1) and Location II from Mensa Aasee to IFGI 1.0 (see Figure 3.2) with similar scales were chosen as testing regions and participants were asked to depict these regions following the given instructions. In current study, the spatial scales of locations and other basic information are described as below (Table 3.1). The data source of Figure 3.1 is from "City Plan" in website of city Muenster[3].

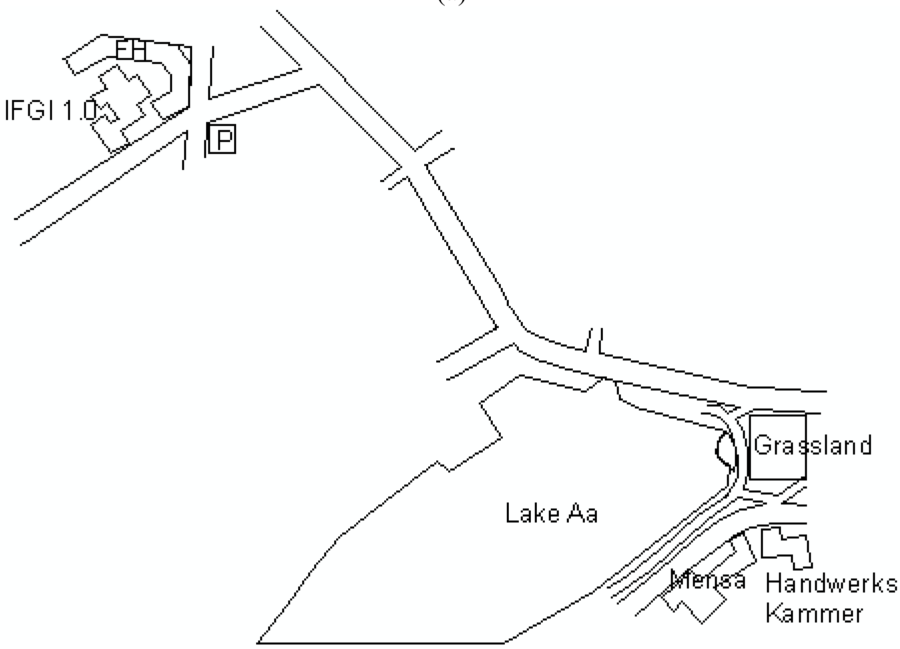
Table 3.1: Basic information of two locations with similar spatial scales.

	Location I from Castle to IFGI 1.0	**Location II from Mensa to IFGI 1.0**
Bounding Box	≈0.21km^2 (0.86*0.24)	≈0.21km^2 (0.59*0.35)
Length of Route	≈0.8 km	≈1.0km
Route Information	1 main curved street Hüffer-Str with 4 main branches; 3 turns	2 connected straight main streets Himmelreichallee & Adenauerallee with curved turns; 3 turns
Intersections	tee shape, cross shape and L shape	tee shape,cross shape and L shape
Fixed features	Castle, FH building (Hüfferstift), IFGI 1.0, ditch encloses castle, parking lot,bakery shop and court	Lake Aa, grassland besides lake, IFGI 1.0, FH building (Hüfferstift), Handwerks Kammer, parking lot, LBS

3 Web link of data source of real map: http://geo.stadt-muenster.de/webgis/frames/index.php?PHPSESSID=59b1d51c35b2c7478d5fd8621f91f046&gui_id=Stadtplan



(a)



(b)

Figure 3.1: Real maps of both locations: (a) overview of the scene from castle to IFGI1.0 and (b) overview of the scene from Mensa Aasee to IFGI 1.0.

Sample Map and Task Descriptions. The instructions are originally in English and each experiment participant was given the paper containing both the instructions for two locations and a sample map (Figure 3.2) as below. The area chose for sample map is the region from supermarket PLUS along "Weserler-Str" to the sports ground at the other side of lake Aa. This sample map has the similar spatial scale both area and route length that people need to draw and likewise, it contains both the geographic objects like water body and salient buildings with irregular shapes like LVM and sports ground. Moreover, sample map describes both the curved streets and straight streets with tee shape and cross shape intersections. participants were instructed to draw streets like two parallel straight or curved lines depending on the reality. The width of branches were made more narrow than the main streets and the outlines of landmarks were closer to the real shape. The original instructed content on the paper which were handed out to participants are provide here as the following:

Task Description of location I: Please draw a sketch map describing the spatial scene you see when you walk from castle to the IFGI 1.0 (Robert-Koch Str 26). Please depict the map with the most salient fixed features along the path you take and try to draw them as accurately as possible.

Materials: A piece of A4 paper, a black pen and a sample map (see Figure 3.2)

Task Description of location II: Please draw a sketch map describing the spatial scene you see when you walk from "Mensa Aasee" near lake Aa, cross over the green land with "Aasee Kugel" and finally arrive IFGI 1.0 (Robert-Koch Str 26). Try to depict the map with the most salient fixed features along the path you take and try to draw them as accurately as possible.

Materials: A piece of A4 paper, a black pen and a sample map (see Figure 3.2)

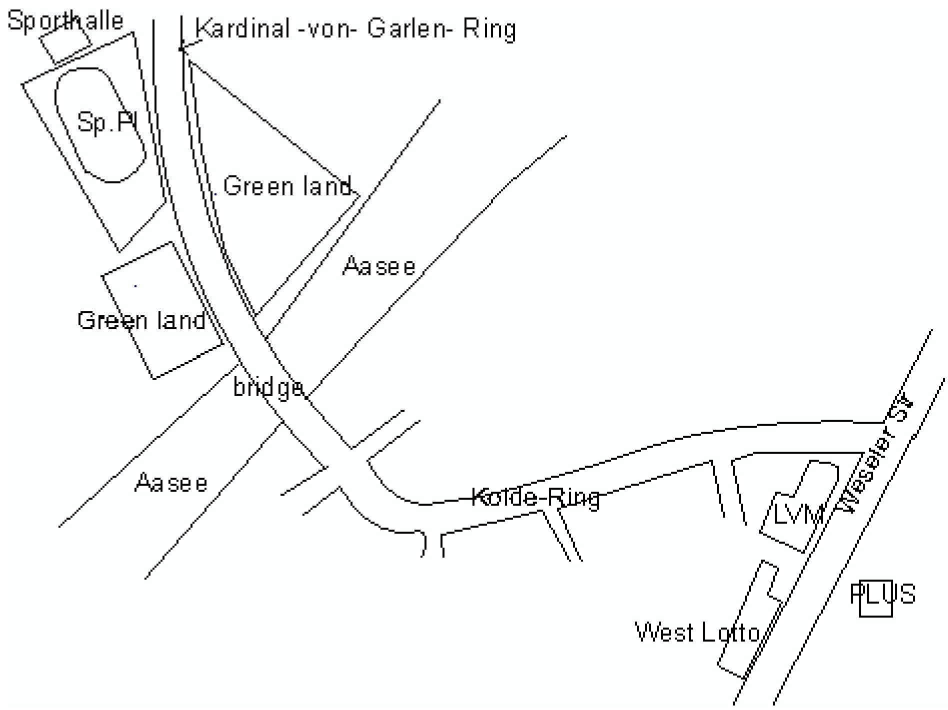


Figure 3.2: A sample map from PLUS to sport ground near lake Aa.

In the end, participants were asked to write down their names, age and gender on the reverse side of maps. Figure 3.3a-c provide outcomes of preliminary experiment of three participants. After comparing with the real maps, the resulting corpus showed that all the participants drawn such main fixed objects as IFGI 1.0, castle, ditch around castle, bakery shop and FH building (Table 3.2). The main route information was depicted as well so the instructions and sample map are suitable for the experiment and the location chosen is proper also. Therefore, they will be kept for the following formal experiment with 10 participants.

Table 3.2: Object participants drew from preliminary experiment.

	Geographic features		Non-geographic features				
	Ditch	Other	Castle	IFGI 1.0	Bakery shop	FH building	Others
PA	O	X	O	O	O	O	Bus stops Botanic garden
PB	O	Trees	O	O	O	O	Parking lot
PC	O	Green land	O	O	O	O	Land Gericht Bus stops

(O-object sketched, X-object not sketched, PA, PB, PC represent participant A, B and C)

3.2.Approach of Sketch Map Analysis

In this thesis, sketch map analysis is mainly focus on two aspects, one is on the map accuracy of curvature, angle and shape and the other is on topological, metric and cardinal directions by borrowing the idea from Egenhofer. The theoretical basis for the former has its root in psychology of spatial cognition. The work flow of sketch map analysis is describe here (Figure 3.3).

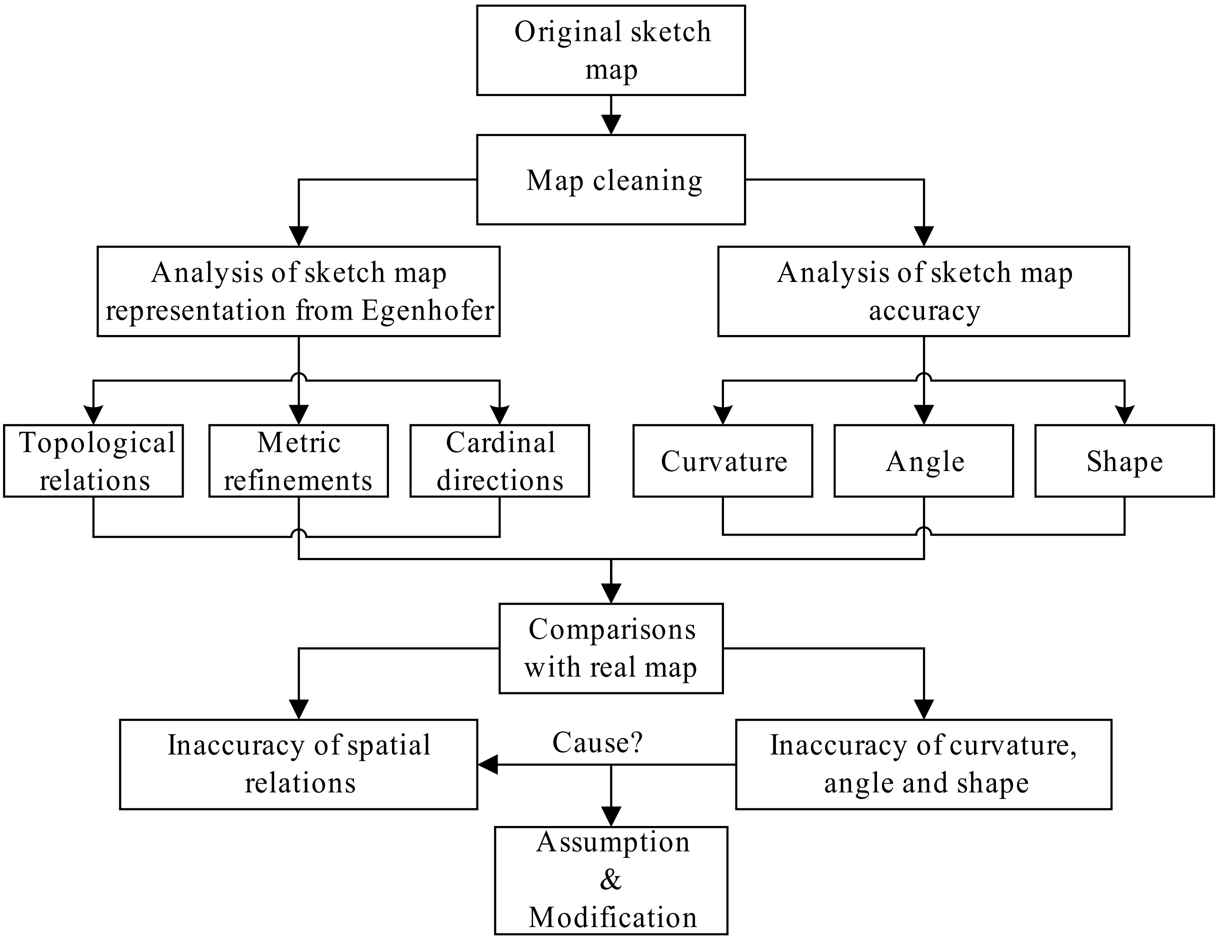
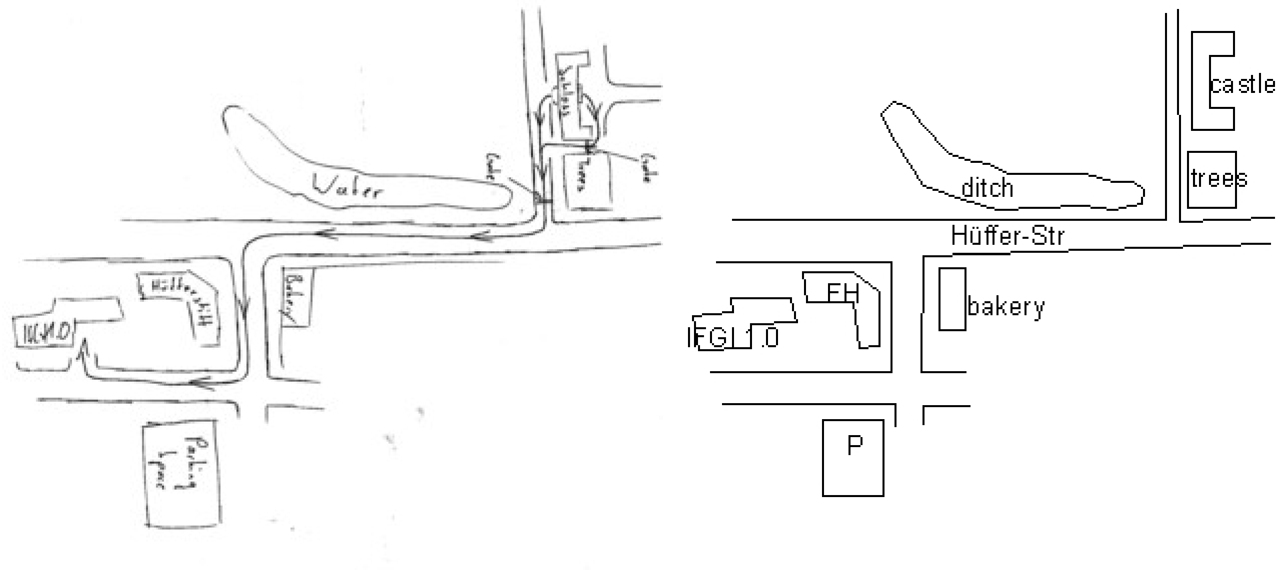


Figure 3.3: Workflow of sketch analysis method.

Map cleaning is using the tool from ArcMap to clean drawing errors such as overshoots, undershoots and silvers. The origin sketch map was imported to ArcMap as raster data and drawing tools were used to trace pictorial elements in original sketch maps and finally we got cleaned maps. In this paper, the sketch map analysis is based on the assumption that all the spatial or non-spatial information have already extracted and interpreted as given information. Figure 3.4 is one example of a cleaned sketch map.



(a) (b)

Figure 3.4: One example of cleaned map in ArcMap. (a) is the original sketch map and (b) is the corresponding cleaned map.

After cleaning the sketches, the next steps were the two main aspects of sketch map analysis. One was the measurement of sketch map accuracy from psychology and the other was focus on the accuracy of different spatial relations using Egenhofer's approach for sketch analysis. The detailed processes were discussed with real maps for both locations as below.

3.2.1.Curvature, Angle and Shape

The locations chosen for experiment were the mixture of route and region. In this thesis, the accuracy measurement was mainly focus on curvature, angle and shape of route and spatial objects.

Location I. The main streets from castle to IFGI 1.0 is “Hüffer-Str” of west-east trend with its intersections with street “Himmelreichallee”, “Robert-Koch-Straße” and a trail behind castle (see Figure 3.5). From Figure 3.5, the segment of main street “Hüffer-Str” is a curved streets with 6 straight branches. These branches are not parallel with each other. Some have their intersected angles with “Hüffer-Str” as obtuse angles, e.g., when turning from “Hüffer-Str” to “Robert-Koch-Str”, the turning angle is much bigger than 90 degree. Some have the exact 90 degree angle which means they are perpendicular with “Hüffer-Str”. Besides, in this location, the salient objects have complex shapes more than simple geometric figures like rectangle and circle. From Figure 3.1a, the ditch is along with “Hüffer-Str” with its ribbon shape as well as the complex outlines of IFGI 1.0 and FH.

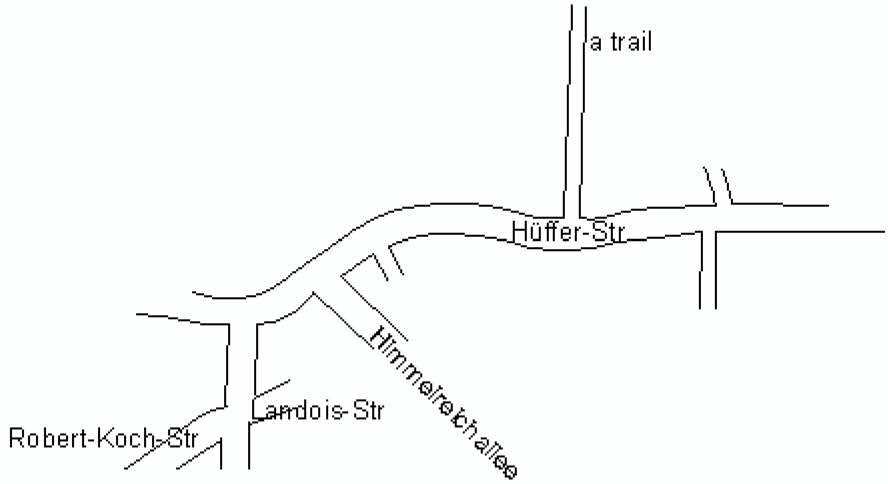


Figure 3.5: Route information of curvature and angle in location I from castle to IFGI 1.0.

Location II. For location II, the main streets from student cafeteria (Mensa Aasee) to IFGI 1.0 are "Bismarck-Allee", "Moderschnweg", "Adenauer-Allee," "Himmelreich-Allee", "Landois-Str" and "Robert-Koch-Str" (Figure 3.6). The route from Mensa Aa to IFGI 1.0 is a twisty path that has in total 3 bends and connects with several other streets or small trails. Compared with the wavy street "Hüffer-Str", streets in location II are more like polylines. Complex shapes of objects were also discovered in location II, such as lake Aa, IFGI 1.0 and FH building (see Figure 3.1b).

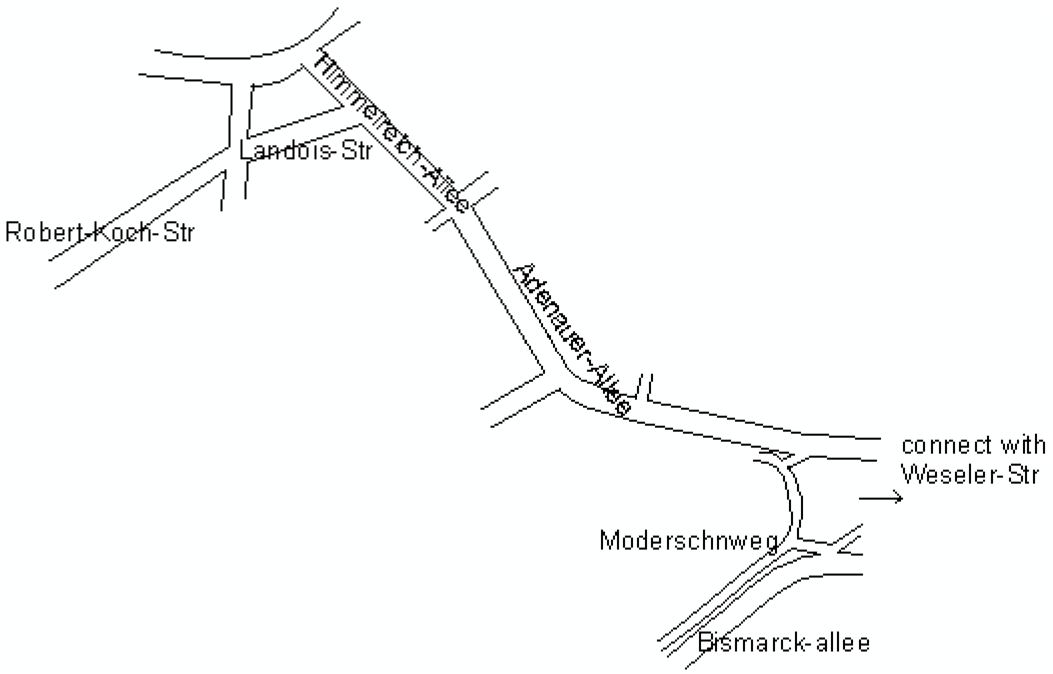
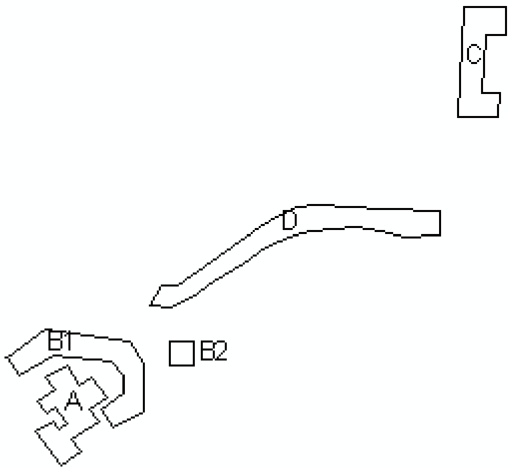


Figure 3.6: Route information of curvature and angle in location I from Mensa Aasee to IFGI 1.0.

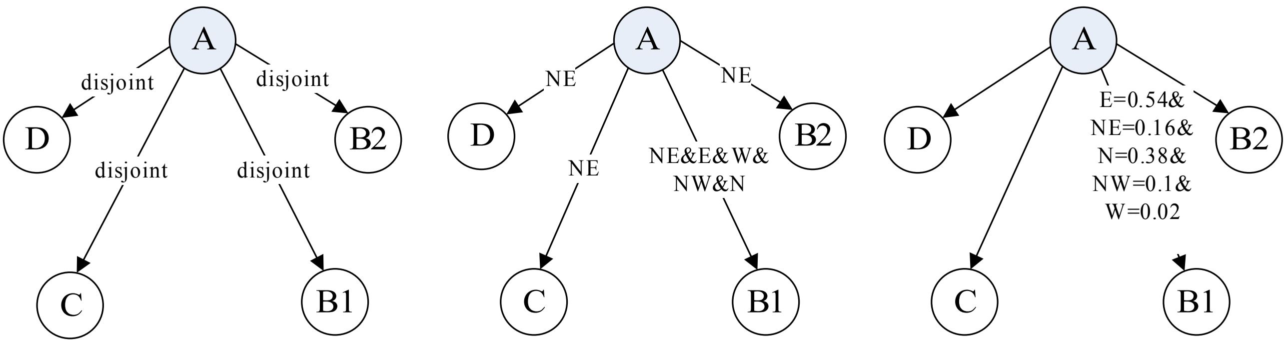
3.2.2.Sketch Map Analysis from Egenhofer

In this thesis, we use the approach from Egenhofer to translate a sketch map into a symbolic representation to process against a geographic database. Using this method, we distinguish five different types of spatial relations: coarse binary topological relations, detailed binary topological relations, metrical refinements, coarse cardinal directions, and detailed cardinal directions. In the following, this approach was applied to map of the reality to explore the spatial relations among objects.

Location I. In location I, almost all the spatial objects are scattered buildings locating along "Hüffer-Str". Therefore when mapping the sketched relations onto 9-intersection relations, we only got one topological relations of "disjoint". Detailed topological relations and metric refinements which are based on non-empty intersections are not available to be calculated. Figure 3.7 is the analysis results of coarse topological relations, coarse cardinal directions and detailed cardinal directions for location I.



(a)



(b) topological relations (c) cardinal directions (d) detailed cardinal directions

Figure 3.7: A real map (a) of location I and the scene networks of (b) topological relations, (c) cardinal directions, and (d) detailed cardinal directions (only the relations for object A are shown)

Figure 3.7 shows 5 areal objects, which received unique identifiers. These identifiers are used consistently throughout the scene network (A, B1, B2, C and D represent IFGI, FH building, bakery shop, castle and ditch respectively in location I). Figure 3.7b-d show subsets of the scene network, focusing on the spatial relations with respect to object A. Figure 3.7b depicts for object A the binary topological relations that were derived from the 9-intersection model. Figure 3.7c shows coarse cardinal directions and 3 objects fall completely into a single partition (B2, D, C), while B1 spans over 5 partitions. Details about the distribution over multiple partitions are captured in Figure 3.7d, recording by how much an object extends over multiple partitions. Table 3.3 is the outcome of cardinal directions among all objects.

Table 3.3: Cardinal directions among all the objects of location I from the real map.

	Castle	IFGI	Ditch	Bakery	FH building
Castle	X	NE	NE	NE	NE
IFGI	SW	X	SW	SW&W	0&S
Ditch	SW	NE	X	NW&N&NE	NE
Bakery	SW	NE	S	X	E
FH building	SW	NW&E&N&NE&W	SW	NW&W&SW	X

Location II. Similarly, the same situation was found in location II. Figure 3.8 is the analysis results of coarse topological relations, coarse cardinal directions and detailed cardinal directions for location II.

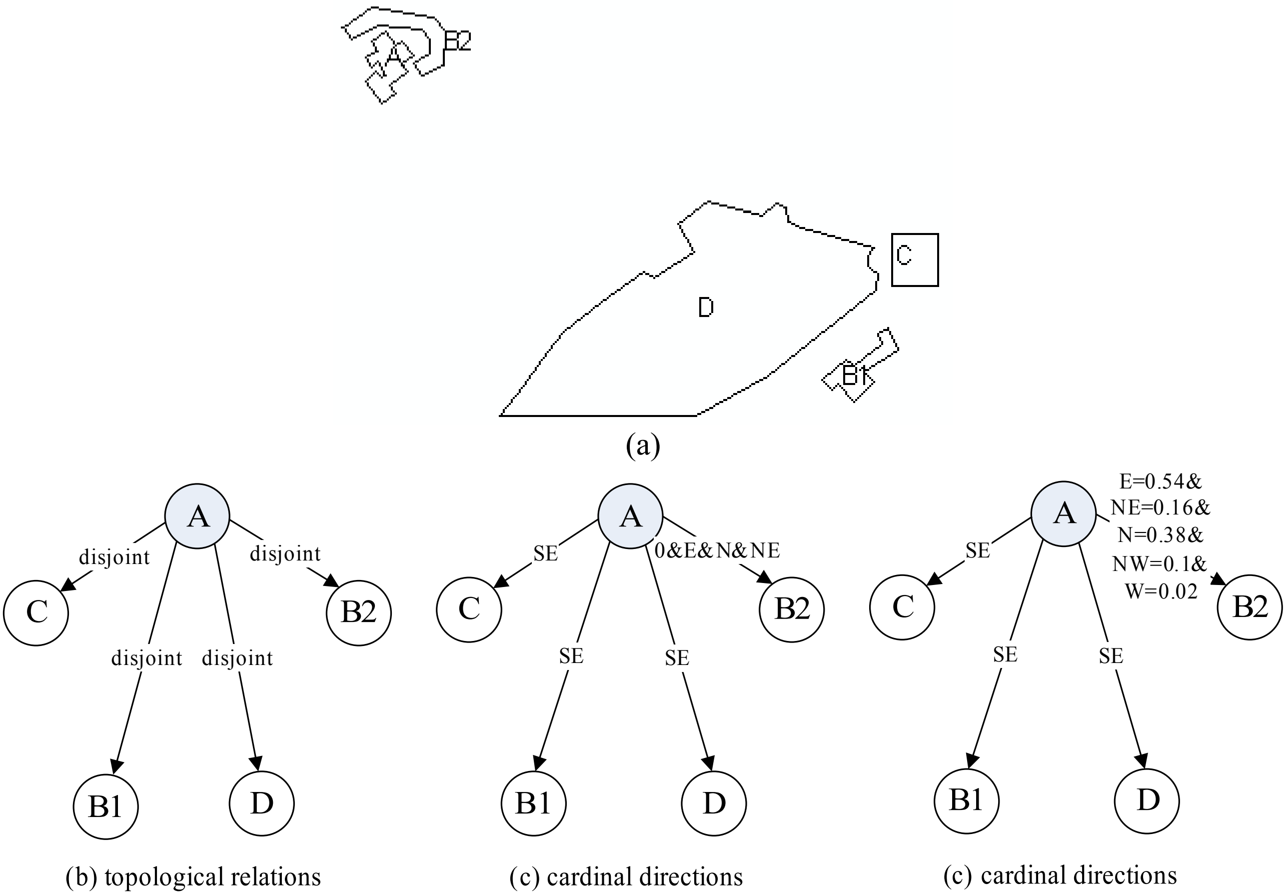


Figure 3.8: A real map (a) of location II and the scene networks of (b) topological relations, (c) cardinal directions, and (d) detailed cardinal directions (only the relations for object A are shown)

Figure 3.8 illustrate the use of approach from Egenhofer for the construction of a scene network. Figure 3.8a shows 5 areal objects, which received unique identifiers. These identifiers are used consistently throughout the scene network(A, B1, B2, C and D represent IFGI, Mensa, FH building, grassland and Lake Aa). Figure 3.8b-c show subsets of the scene network, focusing on the spatial relations with respect to object A. Figure 3.8b depicts for object A the binary topological relations that were derived from the 9-intersection model. Figure 3.8c shows coarse cardinal directions and 3 objects fall completely into a single partition (B1, C, D), while B2 spans over 5 partitions. Details about the distribution over multiple partitions are captured in Figure 3.8d, recording by how much an object extends over multiple partitions. Table 3.4 is the outcome of cardinal directions among all objects.

Table 3.4: Cardinal directions among all the objects of location II from the real map.

	Mensa Aasee	Lake Aa	IFGI	Grassland	FH building
Mensa Aasee	X	0	SE	SW	SE
Lake Aa	N&NW&W&SW&NE	X	SE	NW&W&SW	SE
IFGI	NW	NW	X	NW	0&S
Grassland	NE	E	SE	X	SE
FH building	NW	NW	W&N&NE&E&NW	NW	X

3.3.Experiment Outcomes

Formal experiment was based on the exploratory test with 7 more participants. All the sketch maps were analyzed later to explore how human schematization and systematic errors take effect on map formalization**s.**

3.3.1.General Overview

The introductions, sample map and areas described in exploratory testing were adopted. 10 participants (4 female, 6 male, average age of 27.5) participated in the experiment for the sketching task. They were recruited among the people working and studying at the Institute for Geoinformatics. All of them are familiar with the areas need to be drawn. Though all of them are with GI[4] experience, it doesn't mean that they have a specifically well understanding of sketching spatial scene or have better spatial intelligence and good at spatial reasoning. The demand of terminology such as feature, spatial and non-spatial object or sketch map for this group of people was not necessary.

Each participants were provided with a piece of blank paper with A4 format, a black pen and one more paper with task descriptions and a sample map in English. They were not allowed to get help from real maps as Google Map or Google Earth. The average time for completing two maps was around 30 minutes.

Of all 20 sketch maps for both locations only 14 are included in the following analysis. 6 were discarded because their sketch maps were too simple to be analyzed which means there was only 2 or 3 objects depicted and even the most salient objects were totally ignored. For example, one sketch map depicting location I only contains castle and IFGI as the start and ending points and one more street connecting them. In current study, a certain amount of objects were of vitally requirement. Either the descriptions of routes and landmarks or the analysis of topology, metric and cardinal relations in the following study need enough objects, at least the salient ones.

Table 3.3 and Table 3.4 provide the results of objects people sketched on their maps. The most common objects people drew for location I were castle, IFGI 1.0, FH building (or Hüfferstift), bakery shop (or one participant named it as Cafe) and ditch. And the most drew objects from cafeteria (or Mensa Aasee) to IFGI 1.0 were cafeteria, IFGI 1.0, lake Aa, grassland with “Aasee Kugel” and FH building (or Hüfferstift). The

4 GI is the acronym of “Geographic Information”.

criteria for "most common" objects was that among 10 participants, there were no less than 50% of the people drew such objects.

Table 3.5: Object classes[5] from castle to IFGI 1.0.

	Geographic features		Non-geographic features				
	Ditch	Other	Castle	IFGI	Bakery shop	FH building	Others
PA	O	X	O	O	O	O	Bus stops Botanic garden
PB	O	Trees	O	O	O	O	Parking lot
PC	O	Grassland	O	O	O	O	Court Bus stops
PD	O	Trees	O	O	O	O	Uni building
PE	O	X	O	O	O	O	Uni building
PF	X	X	O	O	X	X	X
PG	O		O	O	O	O	Courts Botanic garden Cemetery Residential areas Swimming pool
PH	X	X	O	O	X	O	Park House besides Gravestones shop
PI	O		O	O	O	O	Court Botanic garden Copy shop Swimming pool Square in front of castle with promenade
PJ	O	Trees	O	O	O	O	Parking lot

(O-object sketched, X-object not sketched)

5 Object classes mean the major types of fixed features such as geographic features like water body or non-geographic features like parks and schools are each counted as separate classes. Using object classes is a way to assess completeness of a sketch map for a given world.

Table 3.6: Object classes from Mensa Aasee to IFGI 1.0.

	Geographic features		Non-geographic features					
	Lake Aa	Grassland with "Aasee Kugel"	Cafeteria (Mensa Aasee)	IFGI	LBS	FH building	Cemetery	Others
PA	O	O	O	O	X	X	X	X
PB	O	O	O	O	O	O	X	Sculpture River Aa Promenade
PC	O	O	O	O	O	O	X	Music school Studentenwerk Promenade Uni building Bar close to Aasee
PD	O	O	O	O	X	O	O	Uni building
PE	O	O	O	O	O	O	X	Uni building
PF	O	X	O	O	X	X	X	X
PG	O	O	O	O	O	O	O	HWK Music school Swimming pool Uni building Pub Promenade
PH	O	O	O	O	X	O	X	Park LVM Gravestones shop
PI	O	O	O	O	X	O	O	Parking lot
PJ	O	O	O	O	X	O	X	Bakery Bus stop Park

(O-object sketched, X-object not sketched)

3.3.2.Curvature, Angle and Shape: Sketch Maps of Location I

The main streets from castle to IFGI 1.0 is “Hüffer-Str” of west-east trend with its intersections with street “Himmelreich-Allee”, “Robert-Koch-Straße” and a trail behind castle. All the participants drew these three streets because they are main streets or close to salient landmarks (Figure 3.9). For other street segments, one small branch was totally ignored and others were only sketched by a few people.

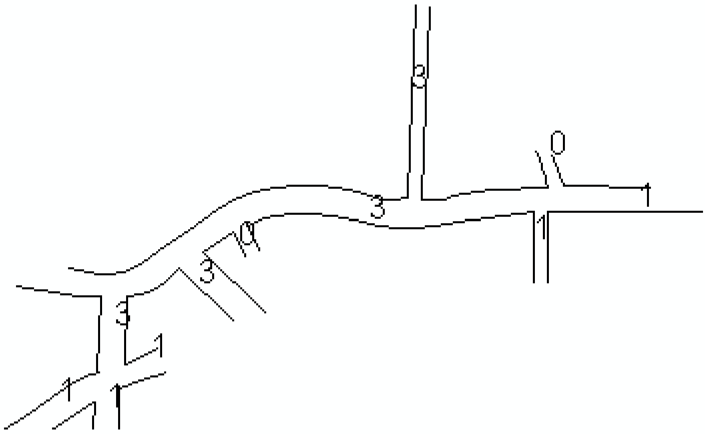
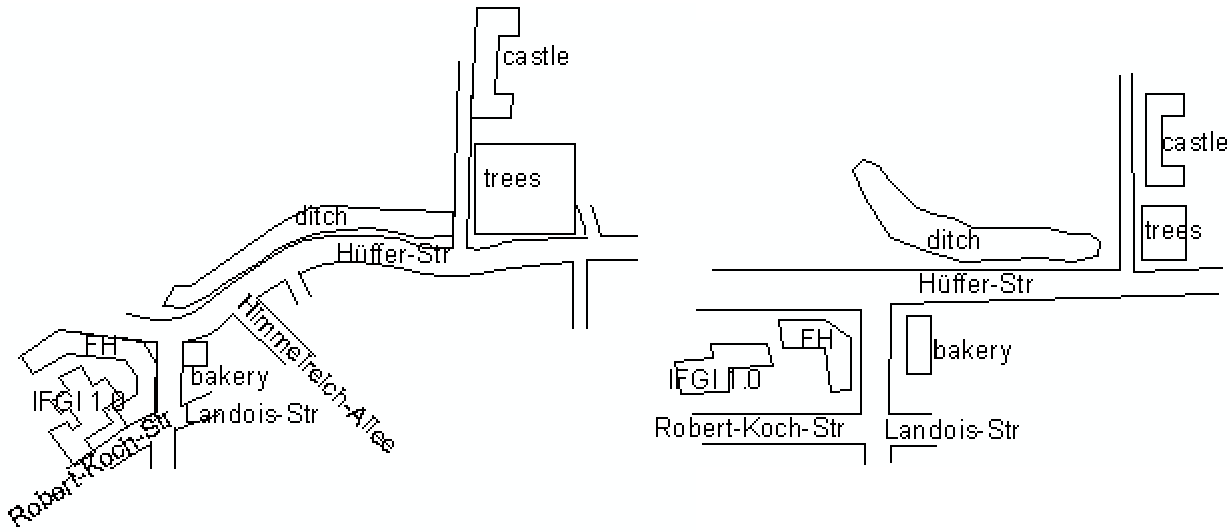


Figure 3.9: Statistics of street information that participants depicted from castle to IFGI 1.0. (The numbers represent numbers of people who drew the street segments in their sketch maps)

Route information was not only omitted but also simplified and distorted. For example, directions got straighted in memory so all the streets were sketched straightly although they are curved in the reality. Likewise, all the angles of turns were simplified to 90 degree. Besides, all the shapes of objects were simplified but not the exact or even similar shapes as they are in the reality. Figure 3.10 is a comparison of one sketch map and its corresponding real map.



(a) (b)

Figure 3.10: An example illustrating differences of curvature, angle and shape between real map and sketch map. (a) is from real map and (b) is from sketch map.

From this comparison, we can see clearly the most common errors people make during their sketching. Firstly, the completeness of information is difficult to be ensured and people omit some information from their sketch map which leads to the missing of street “Himmelreich-Allee” and incomplete shape of FH building. Secondly, information is simplified and distorted as well. In the above example sketch map, “Hüffer-Str” is a straight street and oriented horizontally although it has two main bends in the reality. Likewise, all the angles of turns were drew as 90 degrees even in reality they are just 30 degree, eg., the turn in “Robert-Koch-Str”.

3.3.3.Sketch Map Analysis from Egenhofer : Sketch Maps of Location I

Figure 3.13 illustrate one example of the use of five types of spatial relations for the construction of a scene network. The sketch (Figure 3.11a) from one experiment participant shows six areal objects, which received unique identifiers. These identifiers are used consistently throughout the scene network.(A, B1, B2, C and D represent IFGI, FH building, bakery shop, castle and ditch respectively in location I) Figure 3.11b-d show subsets of the scene network, focusing on the spatial relations with respect to object A. Figure 3.11b depicts for object A the binary topological relations that were derived from the 9-intersection model. Figure 3.11c shows coarse cardinal directions and 3 objects fall completely into a single partition (C, D), while B1 and B2 span over two partitions. Details about the distribution over multiple partitions are captured in Figure 3.11d, recording by how much an object extends over multiple partitions. Since all the objects are disjoint with each other so in our case, there are no calculations of non-empty intersections for detailed topological relations and metric refinements.

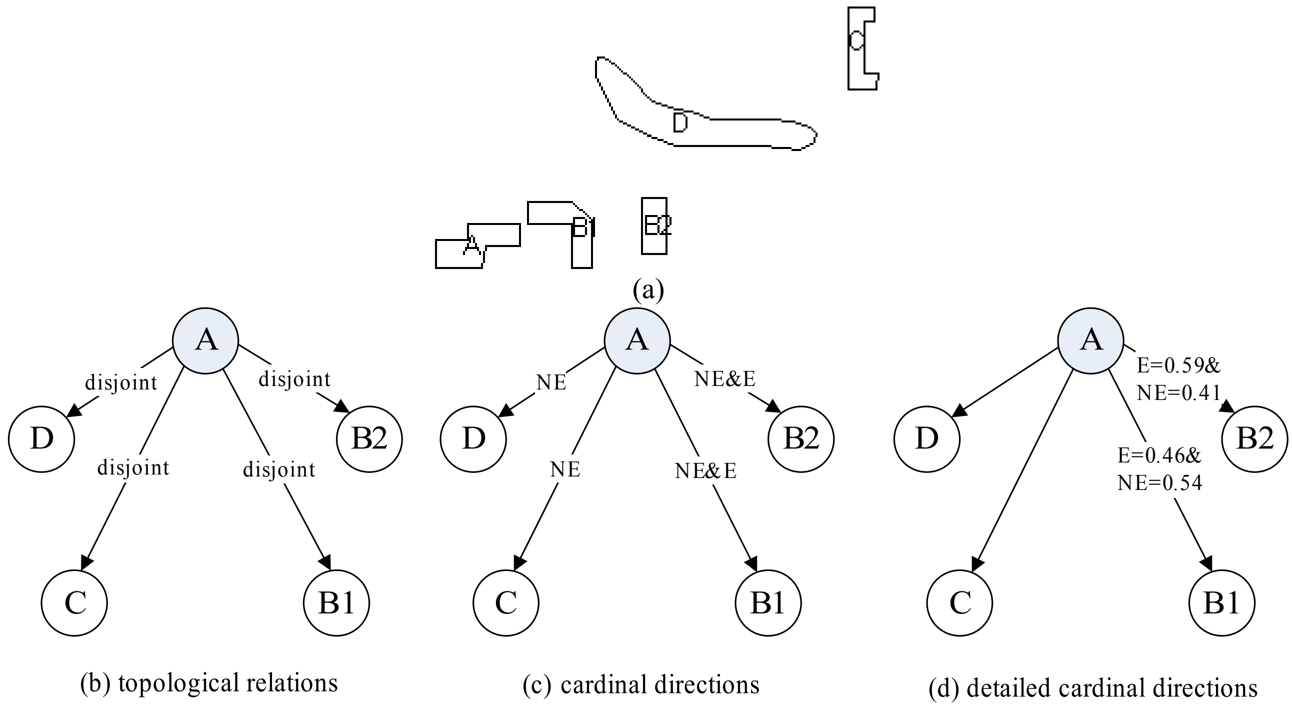


Figure 3.11: A sketch map (a) of location I and the scene networks of (b) topological relations, (c) cardinal directions, and (d) detailed cardinal directions (only the relations for object A are shown)

Data treatment: All the participants drew correct topological relations. Calculations of Cardinal directions were processed among the most common drew spatial objects, in this case, which were IFGI 1.0, ditch, castle, bakery shop and FH building. Among 10 sketch maps, 3 of them were discarded because they did not have enough objects to be analyzed. The number of correctly sketched cardinal directions of the rest 7 participants was 14, 14, 13, 13, 12, 8, 12 respectively. And the average accuracy rate of cardinal directions was 61%. The following tables are results from all participants and italic and bold fonts represent the different cardinal directions people sketched.

Table 3.7: Cardinal directions of location I from participant A. (the same participant whose sketch map was analyzed as an example in Figure 3.11)

Name	Coarse cardinal directions						Inaccuracy
PA		Castle	IFGI	Ditch	Bakery	FH building	6
	Castle	X	NE	***E&NE***	NE	NE	
	IFGI	SW	X	SW	W&SW	***W***	
	Ditch	***SW&W***	NE	X	NW&N&NE	NE	
	Bakery	SW	***NE&E***	S	X	E	
	FH building	SW	***NE&E***	SW	***W&SW***	X	

Table 3.8: Cardinal directions of location I from participant B.

Name	Coarse cardinal directions						Inaccuracy
PB		Castle	IFGI	Ditch	Bakery	FH building	6
	Castle	X	NE	***E&NE***	NE	NE	
	IFGI	SW	X	SW	W&SW	***W***	
	Ditch	***SW&W***	NE	X	NW&N&NE	NE	
	Bakery	SW	***NE&E***	S	X	E	
	FH building	SW	***NE&E***	SW	***W&SW***	X	

Table 3.9: Cardinal directions of location I from participant C.

Name	Coarse cardinal directions						Inaccuracy
PC		Castle	IFGI	Ditch	Bakery	FH building	7
	Castle	X	NE	***E&NE***	NE	NE	
	IFGI	SW	X	SW	***SW***	***S&SE***	
	Ditch	***W&SW***	NE	X	***NW&N&NE***	NE	
	Bakery	SW	NE	S	X	***NE***	
	FH building	SW	***NW&N***	SW	***SW***	X	

Table 3.10: Cardinal directions of location I from participant D.

Name	Coarse cardinal directions						Inaccuracy
PD		Castle	IFGI	Ditch	Bakery	FH building	7
	Castle	X	NE	***E&NE***	NE	NE	
	IFGI	SW	X	SW	***SW***	***S&SE***	
	Ditch	***W&SW***	NE	X	NW&N&NE	NE	
	Bakery	SW	NE	S	X	***NE***	
	FH building	SW	***NW&N***	SW	***SW***	X	

Table 3.11: Cardinal directions of location I from participant E.

Name	Coarse cardinal directions						Inaccuracy
PE		Castle	IFGI	Ditch	Bakery	FH building	8
	Castle	X	NE	***E***	NE	NE	
	IFGI	SW	X	SW	***SW***	***NE***	
	Ditch	***W***	NE	X	***N&NE***	NE	
	Bakery	SW	NE	S	X	***W***	
	FH building	SW	***E&NE***	SW	***SW***	X	

Table 3.12: Cardinal directions of location I from participant F.

Name	Coarse cardinal directions						Inaccuracy
PF		Castle	IFGI	Ditch	Bakery	FH building	12
	Castle	X	NE	***N***	NE	NE	
	IFGI	SW	X	SW	***W&NW***	***W***	
	Ditch	***S&SE&SW***	NE	X	***NE***	***E***	
	Bakery	SW	***E&SE***	***SW***	X	***E&SE***	
	FH building	SW	***NE&N***	***SW&W***	***W&NW***	X	

Table 3.13: Cardinal directions of location I from participant G.

Name	Coarse cardinal directions						Inaccuracy
PG		Castle	IFGI	Ditch	Bakery	FH building	8
	Castle	X	NE	***NE&E***	NE	NE	
	IFGI	SW	X	SW	***SW***	***SW***	
	Ditch	***W***	NE	X	N&NE&NW	***NE&N***	
	Bakery	SW	NE	S	X	E	
	FH building	SW	***NE***	***SW&S***	***SW&W***	X	

From the resulting tables, most of the errors were related to the ditch, IFGI and FH building. After going back to the sketch maps themselves, the systematic errors of spatial memory and judgment which have been documented in psychology were found and other errors like shape which is due to perspective. For example, compared with other objects, the area of ditch was underestimated; participants showed a strong tendency to straighten the streets; all the angles of route intersection were drawn as 90 degree and some participants simplified shapes of IFGI, FH building and castle to rectangles.

3.3.4.Curvature, Angle and Shape: Sketch Maps of Location II

For location II, the main streets from student cafeteria (Mensa Aasee) to IFGI 1.0 are “Bismarck-Allee”, “Moderschnweg”, “Adenauer-Allee,” “Himmelreich-Allee”, “Landois-Str” and “Robert-Koch-Str”. All the experiment participants followed this route from the start point Mensa to the end point IFGI 1.0 so these streets were the most commonly drawn streets for location II. Besides, “Annette-Allee” and “Weseler-Str” which connect with the walking route were drawn by 5 and 4 participants respectively. Additionally, there were 4 participants depicted the promenade on their sketch maps and considered it as the green region containing several alleys. Figure 3.12 represents the analytical results of route information from sketch maps.

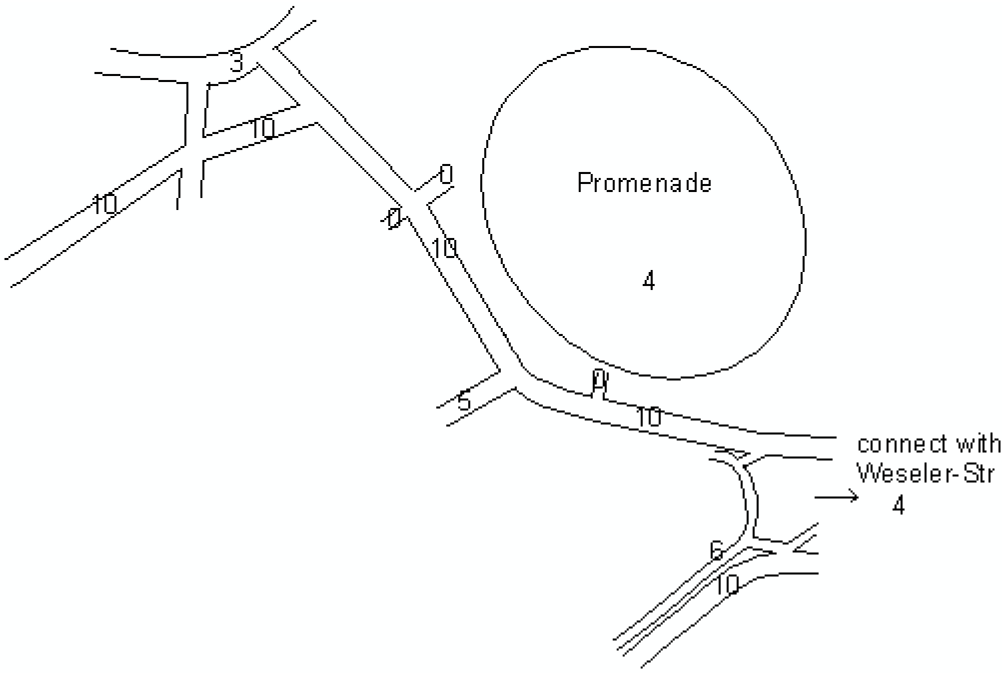
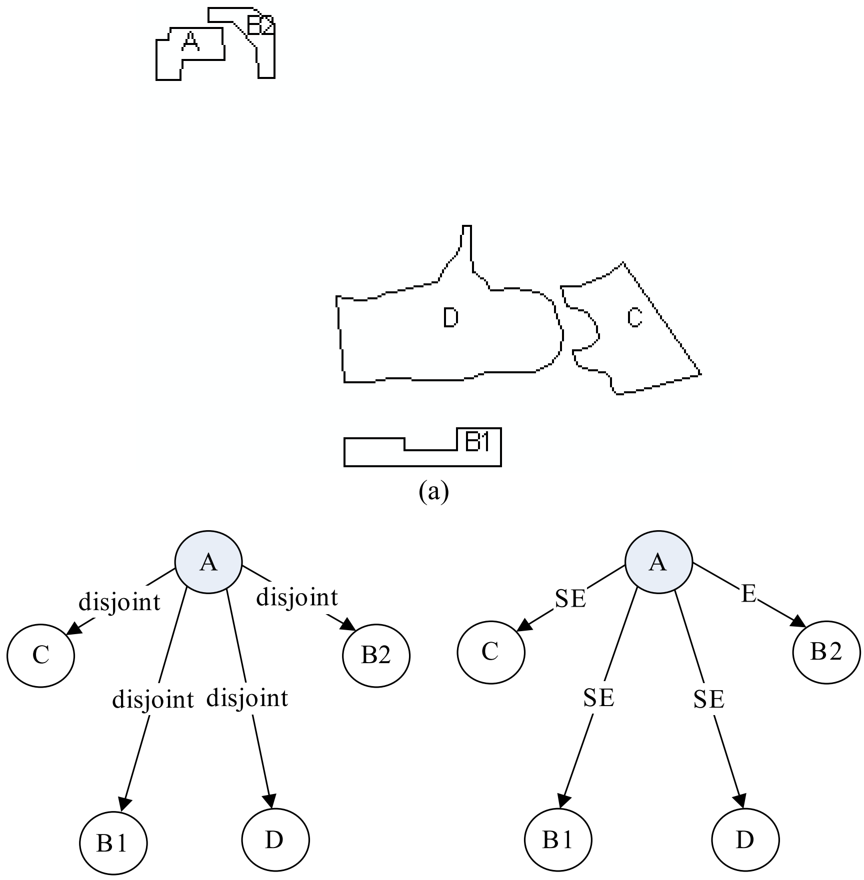


Figure 3.12: Statistics of street information that participants depicted from cafeteria to IFGI 1.0. (The numbers represent numbers of people who drew the street segments in their sketch maps.)

3.3.5.Sketch Map Analysis from Egenhofer : Sketch Maps of Location II

Figure 3.13 illustrate the use of approach from Egenhofer for the construction of a scene network. The sketch (Figure 3.13a) from one experiment participant shows five areal objects, which received unique identifiers. These identifiers are used consistently throughout the scene network.(A, B1, B2, C and D represent IFGI, Mensa, FH building, grassland and Lake Aa respectively in location I) Figure 3.13b-c show subsets of the scene network, focusing on the spatial relations with respect to object A. Figure 3.13b depicts for object A the binary topological relations that were derived from the 9-intersection model. Figure 3.13c shows coarse cardinal directions and all four objects fall completely into a single partition. Detailed cardinal directions was not calculated since there was not object extending over multiple partitions.



(b) topological relations (c) cardinal directions

Figure 3.13: A sketch map (a) of location II and the scene networks of (b) topological relations and (c) cardinal directions (only the relations for object A are shown)

Data treatment: No participants making mistakes of topological relations. Calculations of cardinal directions were processed among the most common drew spatial objects, in this case, which were student cafeteria, IFGI 1.0, lake Aa, grassland with “Aasee Kugel” and FH building. Among 10 sketch maps, 3 of them were discarded because they did not have enough objects to be analyzed. The number of correctly sketched cardinal directions from the rest 17 participants was 15, 11, 11, 11, 14, 10, 12 respectively. The average accuracy rate of cardinal directions was 60%. The following tables are results from all participants and italic and bold fonts represent the different cardinal directions people sketched.

Table 3.14: Relative object positioning from a sketch map (the same participant whose sketch map was analyzed as an example in Figure 3.13).

Name	**Coarse cardinal directions**						**Inaccuracy**
		Mensa	Aasee	IFGI	Grassland	FH building	
	Mensa	X	***S***	SE	SW	SE	
PA	Aasee	***N&NE&NW***	X	SE	***W&NW***	SE	5
	IFGI	NW	NW	X	NW	***W***	
	Grassland	NE	E	SE	X	SE	
	FH building	NW	NW	***E***	NW	X	

Table 3.15: Relative object positioning from a sketch map of participant B.

Name	Coarse cardinal directions						Inaccuracy
PB		Mensa	Aasee	IFGI	Grassland	FH building	10
	Mensa	X	***S***	SE	SW	SE	
	Aasee	***NW&N&NE***	X	***SW&S&SE***	***W***	***SW&S&SE***	
	IFGI	NW	***N***	X	NW	***0&W&SW&S***	
	Grassland	NE	***NE&E***	SE	X	SE	
	FH building	NW	***N***	***E&N&NE***	NW	X	

Table 3.16: Relative object positioning from a sketch map participant C.

Name	Coarse cardinal directions						Inaccuracy
PC		Mensa	Aasee	IFGI	Grassland	FH building	10
	Mensa	X	***S***	SE	SW	SE	
	Aasee	***NW&N&NE***	X	***SW&S&SE***	***W***	***SW&S&SE***	
	IFGI	NW	***N***	X	NW	***0&W&SW&S***	
	Grassland	NE	***NE&E***	SE	X	SE	
	FH building	NW	***N***	***E&N&NE***	NW	X	

Table 3.17: Relative object positioning from a sketch map participant D.

Name	Coarse cardinal directions						Inaccuracy
PD		Mensa	Aasee	IFGI	Grassland	FH building	9
	Mensa	X	***S***	SE	SW	SE	
	Aasee	***NW&N&NE***	X	***S&SE***	***W***	***SW&S&SE***	
	IFGI	NW	***N***	X	NW	***W***	
	Grassland	NE	E	SE	X	SE	
	FH building	NW	***N***	***E***	NW	X	

Table 3.18: Relative object positioning from a sketch map participant E.

Name	Coarse cardinal directions						Inaccuracy
PE		Mensa	Aasee	IFGI	Grassland	FH building	6
	Mensa	X	***S&SE***	SE	SW	SE	
	Aasee	***N&NW***	X	SE	***W***	SE	
	IFGI	NW	NW	X	NW	***SW***	
	Grassland	NE	***E&NE***	SE	X	SE	
	FH building	NW	NW	***NE***	NW	X	

Table 3.19: Relative object positioning from a sketch map participant F.

Name	Coarse cardinal directions						Inaccuracy
PF		Mensa	Aasee	IFGI	Grassland	FH building	10
	Mensa	X	***S***	SE	SW	SE	
	Aasee	***NW&N&NE***	X	***S&SE***	***W***	***SE&S&SW***	
	IFGI	NW	***N***	X	NW	***W&SW***	
	Grassland	NE	***E&NE***	SE	X	SE	
	FH building	NW	***N***	***E&NE***	NW	X	

Table 3.20: Relative object positioning from a sketch map participant G.

Name	Coarse cardinal directions						Inaccuracy
PG		Mensa	Aasee	IFGI	Grassland	FH building	8
	Mensa	X	***S***	SE	SW	SE	
	Aasee	***N&NE***	X	***SE&E***	***W***	SE	
	IFGI	NW	***W&NW***	X	NW	***S&0&W&SW***	
	Grassland	NE	E	***E&SE***	X	SE	
	FH building	NW	NW	***N&NE&E***	NW	X	

From the resulting tables, most of the errors were related to Lake Aa, FH building and IFGI. People made errors of shapes, relative areas and angularity of these objects. In participant's sketches (Figure 3.10), instead of drawing the exact or approximate shapes of IFGI , FH building and lake Aa, people simplified them into rectangles or oblongs or ellipses. In addition, the directions of the main roads got straightened in sketch maps which change the relative positional relations between objects nearby.

3.4.Discussion of Outcomes

In order to figure out relationships between inaccuracy or errors participants made and the accuracy of calculations for spatial relations, especially cardinal directions, one assumption was raised as below. Here we focus on how documented errors, especially distortions or simplification on shapes, curvatures and angle, influence cardinal directions. We assumed that these three errors mainly cause the mistakes in cardinal directions. The method for the assumption-proof is changing the pictorial elements from assumption and their related elements and keep all other sketch elements the same as the original. Then cardinal directions will be calculated on modified sketch map again and the correlation of accuracy of cardinal directions and pictorial elements will be built. The experiment was based on Location I and only one participant's sketch map was analyzed as below.

Curvature. To verify this assumption, the sketch map needed to be modified: the street “Hüffer-Str” were made curved as it looks like in the reality while all other pictorial elements such as size, shape or relative metric properties were keep the same. However, to keep the same positional relation of ditch with relative to street “Hüffer-Str”, it was impossible to maintain the original shape of ditch as participant drew . From participant's perception, ditch is along with the segment of street “Hüffer Str”. As the reflection of participant's perception, in sketch map, the ditch extends along with the street “Hüffer-Str” and changes its trend at the intersection near FH building. Therefore, the outline of ditch had to be modified as an associated element with path curvature. Likewise, the shape of building FH building was modified to make its edges along with the street as participant perceived (Figure 3.14).

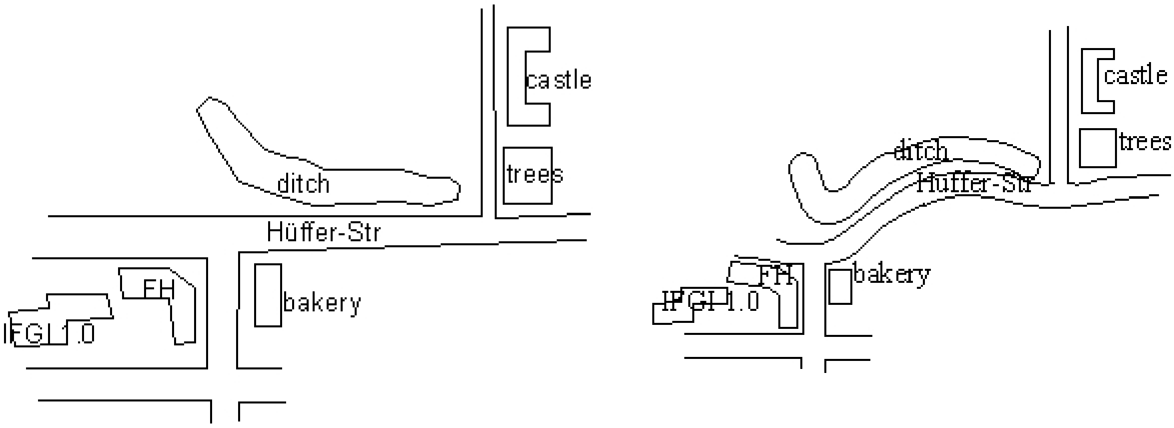


Figure 3.14: Modified sketch map with curved path and all other pictorial elements remain the same (The right map is the original one with straightened street “Hüffer-Str”)

The same approach for cardinal directions applied to the modified map. All other pairs of cardinal directions remained unchanged, only pairs of relations including ditch or FH building were computed here. Compared with Table 3.3, the resulting tables (Table 3.21) shows that the map with modified elements of curved path and its related objects corrects 3 errors (bold and italic fonts) of cardinal directions from original map and make the sketches more accurate. As a consequence, it is reasonable to conclude that the accuracy of path curvature and the shape of its related path- extent objects influence the accuracy of cardinal directions. If coefficient r is imported to indicates the degree of linear relationship or correspondence between these elements, the following equation represents the fact that to some extend, accuracy of path curvature and the shape of its related path- extent objects account for the accuracy of cardinal directions.

$$Y = r_1 X_1 + \sum_{i=2}^{n} (r_i X_i) \qquad \text{(Equation 3.1)}$$
$$X_1 = f_1(Cuv, Shp)$$

In this equation:

Y is the value of cardinal directions accuracy

X_1 is a function with two variants Cuv and Shp. Cuv is the accuracy of path curvature and Shp represents the shape of path-extent objects.

r_1 describes the degree of relationship between Y and X_1. In this case $r_1>0$ which means positive correlation of X_1 to Y.

From previous assumptions, $\sum_{i=2}^{n} (r_i X_i)$ describes other sketch components which may influence the cardinal directions.

Table 3.21: Cardinal directions of modified sketch map of curvature.

Cardinal directions relative to all other spatial objects				
	Castle	IFGI	Parking lot	Bakery
FH building	SW	NE&E	N&NW	***SW&W&NW***
Ditch	***SW***	NE	NE	N
Cardinal directions relative to FH and ditch				
	FH building		Ditch	
Castle	NE		NE	
IGFI	W		SW	
Ditch	NE		X	
Parking lot	S		SW	
Bakery	E		S	
FH building	X		SW	

Angle. To verify this assumption, participant sketch map was modified as the following picture: angels of intersections were depicted as they look like in the reality while all other pictorial elements were keep unchanged (Figure 3.15). However, it was impossible to both keep the correct path angles and the original relative positional relations at the same time. From participant's mind, edges with mark numbers of IFGI and FH building are all paralleled with their adjacent street segments. To keep the same relative positional relations with modified paths, the integral parcel (to keep the relative positional directions between objects inside parcel unchanged) of IFGI and FH building needed to rotate anticlockwise until edge 1 paralleled with the adjacent street "Robert-Koch-Str" and then do the translation to make sure that the distance to adjacent streets were unchanged. Bakery and parking lot were rotated in the same way to make their positions with relative to modified streets the same as original map. Moreover, the shape of FH building was modified to make edge 3 and edge 4 being parallel with adjacent streets.

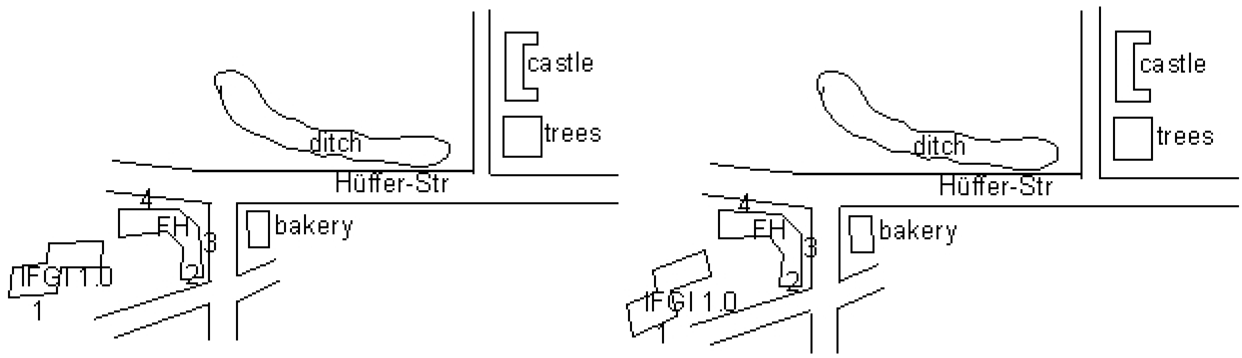


Figure 3.15: The left one is with angle modified only and right one is with additional modifications (1, 2, 3, 4 represent related edges which need to be modified).

cardinal directions analysis applied to the modified map again. Because all other pairs of cardinal directions remained unchanged, only pairs of relations including IFGI, FH building, parking lot and bakery were computed again. By being compared with Table 3.3, the resulting tables (Table 3.22) shows that the map with modified elements of curved path and its related objects corrects 2 errors (bold and italic fonts) of cardinal directions from original map and make the sketches more accurate. Considering the outcome of assumption 1, correctness of angles is one main influence for map goodness but not the leading cause for map errors.

Table 3.22: Cardinal directions of modified sketch map of angle.

Cardinal directions relative to other objects				
	Castle	IFGI	Bakery	Parking lot
IFGI	SW	X	SW&W	NW
FH building	SW	E&NE	***SW&W&NW***	N&NE

Cardinal directions relative to FH and IFGI		
	IFGI	FH building
Castle	NE	NE
IGFI	X	SW&W
Ditch	NE	NE
Parking lot	SE	S
Bakery	***NE***	E
FH building	E+NE	X

Equation 3.1 can be modified as the following:

$$Y = r_1 X_1 + r_2 X_2 + \sum_{i=3}^{n} (r_i X_i) \qquad \text{(Equation 3.2)}$$

$$X_2 = f_2(Ang, Shp)$$

In this equation:

X_2 is a function with two variants Ang and Shp. Ang is the accuracy of path angles and Shp represents the shape of path-extent objects.

r_2 describes the degree of relationship between Y and X_2. In this case, $r_1 > r_2 > 0$ which means the correlations of X_2 to Y is positive but the degree is not as strong as X_1.

Shape. To verify this assumption, all the object shapes were modified to the same as they look like in the reality. In this case, the shapes of FH building, IFGI and ditch were modified and all other pictorial elements were kept the same as original ones. However as discussed before, to make relative relations of other objects unchanged, extra modifications were inevitable to apply to path angles and curvatures. In this case, if the path angles and curvatures were kept the same as participant did, after correcting the shapes, both the original cardinal directions and topological relations would be broken (Figure 3.16). As showed in the following figure, instead of being along with main street "Hüffer-Str" and disjoint with bakery and FH building, ditch is overlap with the street and meets bakery and Hüfferstiff. Likewise, instead of being paralleled with the adjacent street, the edge 1 of IFGI is overlap with "Robert-Koch-Str" and so as the edges of FH building.

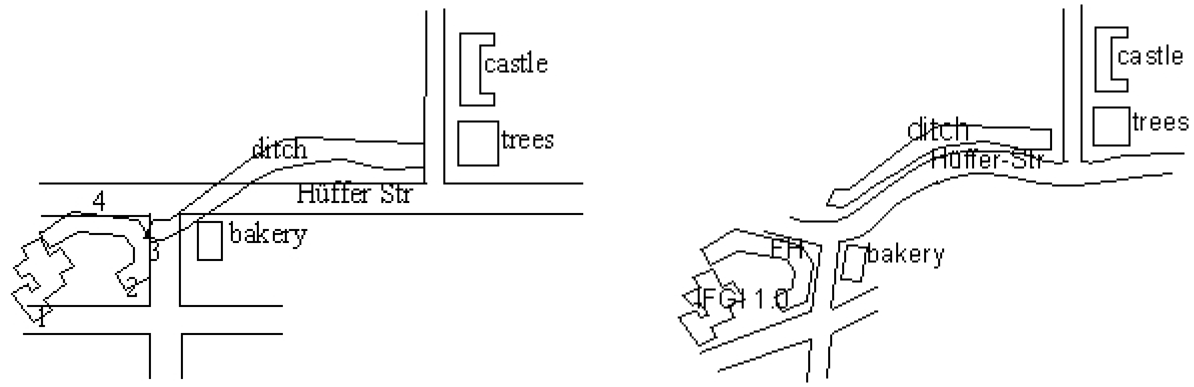


Figure 3.16: The left one is the modified map only with shapes changed and the right one is modified map with both shapes and its related elements as curvature and angle changed at the same time.

The outcome of cardinal directions for modified sketch map corrected 5 errors from the original one(bold and italic characters in Table 3.23). Similarly, the original equation can be further adjusted to equation 3.3 as the following:

$$Y = r_1X_1 + r_2X_2 + r_3X_3 + \sum_{i=4}^{n}(r_iX_i)$$

$$X_3 = f_3(Shp, Cuv, Ang) \qquad \text{(Equation 3.3)}$$

In the equation:

Shp represents the shapes needed to be corrected; Cuv and Ang represent the path curvature and intersection-angle which are adjacent to the objects whose shapes need modification.

r_3 describes the degree of relationship between Y and X_3 . In this case $r_3>r_1>r_2>0$ which means the positive correlation of X_3 to Y and moreover, among all three influential factors, X_3 has the most strongest correlation with Y.

Table 3.23: Cardinal directions of modified sketch map of shape.

	Castle	**IFGI**	**Ditch**	**Parking lot**	**Bakery**	**FH building**
Castle	X	NE	***NE***	NE	NE	NE
IFGI	SW	X	SW	NW	SW&W	***0&W&SW***
Ditch	***SW***	NE	X	NE	NW&N&NE	NE
Parking lot	SW	SE	SW	X	SW	S
Bakery	SW	E&NE	S	NE	X	E
FH building	SW	***E&N&NE***	SW	N&NW	***NW&W&SW***	X

Over all conditions discussed in this experiment, the accuracy of shape, path curvature and angle has strong correlation with the accuracy of coarse cardinal directions. It makes sense to conclude that these three pictorial elements mainly cause the errors of cardinal directions for depicted regions like location I. Meanwhile, these three influential elements always react together so if one of these elements is depicted correctly, the rest ones which are associated with this element may be depicted accurately as well. On the contrary, when people distorted one of these elements, the rest ones which are related to this sketched element may be distorted either.

Chapter 4
Modification & Formalization

In this chapter, the current study is based on the outcomes from chapter 3 and explores how to improve the existing approach from Egenhofer to make it more feasible and applicable. We discuss two available approaches for better capturing the essence of sketches, especially on capturing more accurate spatial relations. One is the provision of map toolkits as drawing assistants and the other is the modification of Egenhofer's approach for sketch map analysis. Considering the single topological relation we got from all the sketch maps as disjoint, the modification was only processed on coarse cardinal directions and detailed cardinal directions.

4.1.Map Toolkits

From study results in chapter 3, we have already known that simplification and distortion of object shapes, curvatures and angles are notable errors people make during sketching and they have negative effects on accuracy of spatial relations from sketch maps. If various patterns of paths and intersections or shapes of landmarks are given as toolkits, it will both ease the drawing procedures for toolkit users and reduce non-cognitive errors. The toolkit design is based on the map toolkit that Tversky used for the research of similarity between depictions and directions (Tversky, B. & Lee, P. 1999), as well as taking a wide variety of routes and landmarks into account. The shapes and line types which people can use for sketches are not only restricted to the toolkits. The components of the map toolkits are pictorial elements and users will be encouraged to supplement them as they see fit. The map toolkit (Figure 4.1) we proposed in this thesis contains:

- Three types of intersections, X, T and L.
- Two types of paths, curved and straight.
- Two types of arrows, bent and straight.
- Three types of landmarks as rectangles, circles and one landmark of building with accurate shape.
- Sample representations for the most common geographic features as water body and mountains.

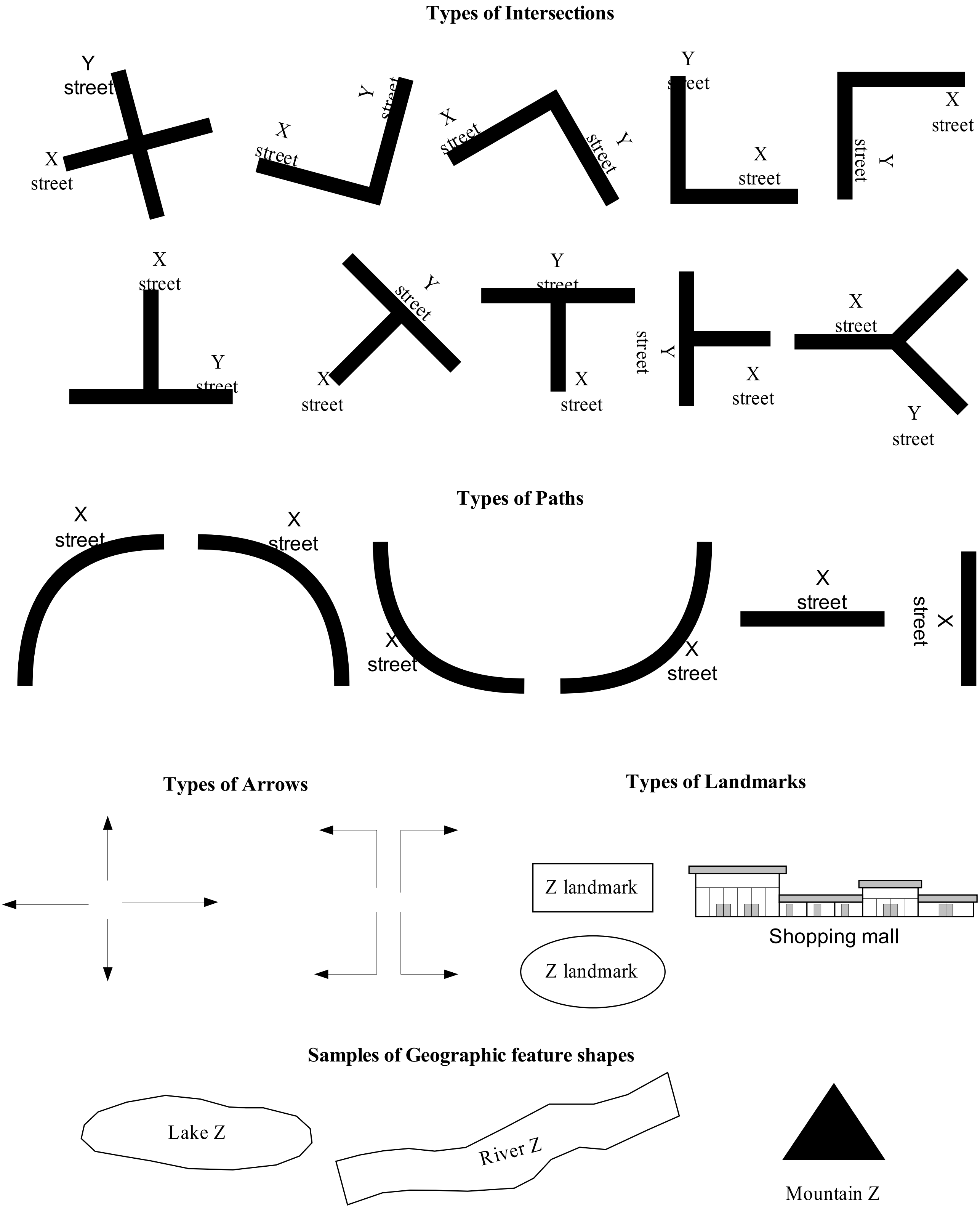


Figure 4.1: One example of map toolkits.

These toolkits can remind people of drawing curved roads or correct angles of intersections to make the spatial relations of sketches more close to the real environment. Likewise, toolkits show users two possible ways to depict landmarks. One is using blobs and another is drawing the exact shape or approximate shape if users are families with the outline of this landmark.

Map toolkit is working as a drawing assistant during human sketching. It can inspire toolkit users and give them “hints” of sketched elements look like. For example, arrows may remind users of adding arrows to explicitly represent orientations and curved path may remind users not always draw straightened streets if they perceive the streets as curved. However, map toolkit do not solve problems from the root. It cannot overcome or even reduce cognitive errors and distortions fundamentally. If toolkit users perceive a curved street straight in their minds or a building with rectangle shape instead of its exact outline, they will just draw what in their minds on paper no matter how many sample streets or buildings provided in map toolkit. Sometimes map toolkit might more problematic because it provides only typical types of sketched elements which may even support human schematic thinking somehow. For instance, in figure 4.1 there is only types of angels of 90° and 60° so it may happen that toolkit users will just draw two kinds of angles instead of exact angles in the reality. Consequently, map toolkit helps only with drawing problems and enhances the drawing abilities and we will not go further in this direction neither in this thesis nor in the future work.

4.2.Modifications of Cardinal Directions

In this thesis, the modifications mainly focus on coarse cardinal directions and detailed cardinal directions from Egenhofer's approach for sketch map analysis. In our experiment, all the participants drew spatial objects disjoint with each other so among all five types of spatial relations, there are only coarse topological relations, coarse cardinal directions and detailed cardinal directions available for sketch representation. Detailed topological relations and metric refinements that are both based on non-empty intersections will not discussed in this thesis. As discovered before,both coarse and detailed cardinal directions of sketch maps differ a lot from the corresponding ones in real maps. For instance, compared with real map for location I from castle to IFGI, there are in total 54 inaccuracies of coarse cardinal directions among 7 participants (Table 3.6-3.12). The 61% of average accuracy rate makes us doubt whether the sketched cardinal directions with the cardinal directions recorded in the real maps may necessarily provide an exact match. As discussed before, cardinal directions that Egenhofer used for calculating relative positional relations are processed among all sketched spatial objects. So if the number of total sketch objects is *N*, the algorithm of Egenhofer's way to calculate relative positional relations can be described as the following pseudo-code.

```
public static boolean cardinal_Egenhofer (int N)          /*N is the number of sketched spatial objects*/
{
      int i = 0, j=0;
      if (N > 0){
            for (i = 0; i < N; i++)
                  for (j=0; j < N-1; j++)
                  calculation();                /*calculate cardinal directions of each pair of sketched objects*/
      }
      else
            return FALSE;                /*return a false value if there is no sketched objects to be analyzed*/
      return TRUE;
}
```

The algorithm complexity is O (N^2) and the calculations will be more complex and take more time if there are more spatial objects sketched by people. Moreover, the calculations of position relations that are on the basis of nine partitions are not necessary for sketched objects. Humans draw spatial objects roughly and without accurate positions with relative to other objects. Complexity in calculations may cause more inaccuracies because humans do not perceive directions as detailed as Egenhofer's approach. To the contrary, simplicity works better in calculations because it can relax constraints in cardinal directions and consider not only exact matches but also similar matches between the reality and what human drew. For example, if two sketched objects are related to an oriented path, it is useful to talk about one object being above (or to the north), below (or to the south), right (or to the east), left (or to the west) or at the same location along the path but not being northeast or northwest to the reference object.

In our experiment, sketch maps for both two locations contain regions and routes[6] and almost all the salient features are located along the main route. As a result, a new reference frame can be built to calculate relative positional relations which use streets as reference objects but not calculate all cardinal directions of pairs of any objects. In this new reference frame, the main streets and their branches that run through the whole region are the reference objects and positional relations of all other spatial objects are computed with respect to these streets.

Cardinal directions in 4 half-planes. Cardinal directions based on projections have two kinds of systems of directions. One is D_4 = {N, E, S, W} and the other is extensive D_8 = {N, E, S, W, NE, NW, SE, SW}. Egenhofer's approach of cardinal directions is based on D_8 with additional direction *0* representing identical position. In this thesis, cardinal directions in 4 half-planes that are on the basis of D_4 are imported as the theoretical basis for the modified approach we proposed. This kind of cardinal directions can be found in the structure geographic longitude and latitude imposes on the global (Frank, 2006). The four directions are pair-wise opposites and each pair divides the plane into two half-plains (Figure 4.2). The direction operation assigns for each pair of objects a composition of two directions, e.g., South and East for a total of 4 different directions (Peuquet and Zhan, 1987). In our case, because of the arbitrarily shaped routes in sketch maps, the assigned directions are relative to straight street segments or the minimum bounding box of curved ones which are both considered as enclosing polygons.

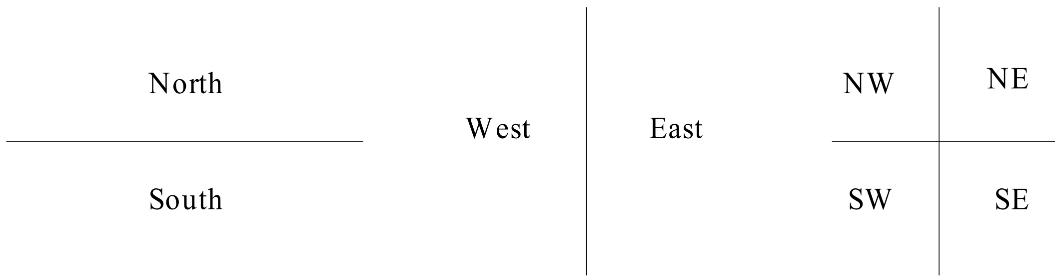


Figure 4.2: Two sets of half-planes and directions defined by half-planes.

As the following, we discussed the all possible situations to define “above”, “below” and “at the same location” (Figure 4.3) and in Figure 4.4 we discussed the possibilities of “right”, “left ” and “at the same location”in 4 half-planes.

6 There are two broad classes of maps: those that convey regions and those that convey routes (Tversky, B. 2002).

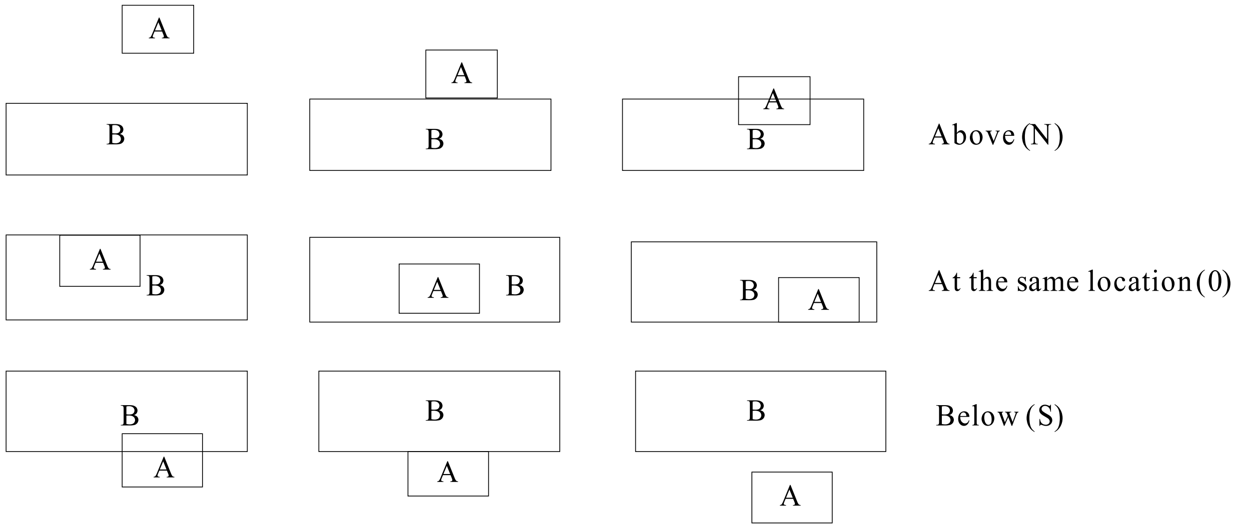


Figure 4.3: Possible positional relations as "above", "at the same location" and "below" with respect to reference object B.

Above: $Y_{maxA} > Y_{maxB}$

At the same locations: $(Y_{maxA} \leq Y_{maxB})$ & $(Y_{minA} \geq Y_{minB})$

Below: $Y_{minA} < Y_{minB}$

Y_{min}, Y_{max} is minimum y value and maximum y value of bounding box respectively. B is reference object.

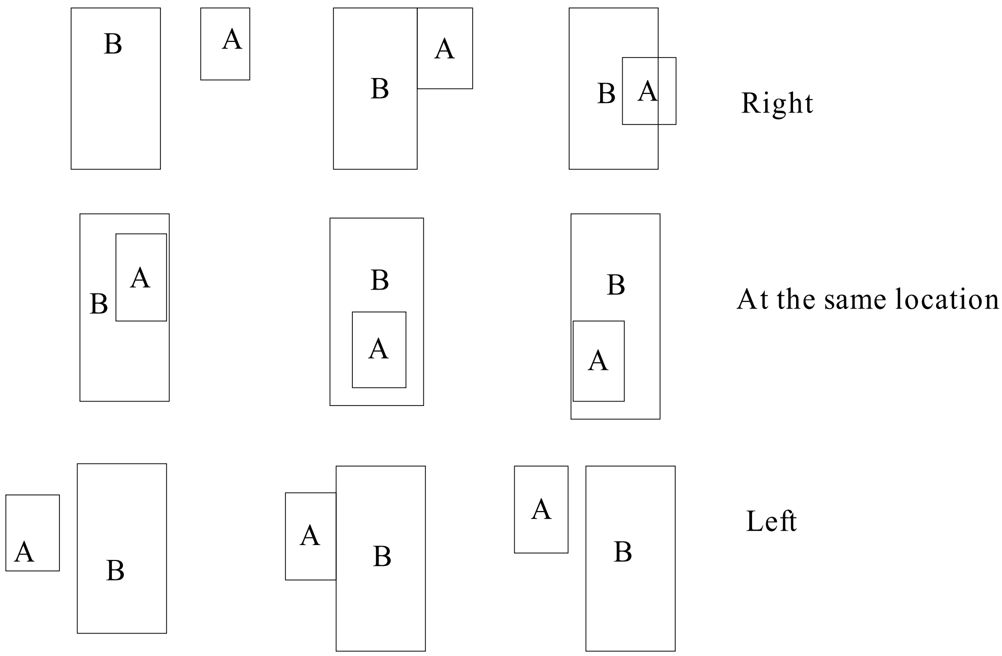


Figure 4.4: Possible positional relations as "right", "at the same location" and "left" with respect to reference object B.

Right: $X_{maxA} > X_{maxB}$

At the same location: $(X_{maxA} \leq X_{maxB})$ & $(X_{minA} \geq X_{minB})$

Left: $X_{minA} < X_{minB}$

X_{min}, X_{max} is minimum y value and maximum y value of bounding box respectively. B is reference object.

All the metric measurements are processed in 2-D Cartesian coordinate systems and where to build the origin and set the datum are dependent with the shape of street segment. Figure 4.5 shows different situations to measure positional relations with the street shapes of horizontal, vertical and inclined.

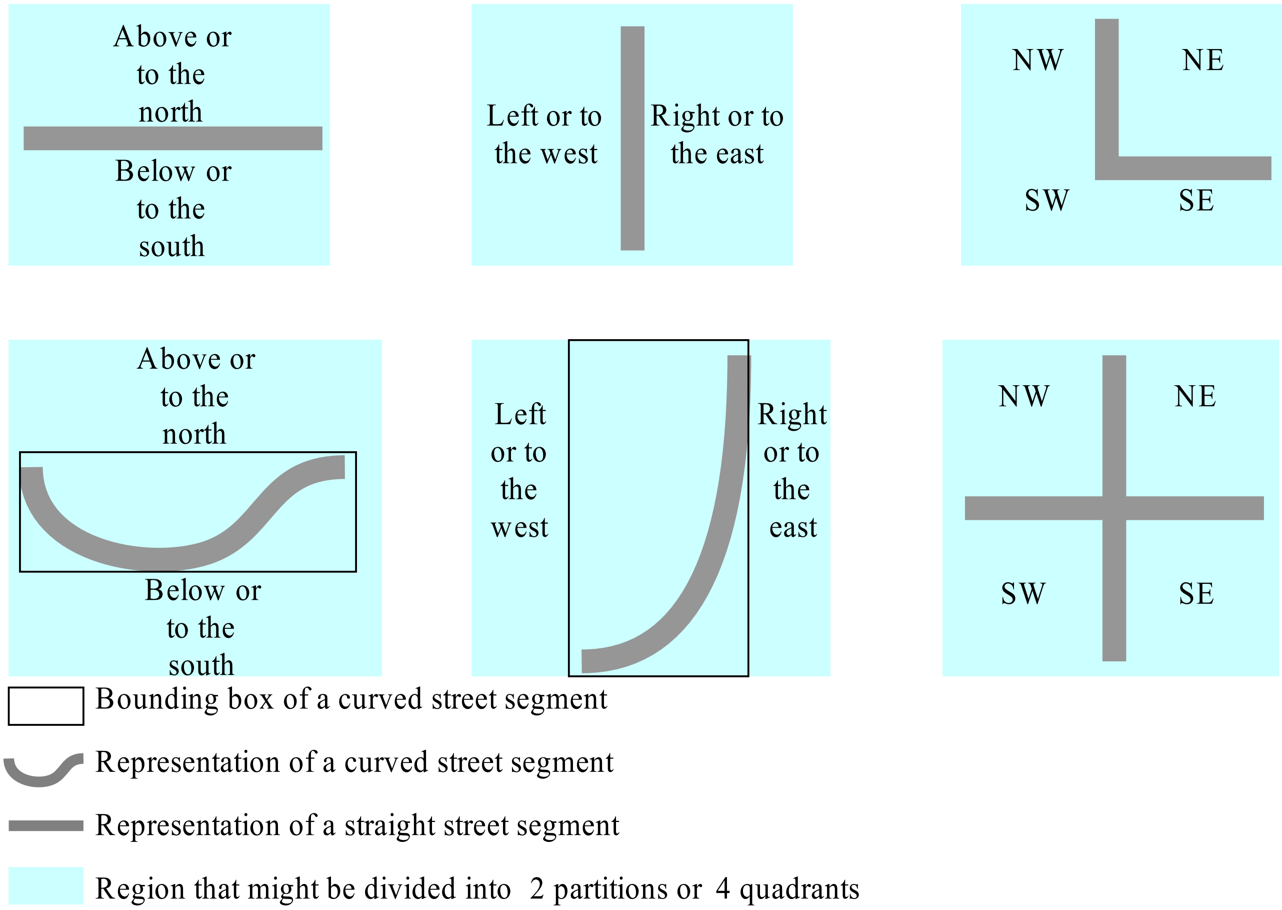


Figure 4.5: Build up a datum for qualitative metric measurement.

Refinements of Modified Approach using Object Orders. The same as the most formalizations or implementations of spatial reasoning, qualitative positional relations rely on the Euclidean geometry and the Cartesian coordinate system, and there is a clear need for a fully qualitative system of positional relation reasoning, combing topological and metric relations (Frank, 2006). In this case, metric properties such as relative distances to reference objects are indispensable for positional relations reasoning. Only modified cardinal directions is insufficient to characterize accurate positional relations. What Egenhofer did was recording for each object that falls into more than one direction partition the percentage of the common intersection between a partition and the object (Egenhofer, M. 1997). However, as we discussed before, coarse cardinal directions from Egenhofer cause more inaccuracies and errors because humans can not distinguish 9 partitions during their drawing. So Egenhofer's approach for cardinal directions refinements needs to be modified as well. We propose object order as a refinement of cardinal directions based on 4 half-planes. Object order is calculated by recording the sequences of objects with relative to the reference object. Compared with exact distances to reference object, humans make much less errors on drawing object orders. As showed below, people made mistakes of relative distances among objects, but the object sequence they drew is correct (Figure 4.6).

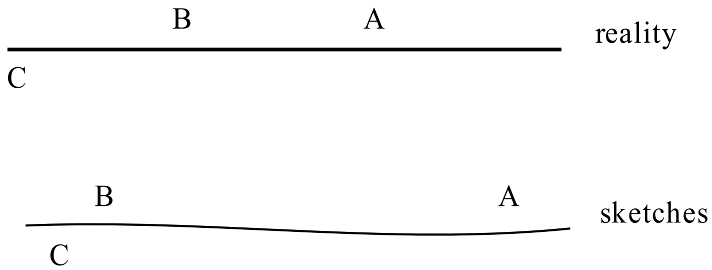


Figure 4.6: Distances among object A, B, C are not the same as they are in the reality but people always sketch correct object orders.

4.2.1. Workflow of Modified Approach

Before the calculation, it is necessary to make a decision of reference objects. The basic principle to choose reference object is to find the streets which have at least two objects along either side of them and only trend towards one direction or with cross shapes (Figure 4.2). It is common that there are not only one reference object to be chose (Figure 4.7a-b). Among these reference objects, the next step is to mark them with different calculation resolutions. For example, as Figure 4.7a shows, the “Hüffer-Str” is marked as 1 which means in the most coarse level of positional relations calculation, this street is taken as the reference object. Two branches marked with 2a and 2b are the reference objects for calculations of positional relations which will make further partitions of directions with more details. For instance, street segment “2a” is a partition of space above street segment “1”, which will be assigned for directions of left (or west) and right (or east). As a result, objects above street segment “1” can be further distinguished by their positional relations with relative to reference object “2a”.

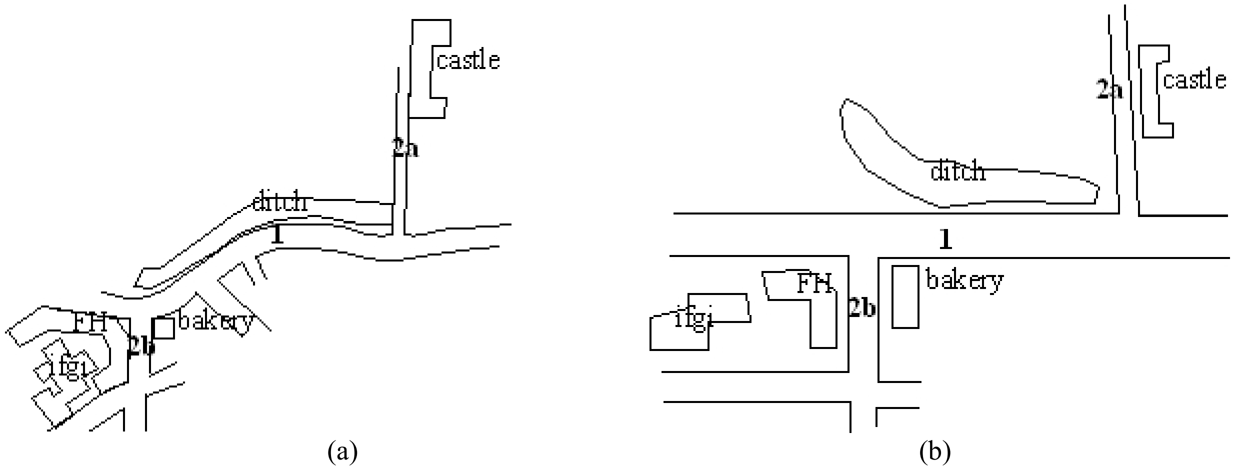


Figure 4.7: 1, 2a and 2b are street segments which will be reference objects for relative positional relationship calculation in (a) real map and (b) sketch map respectively.

For the coarse positional relations, street segment “1” roughly divided all the objects into two parts: ditch and castle which are above of it and IFGI, FH building and bakery which are below of it. To calculate whether one object being head or behind another one, both Y values of the upper left side (or upper right side) and lower right side (or lower left side) of object's bounding box are required.

As below are the calculation results from both real map and sketch map (Table 4.1a-b) in Figure 4.1 when street "1" was considered as reference object. They two have exactly the same positional relationships when segment of Hüffer-Str was taken as reference object.

Table 4.1a: Relative positional relations from real map with reference object 1.

Reference Object	**Positional Relationships**	
1 (Segment of Hüffer-Str)	Above	Castle, Ditch
	Below	IFGI, FH building, Bakery

Table 4.1b: Relative positional relations from sketch map with reference object 1.

Reference Object	**Positional Relationships**	
1 (Segment of Hüffer-Str)	Above	Castle, Ditch
	Below	IFGI, FH building, Bakery

After the first round calculation of coarse positional relations, objects in maps were roughly divide into two groups. One group with castle and ditch that were located above the reference object while another group with the rest of objects which were below the reference object. If more detailed positional relations were demanded, the second round calculations of positional relations were carried out respectively in the region above segment of "Hüffer-Str" with its reference objects "2a" and the region below segment of "Hüffer-Str" with its reference object "2b". Table 4.2-4.3 are the results of further calculations of positional relations from real map and sketch map. Again we got exactly the same results and the region above segment of "Hüffer-Str" was sub divided into two parts, one with bakery which was to the right of the reference object "2b"and another with IFGI and FH building which were both to the left of reference object. Likewise, the region above segment of "Hüffer-Str" was sub divided into two parts with ditch and castle respectively.

Table 4.2a: Relative positional relations from real map with reference object 2a.

Reference Object	**Positional Relationships**	
2a (branch of Hüffer-Str)	Right	Castle
	Left	Ditch

Table 4.2b: Relative positional relations from sketch map with reference object 2a.

Reference Object	**Positional Relationships**	
2a (branch of Hüffer-Str)	Right	Castle
	Left	Ditch

Table 4.3a: Relative positional relations from real map with reference object 2b.

Reference Object	**Positional Relationships**	
2b (segment of Robert-Koch-Str)	Right	Bakery
	Left	IFGI, FH building

Table 4.3b: Relative positional relations from sketch map with reference object 2b.

Reference Object	Positional Relationships	
2b (segment of Robert-Koch-Str)	Right	Bakery
	Left	IFGI, FH building

Until now, we got positional relations with respect to all street segments and among all 5 objects, positional relations of 3 objects can be given without ambiguities. To distinguish the positional relations between IFGI and FH building, object orders to reference object "2b"were calculated (Table 4.4). In this case, compared with FH building, IFGI is far from the segment of "Robert-Koch-Str" which means $O_I > O_F$.

Table 4.4: Positional relationships with respect to different reference objects.

Object	**Positional Relationships**
Castle	(above "1") & (right to "2a")
Ditch	(above "1") & (left to "2a")
Bakery	(below"1") & (right to "2b")
IFGI	(below "1") & (left to "2b") & (O_I)
FH Building	(below "1") & (left to "2b") & (O_F)

(O_I,O_F are object orders of IFGI and FH with respect to reference object "2b")

Using this approach we proposed, the differences for positional relation between real map and sketch map can be decreased to 0, which means an exact match between sketched positional relations and the positional relations recorded in real map.

4.2.2.Formalization of Modified Approach

As the following some strategies for approach applicability are summarized:

- This approach can be used in the map which is the mixture of route and region
- The precondition to use this approach is that route information has already abstracted as known elements
- Salient objects are located approximate equably along both sides of streets
- This approach has better effect than traditional cardinal directions when people distort the route information such as curvature or angle
- If there is a path-extent object like lake or promenade instead of streets, this approach can be applied as well.

The algorithm of this approach can be mainly described as the following flowchart (Figure 4.8).

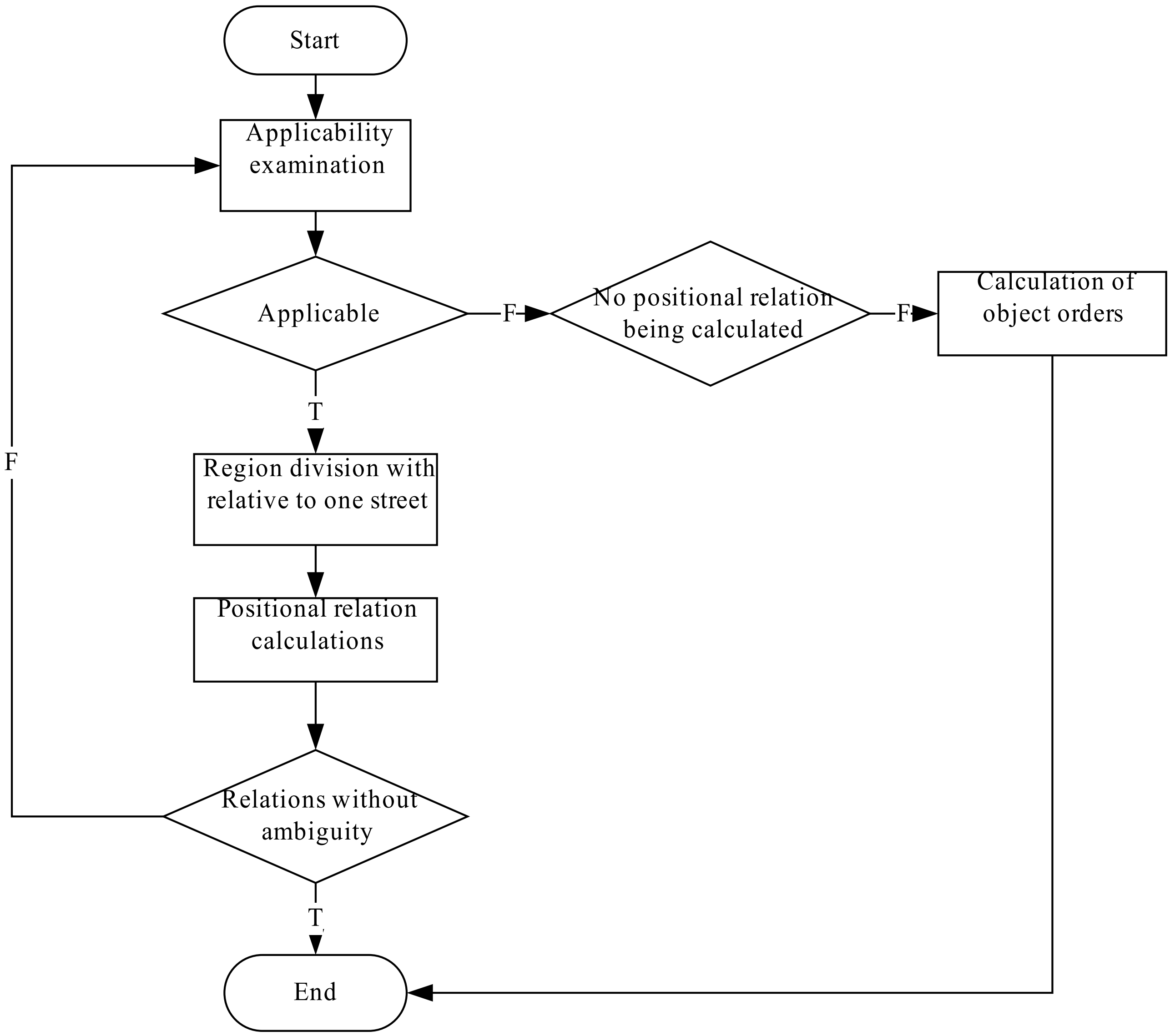


Figure 4.8: Graphically representation of the algorithm of modified cardinal directions analysis.

In the beginning, it is necessary to check the approach applicability on sketch maps. If this approach is applicable, the first street which are normally the most salient one on the map will be extracted as the reference object and divide the whole region into two parts or four quadrants which depends on its shapes. Calculations of positional relations are processed among objects in each sub-region. If all the objects can not be distinguished by positional relations without ambiguities after calculation, there are two different ways to go after checking the applicability again in each sub-region. One is choosing another street and further divide the sub-region to which the objects with ambiguous relations belong. Another is applying for metric refinements to these objects which means the relative distances are calculated to reference object in previous step. The latter one is based on the case that there is no more objects available to be reference objects.

4.3.Summary

There are two approaches to sketch map analysis are described in this chapter: (1) to provide people well-

designed map toolkits, and (2) to modify existing analytical method from Egenhofer for cardinal directions.
Map toolkits can be considered as drawing assistants during people's sketching. It will tell people how the depicting elements look like in sketch maps such as geographic objects like lakes or non-geographic objects like buildings.
The modified approach for calculating positional relations are based on cardinal directions on 4 half-planes. Compared with original cardinal directions by Egenhofer, it is more applicable for the sketch maps which are mixtures of route and regions. Human make inaccuracies of street shapes, curvatures and angles, and in chapter 3 it has already documented that these distortions and simplifications affect the accuracy of cardinal directions analysis. The new approach proposed in this chapter takes streets or path-like objects as reference objects so the correct cardinal directions will be obtained as long as people draw correct positional relations with relative to reference objects. In general, it is much easier to draw "a house to the north of a lake" than the exact shape and curvature of this lake.

Chapter 5
Conclusions & Future Work

This chapter summarizes the findings of this thesis and discusses possible future research topics as well as extensions and refinements to the current modified approaches.

5.1.Summary

This thesis is concerned with how human schematization and systematic distortions impact on sketch map formalizations. It is scientifically motivated by the current situation that existing analysis approach is applied to capture the sketch essence without considerations of human schematization and systematic distortions.

Our case study illustrates an accuracy issue on sketch analysis within the scenario of drawing tasks for two areas. In the first part of our experiment, it mainly focused on accuracy analysis of sketched curvature, angle and shape. After the comparison with real map, such errors as distortion, simplification and elimination are discovered. As which has been explained in psychology, the structure captured by sketches is not the structure of the reality, but rather, the conceptual structure of the information (Tversky, B. 2002). In the second part of the experiment, it mainly focused on the five types of spatial relations from Egenhofer for sketch analysis. A lot of differences between sketch map and real map are discovered while Egenhofer's approach is processed for sketch analysis. In our case, all the differences are from coarse cardinal directions and detailed cardinal directions. The following assumptions and verifications that are based on the previous outcomes prove that if inaccuracies and errors of curvature, angle and shape can be taken into account and corrected somehow, more accurate sketch relations would be captured. As a result, possible methods to improve Egenhofer's approach to sketch analysis is discussed. One proposed approach is to provide sketch users a properly designed map toolkits and another is to modify and re-formalize the existing approach from Egenhofer for sketch analysis, especially cardinal directions.

In this thesis, all the studies are on the basis of experimental locations but not the general situations. In the locations we chose, objects are disjointed with each other. So among all five types of spatial relations, only coarse topological relation, coarse cardinal directions and detailed cardinal directions are available in our study.

5.2.Major Result

The research conducted within the scope of exploring the impact from human schematization and systematic errors on sketch formalization leads to 3 result statements that are described here.

- *Human schematization and systematic errors which have already been documented in psychology have negative impact on accuracy of existing sketch analysis.*

This conclusion is supported overwhelmingly by the outcomes of Chapter 3, and refers to the psychological knowledge discussed in Chapter 2. When people use or try to remember knowledge from spatial representations of the environment, they produce systematic errors (Tversky, B. 1991). The experiment results in Chapter 3 report these errors that are found in sketch maps and moreover, inaccuracy is discovered during the process of sketch analysis. Compared with real map, different spatial analysis results are obtained although we use the same method by Egenhofer. If existing analysis approach is applied for spatial query by sketches, probably the query results are wrong or even null. Clearly, human schematization and systematic errors during sketches have negative effect on accuracy of existing analysis approach.

- *Curvature, shape and angle are the significant influential factors that lead to errors on cardinal directions in our case.*

This conclusion is stated as an assumption in Chapter 3, supported by the following verifications in the same chapter. Curvature, shape and angle of objects are modified to what they look like in the reality, and Egenhofer's approach to sketch analysis is processed again to calculate cardinal directions. The results show that cardinal directions from modified sketches are more accurate than the original ones.

- *For sketch map mixed with region and route, a modified method that considers streets or path-like extent objects as reference objects can be applied to calculate positional relations instead of existing approach from Egenhofer.*

In chapter 4, we proposed a new approach to calculation positional relations. The core part of this approach is an iteration algorithm (Figure 4.8). It repeats the procedure of checking approach availability, choosing reference objects and calculating positional relations until there is no more ambiguities on positional relations among all the objects. Location I in Chapter 3 is used for testing this approach. The resulting tables (Table 4.1-4.4) showed that sketch map has the exact match with real map on positional relations by the use of this new approach.

5.3.Future Work

The thesis leads to various directions of future work. We first refer to our modified approach and then to a more general direction.

5.3.1.Detailed Analysis of Equation Settings

From Chapter 3, we have already got the conclusion that human schematization and systematic errors have negative effect on sketch analysis as representation and formalization. In this thesis, among them, curvature, shape and angle are the leading influential factors (see Chapter 3). For the future work, a certain amount of tests are necessary to fix the exact value or range of parameters from equations in Chapter 3 (Equation 3.1, Equation 3.2, Equation 3.3). As a result, these equations can clearly represent quantitative relations between documented errors in psychology and accuracy of sketch map itself. Considering the different weights of influential factors, sketch analyst can think of adopting proper analytical method for capturing more accurate spatial properties and relations.

5.3.2.Assessment of Map Toolkits Design and Improvement

The main question for map toolkits is that whether they are sufficient or not. In the future work, it is necessary to make several rounds of assessment of map toolkits with a large number of participants. participants will be numerical equally divided into two groups and ask to draw the same location. One group of participants will be provide with map toolkits and they will be told that the toolkits are insufficient and that they can supplement them as they see fit. Another group will depict locations without map toolkits. Map accuracy rate of each group is calculated by comparing with the real map. Moreover, it is also important to record which toolkit elements are used by most of the participants and which are less. It suggests the different importances of toolkit elements and inspire toolkit designer that some elements may need to be extended in shapes or sizes somehow, other may not. After the first round of assessment, map toolkits will be modified on the basis of analytical statistics and new elements participants added. The following round of assessment will carry out on improved toolkits with same participants but different locations with same scale. The other possible improvement direction may test if the map toolkits is sufficient in general. Locations of different scales will be tested.

5.3.3.Detailed Analysis and Extensions of Modification and Formalization

Similar to map toolkits assessment, more participants will be required to evaluate the modified approach. The applicable situations need further refinement. It is better to make a definition of such locations that can be applied to modified approach directly. The definition has its constraints on location scale, map type which means it is a route map or region map or a mixture with route and region, object amount and object distribution on the map. For some detailed questions, like how to make decisions of the first reference object; how to divide a route into several segments and set up different levels of reference system; how to implement it in computer? A prototype of this modified approach is expected to be built in the future work.

Not only the refinements of modified approach, we are also thinking about the extension of it. In the thesis, all the objects were disjoint with each other. Is this modified approach also effective if there are more topological relations among objects? If not, how to make it applicable to more general situation? Or is it better to think about another approach? Such questions need to be answered in future study.

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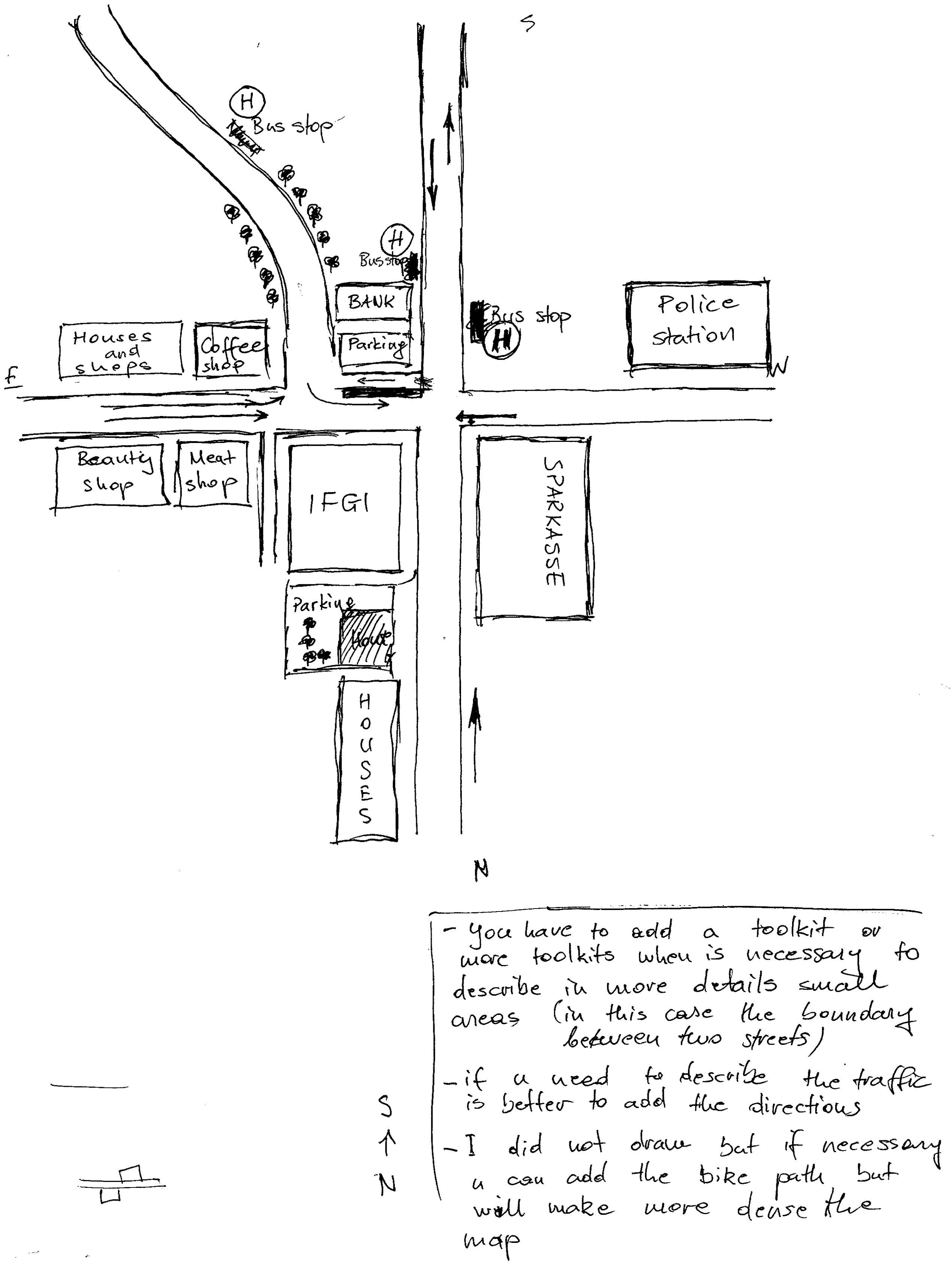
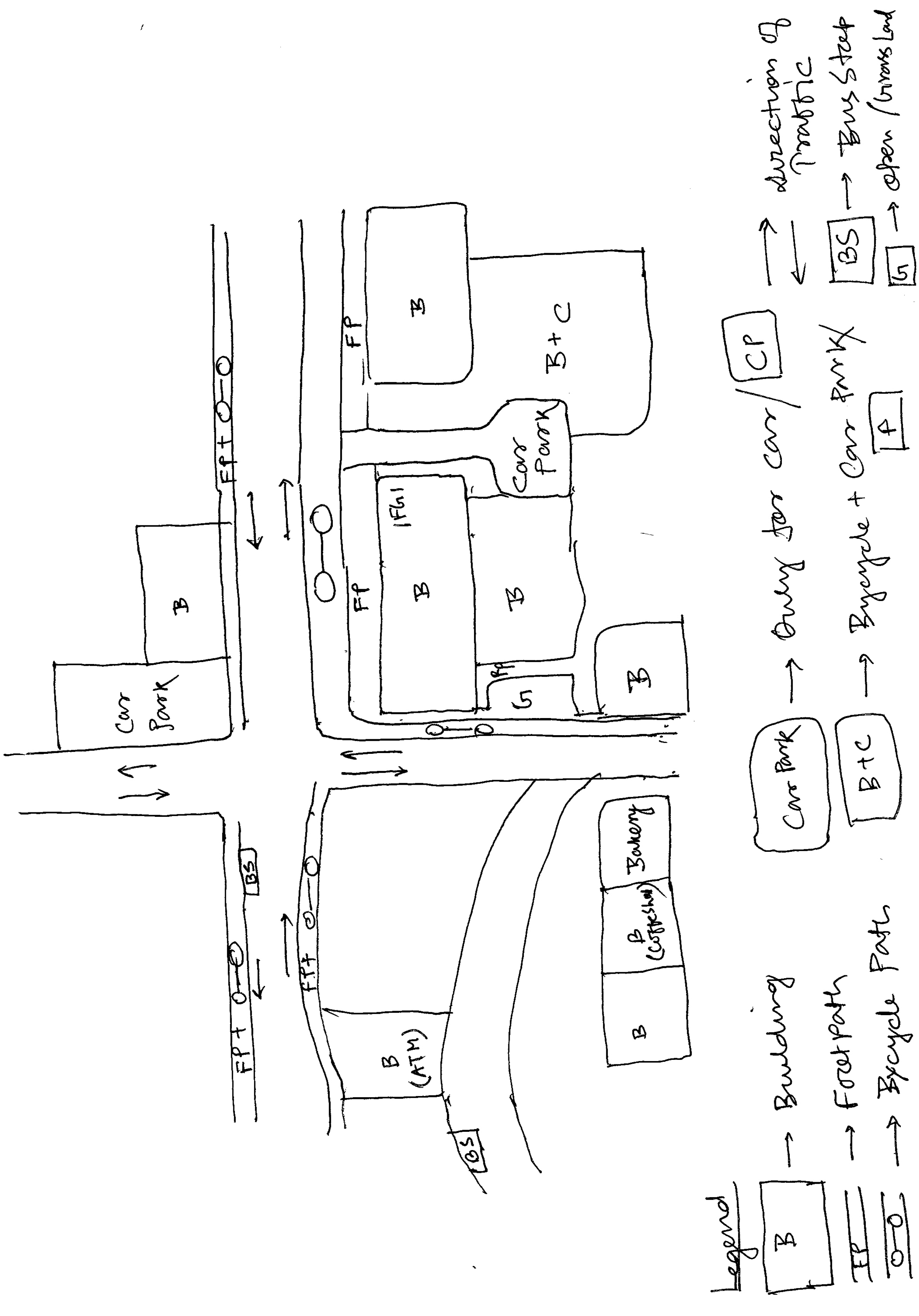
Appendix

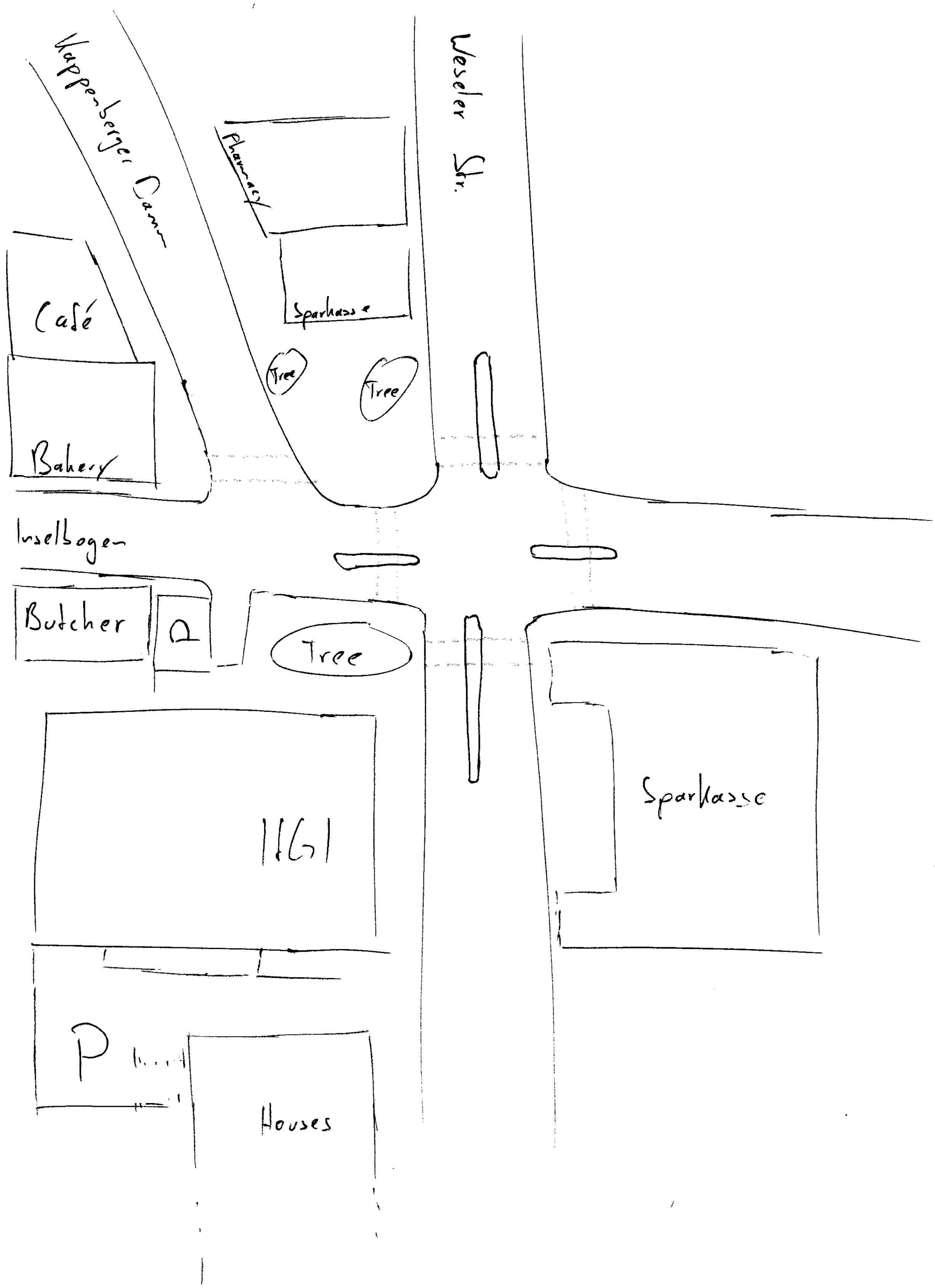
Appendix 1: Sketch map depicting the neighborhood of IFGI 2.0 for location choice from one participant in section 3.1.



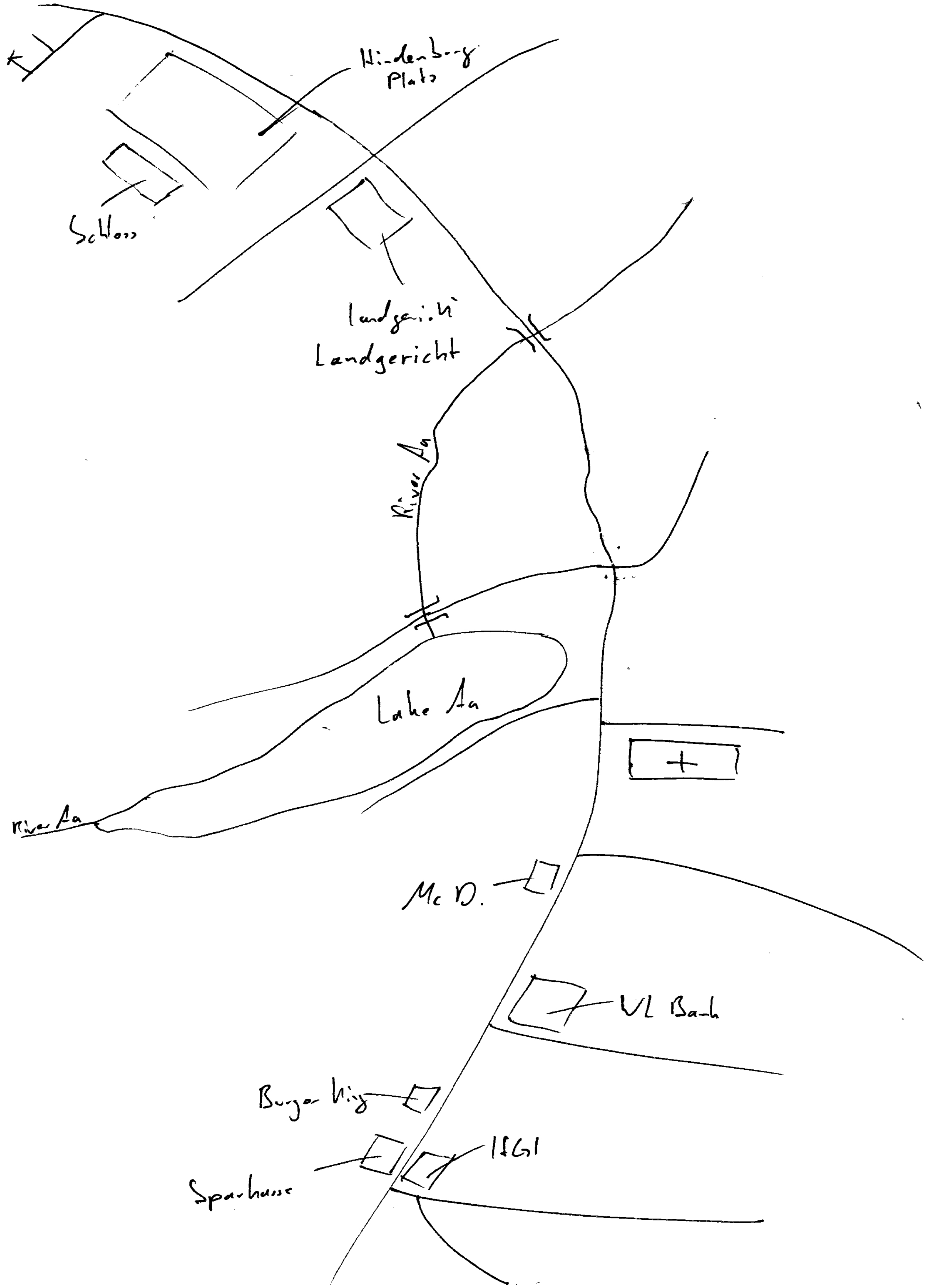
Appendix 2: Sketch map depicting the neighborhood of IFGI 2.0 for location choice from one participant in section 3.1.



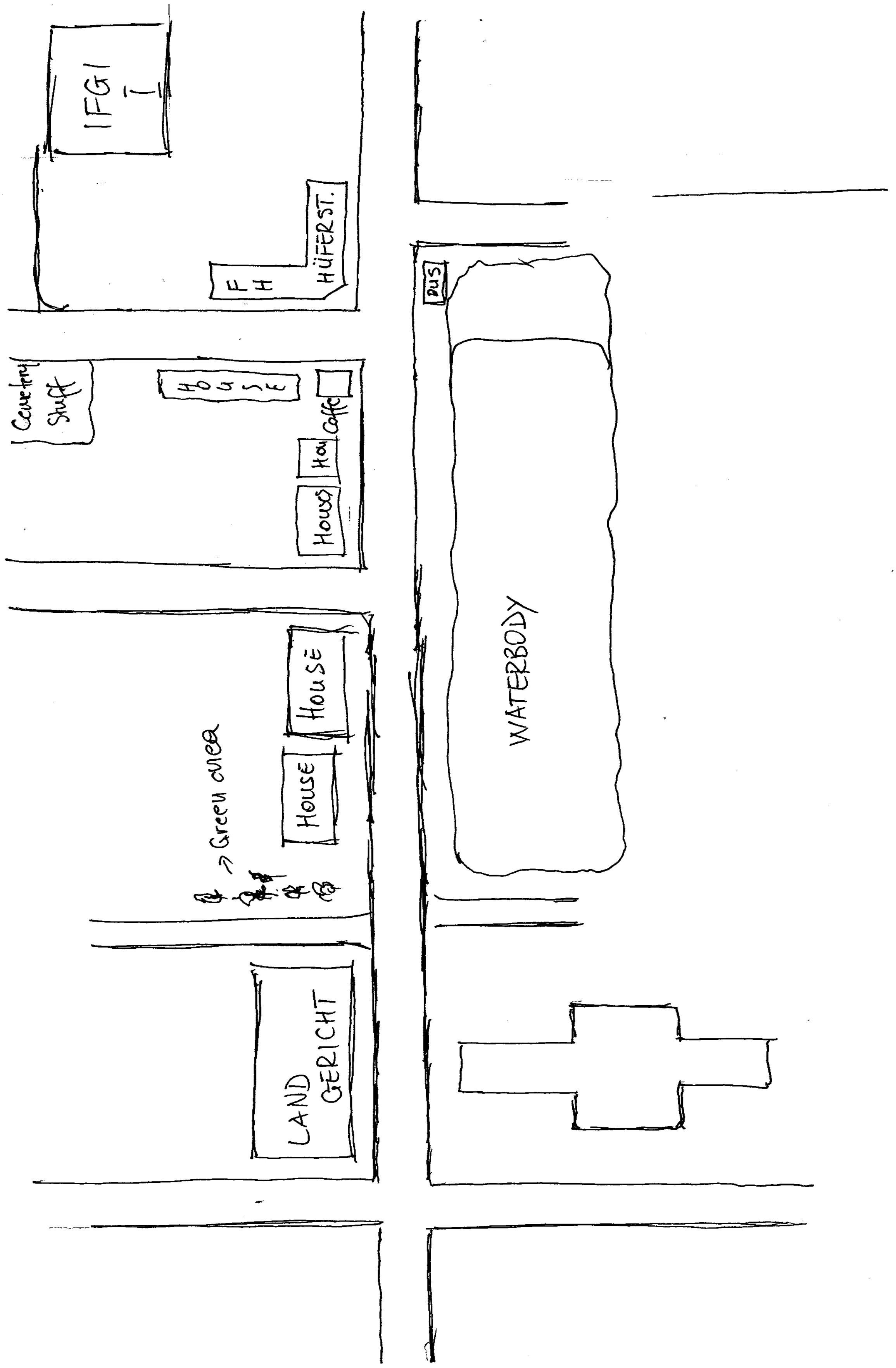
Appendix 3: Sketch map depicting the neighborhood of IFGI 2.0 for location choice from one participant in section 3.1.



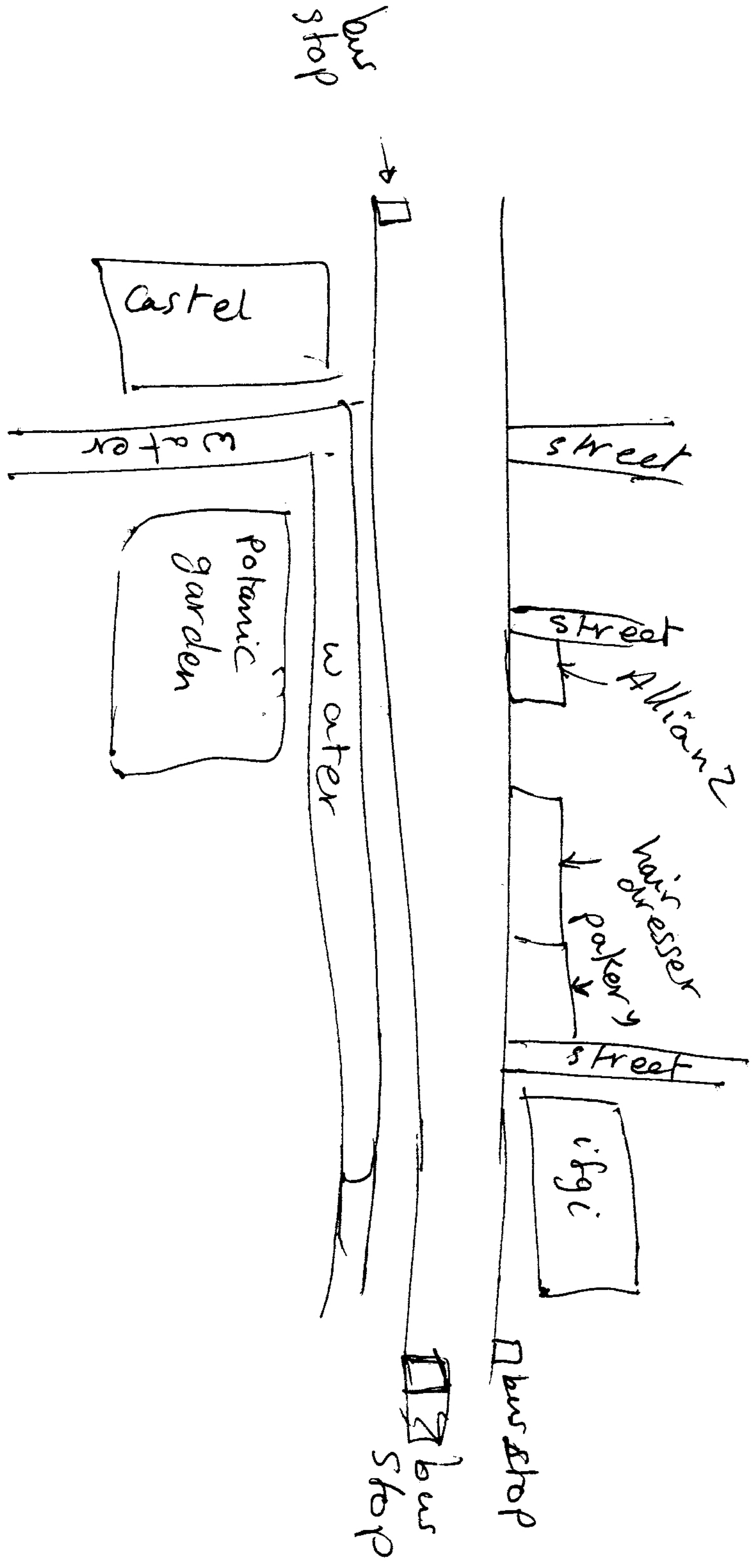
Appendix 4: Sketch map depicting the area from IFGI 2.0 to castle for location choice from one participant in section 3.1.



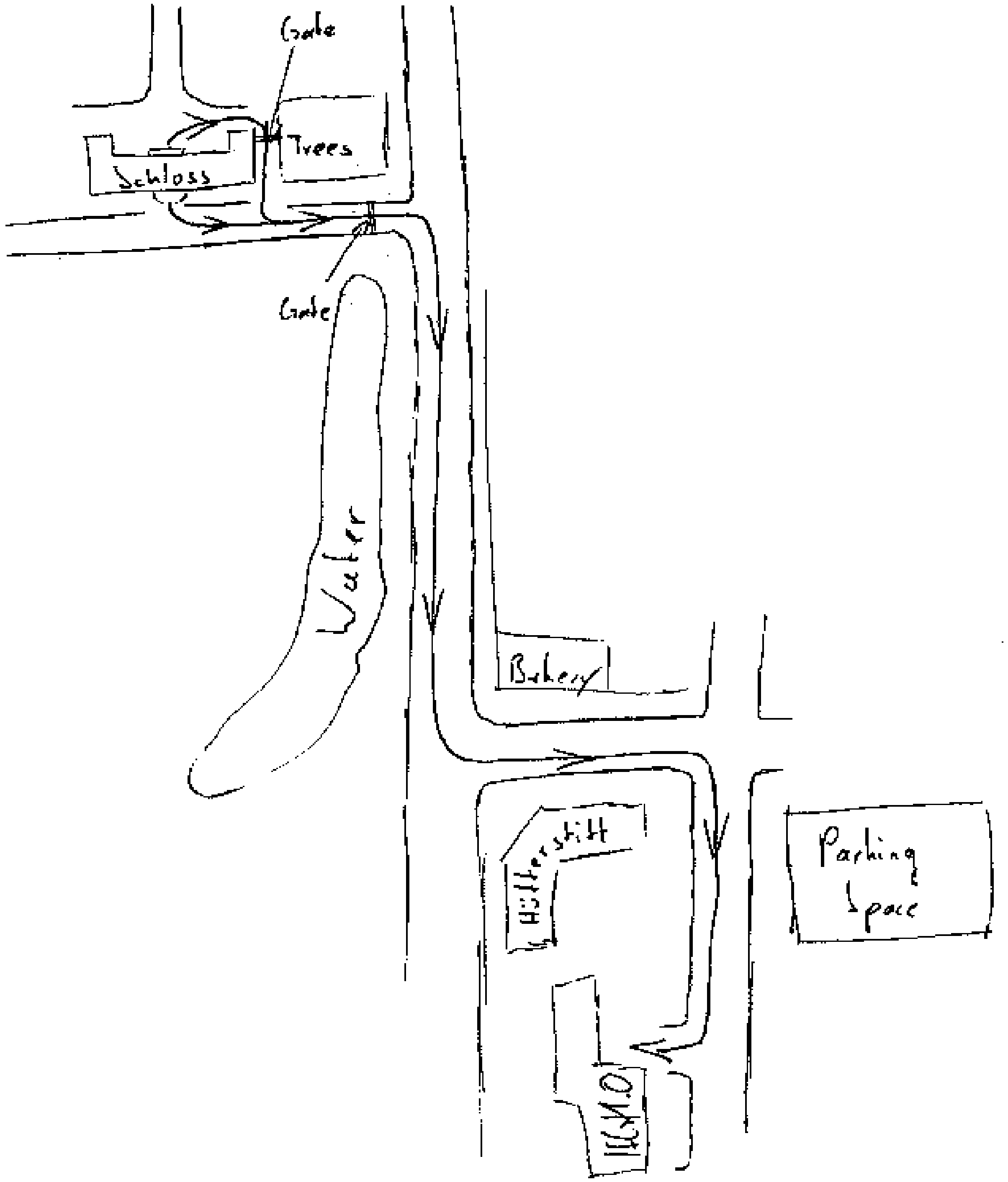
Appendix 5: One sketch map of castle to IFGI 1.0 from Preliminary test among three participants.



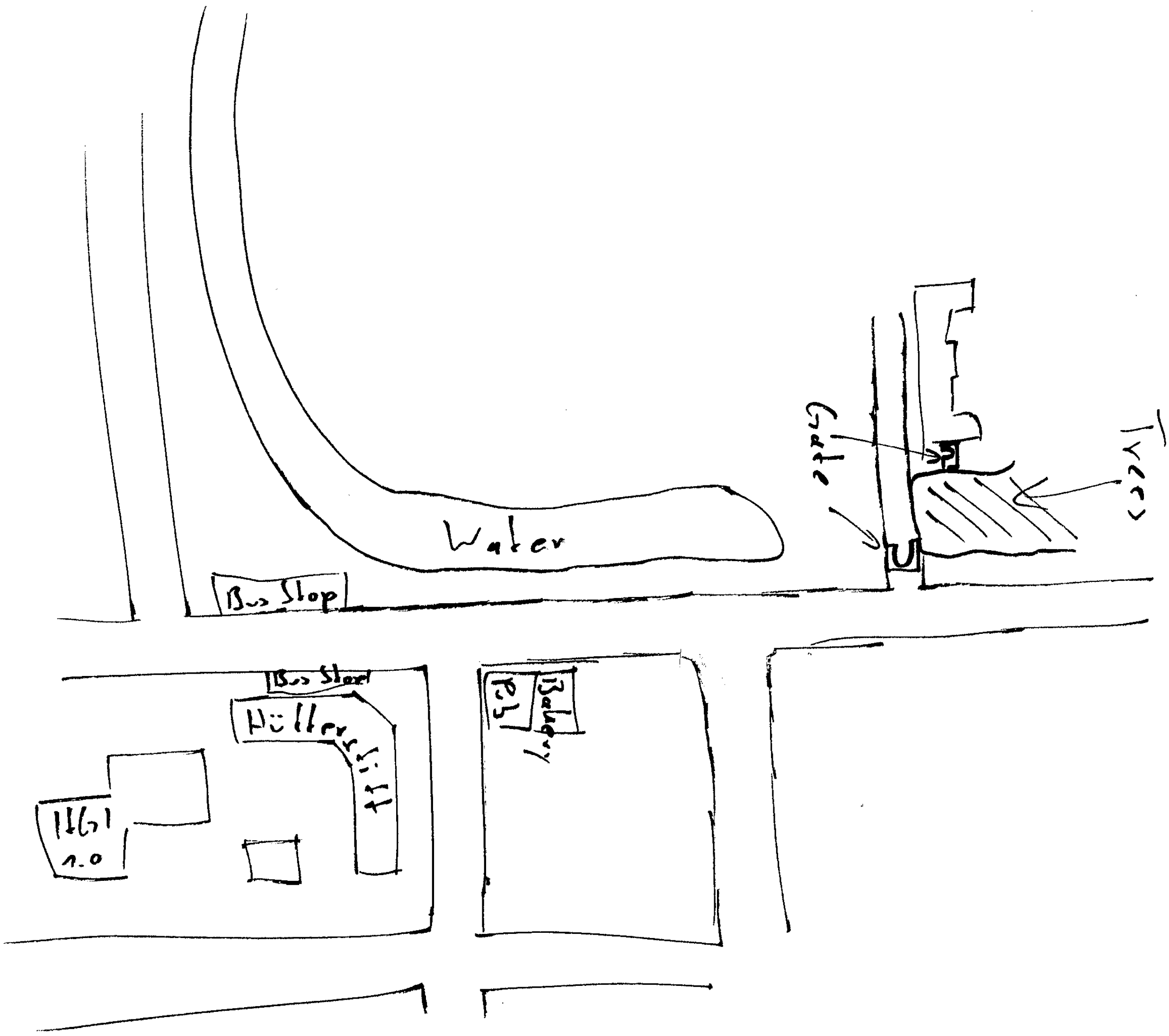
Appendix 6: One sketch map of castle to IFGI 1.0 from Preliminary test among three participants.



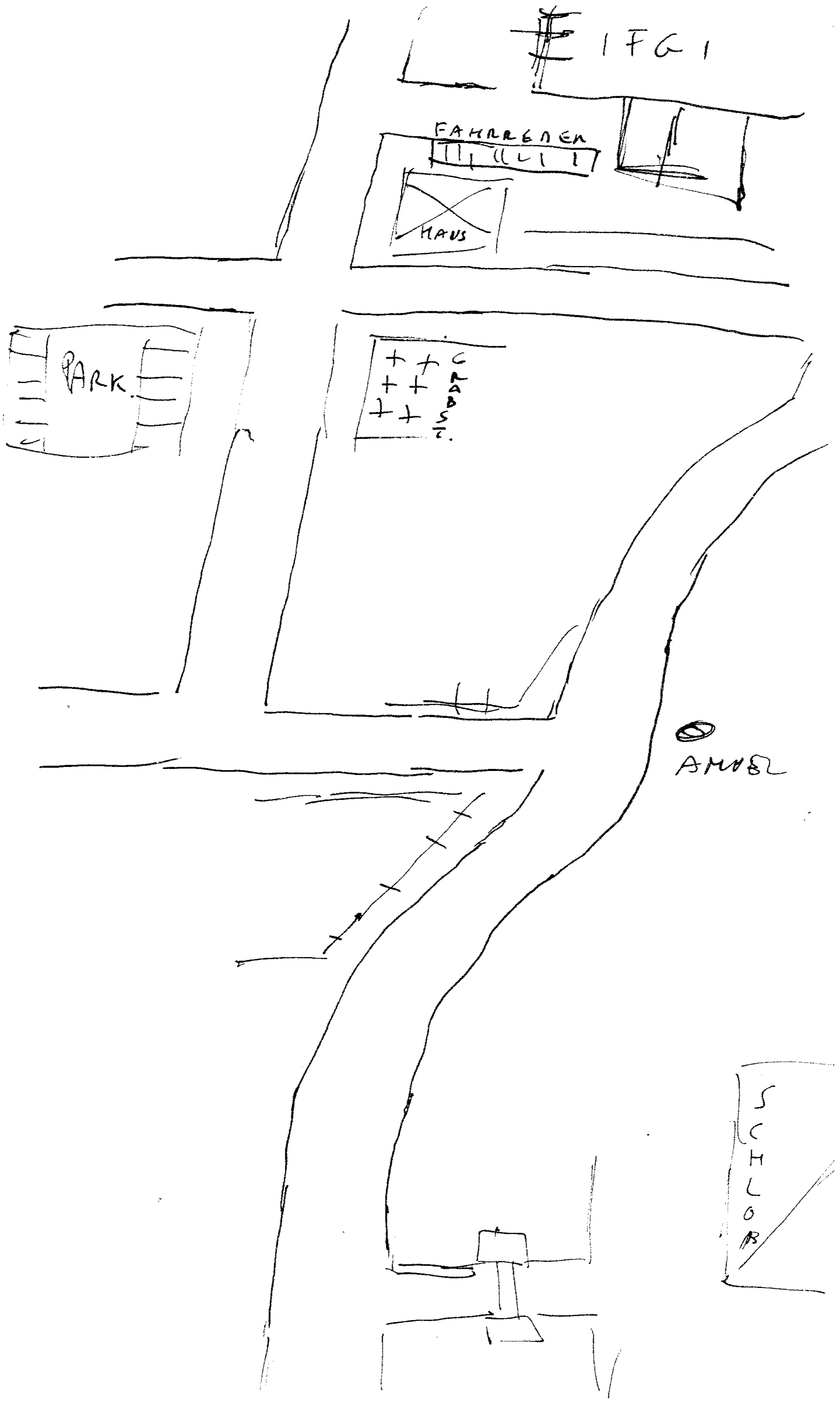
Appendix 7: One sketch map of castle to IFGI 1.0 from Preliminary test among three participants.



Appendix 8: One sketch map of Location I from formal experiment and for sketch map analysis.

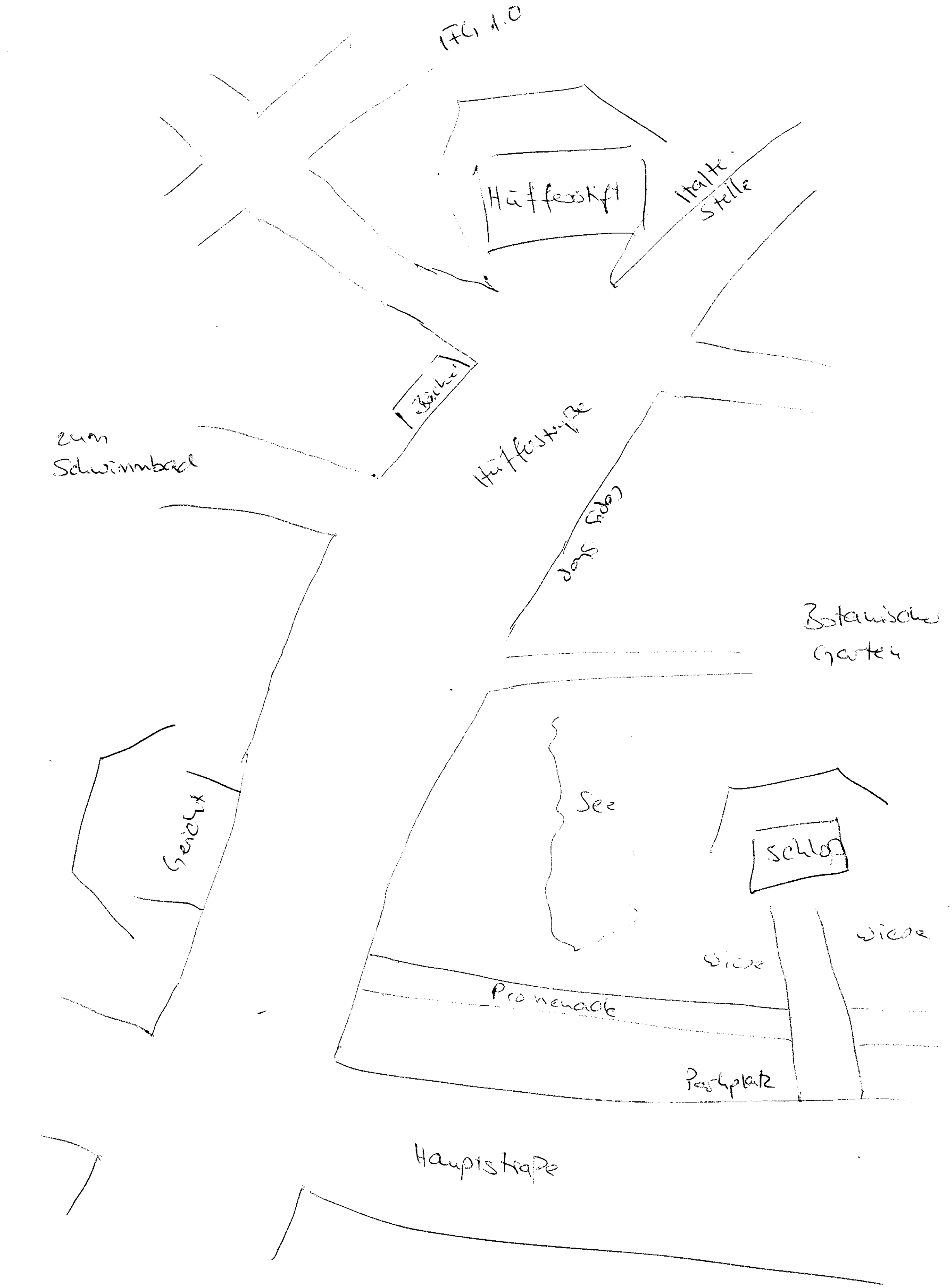


Appendix 9: One sketch map of Location I from formal experiment and for sketch map analysis.

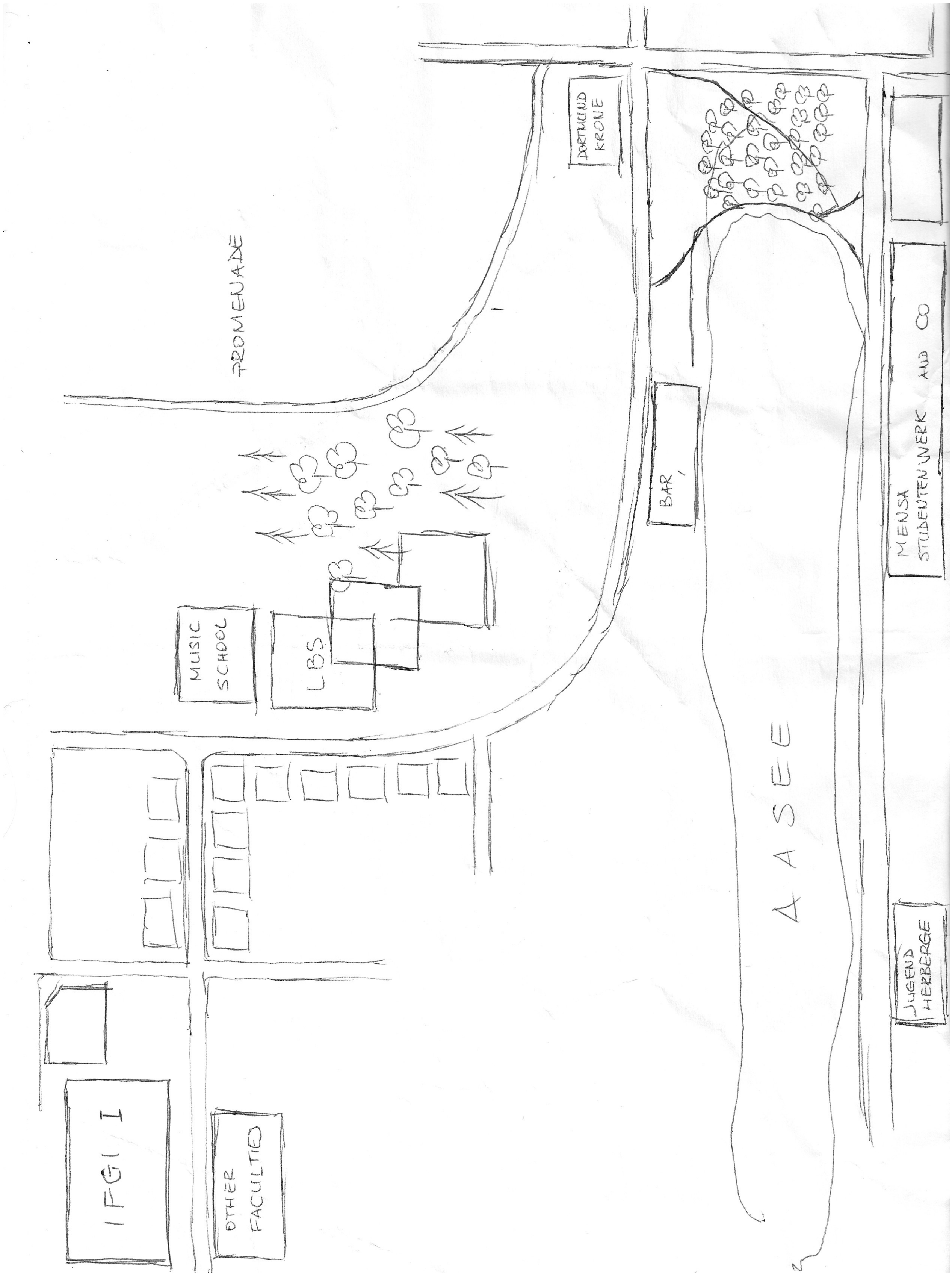


Appendix 10: One sketch map of Location I from formal experiment and for sketch map analysis.

Appendix 11: One sketch map of Location I from formal experiment and for sketch map analysis.

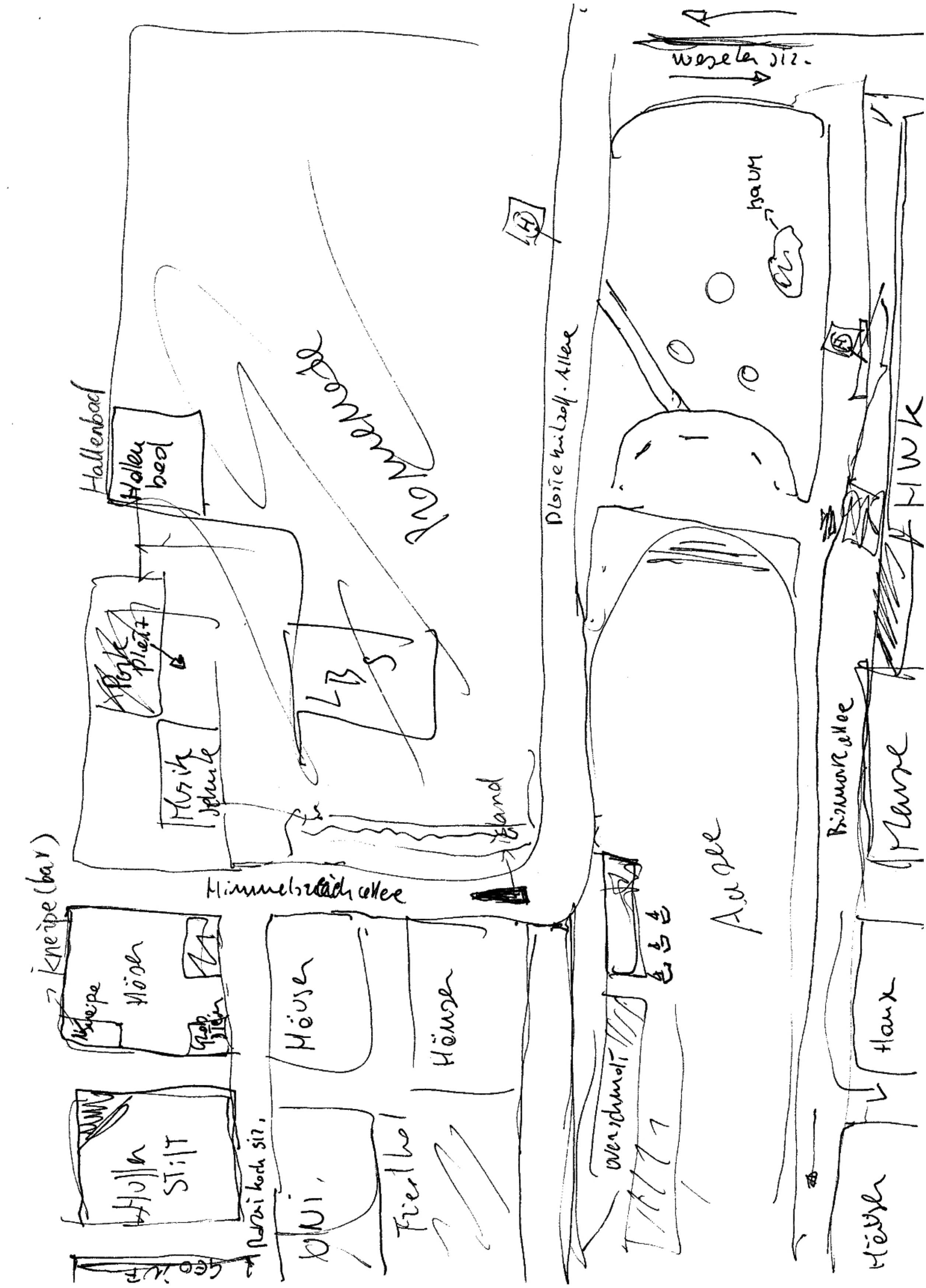


Appendix 12: One sketch map of Location II from formal experiment and for sketch map analysis.

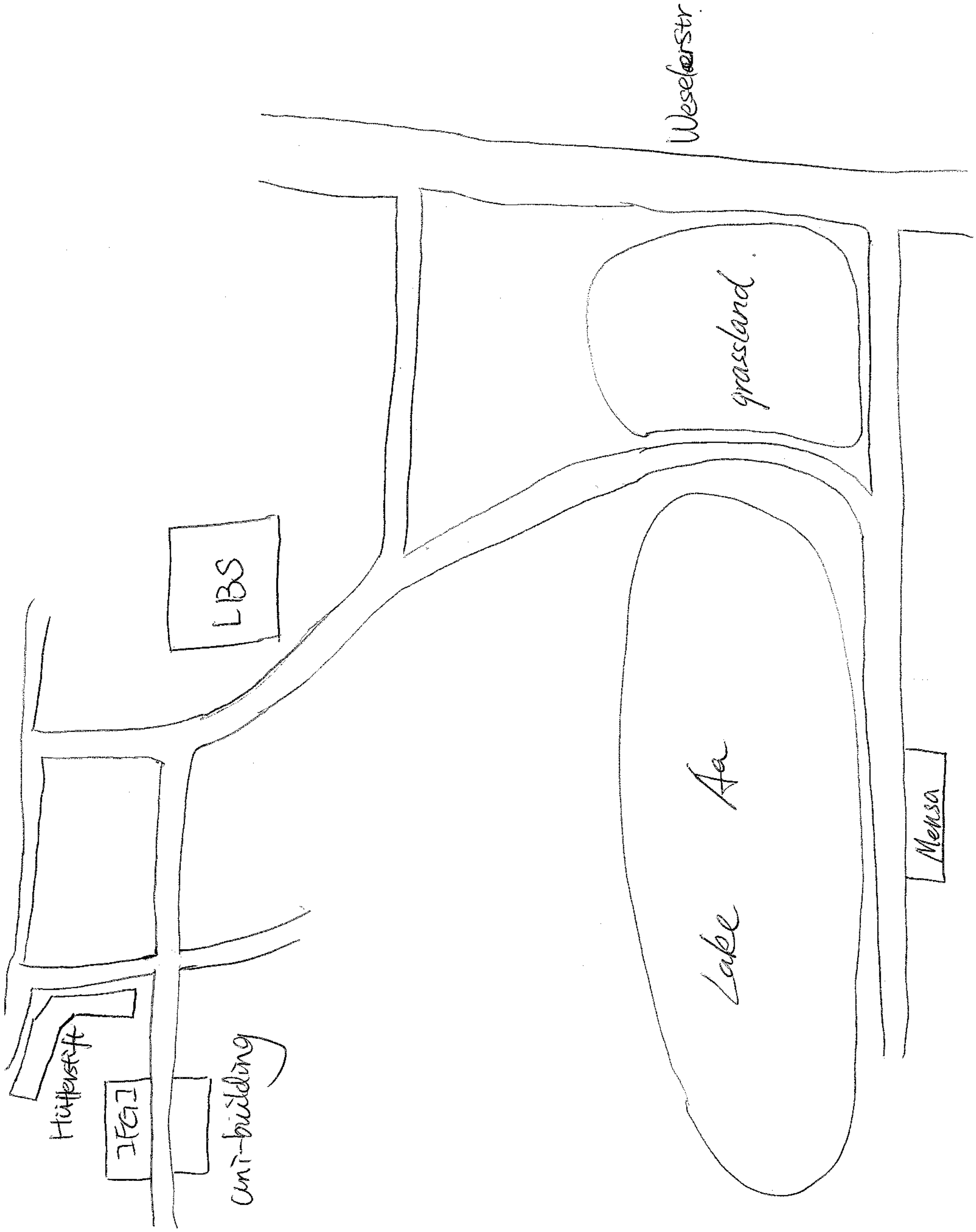


Appendix 13: One sketch map of Location II from formal experiment and for sketch map analysis.

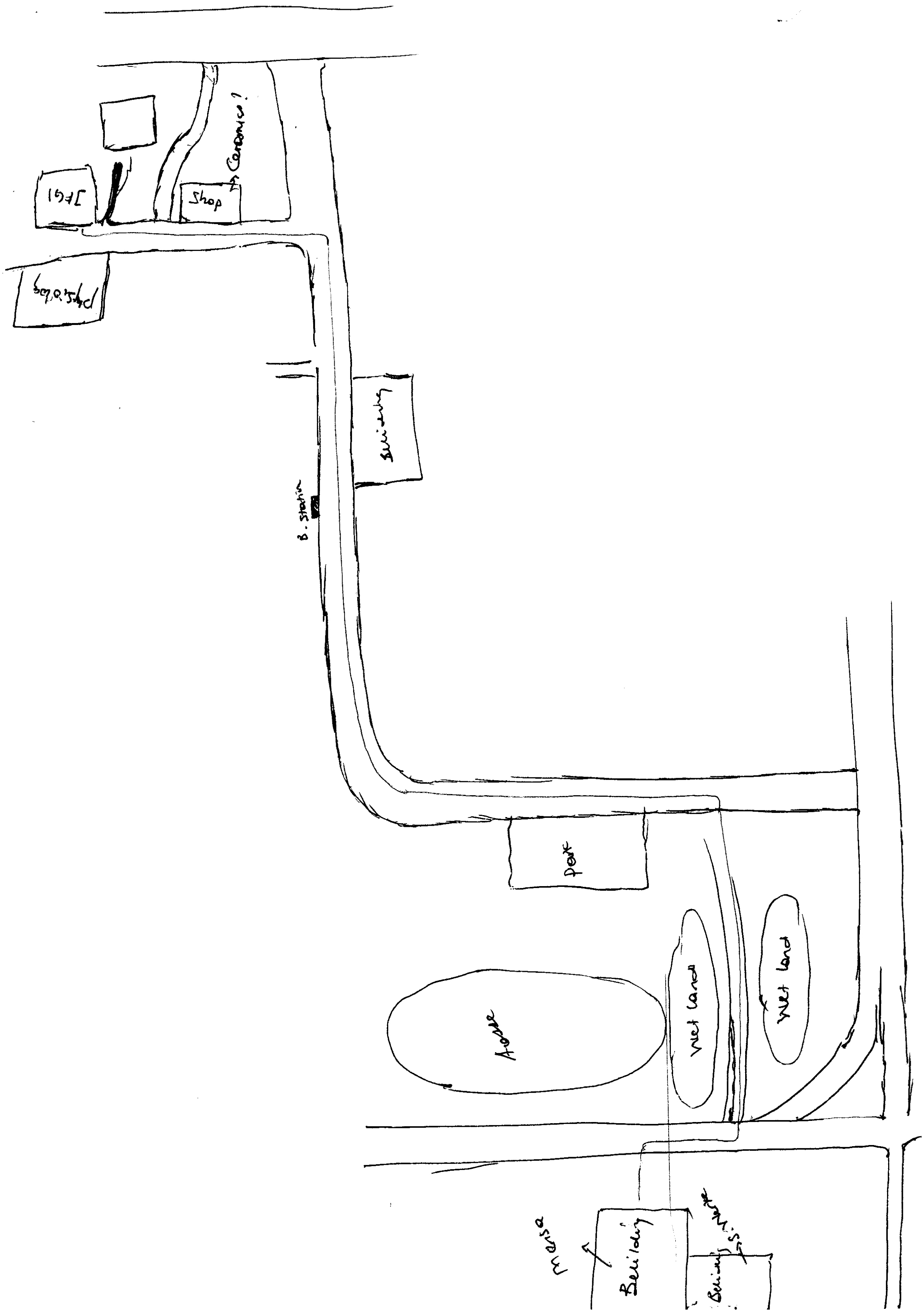
Appendix 14: One sketch map of Location II from formal experiment and for sketch map analysis.



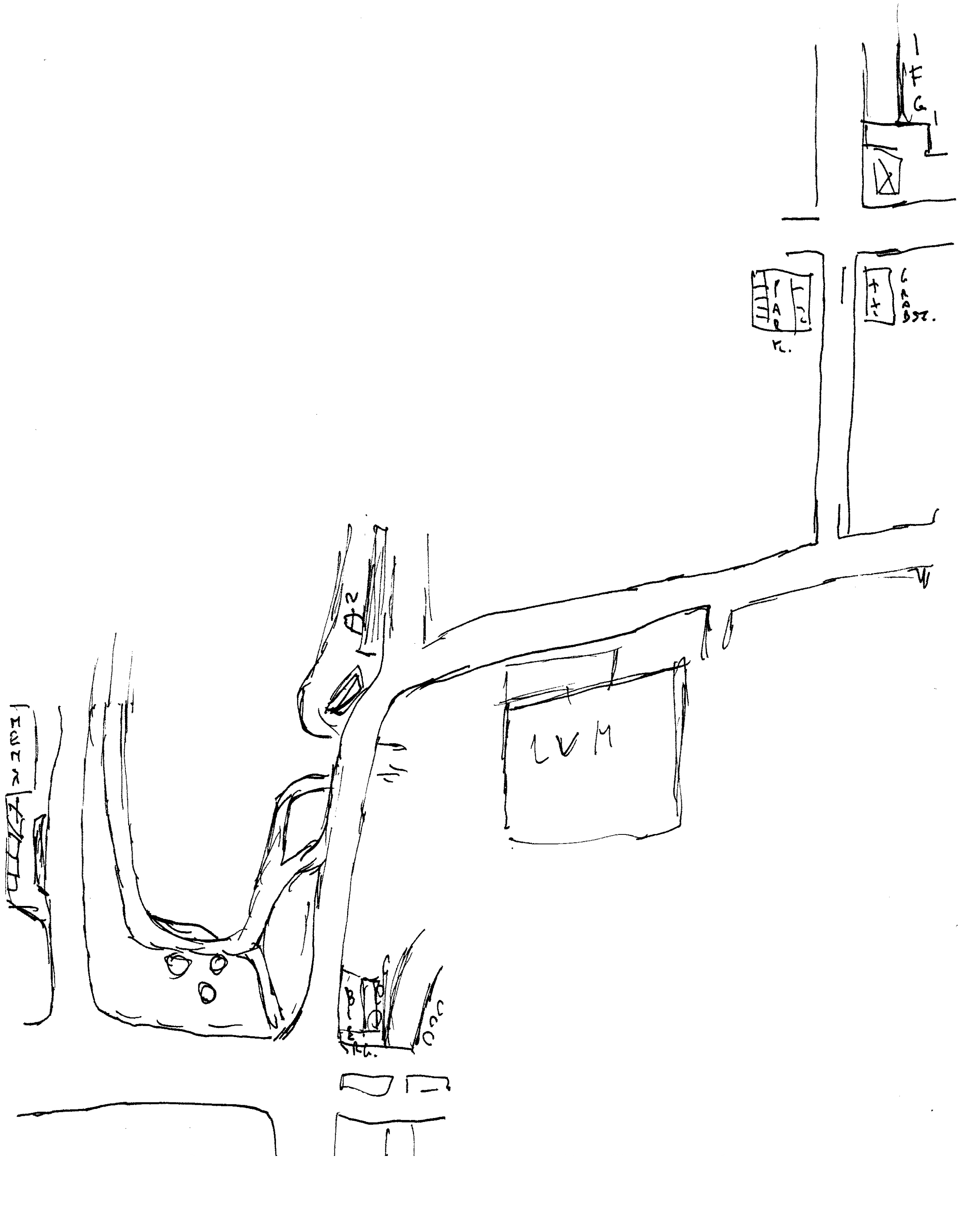
Appendix 15: One sketch map of Location II from formal experiment and for sketch map analysis.



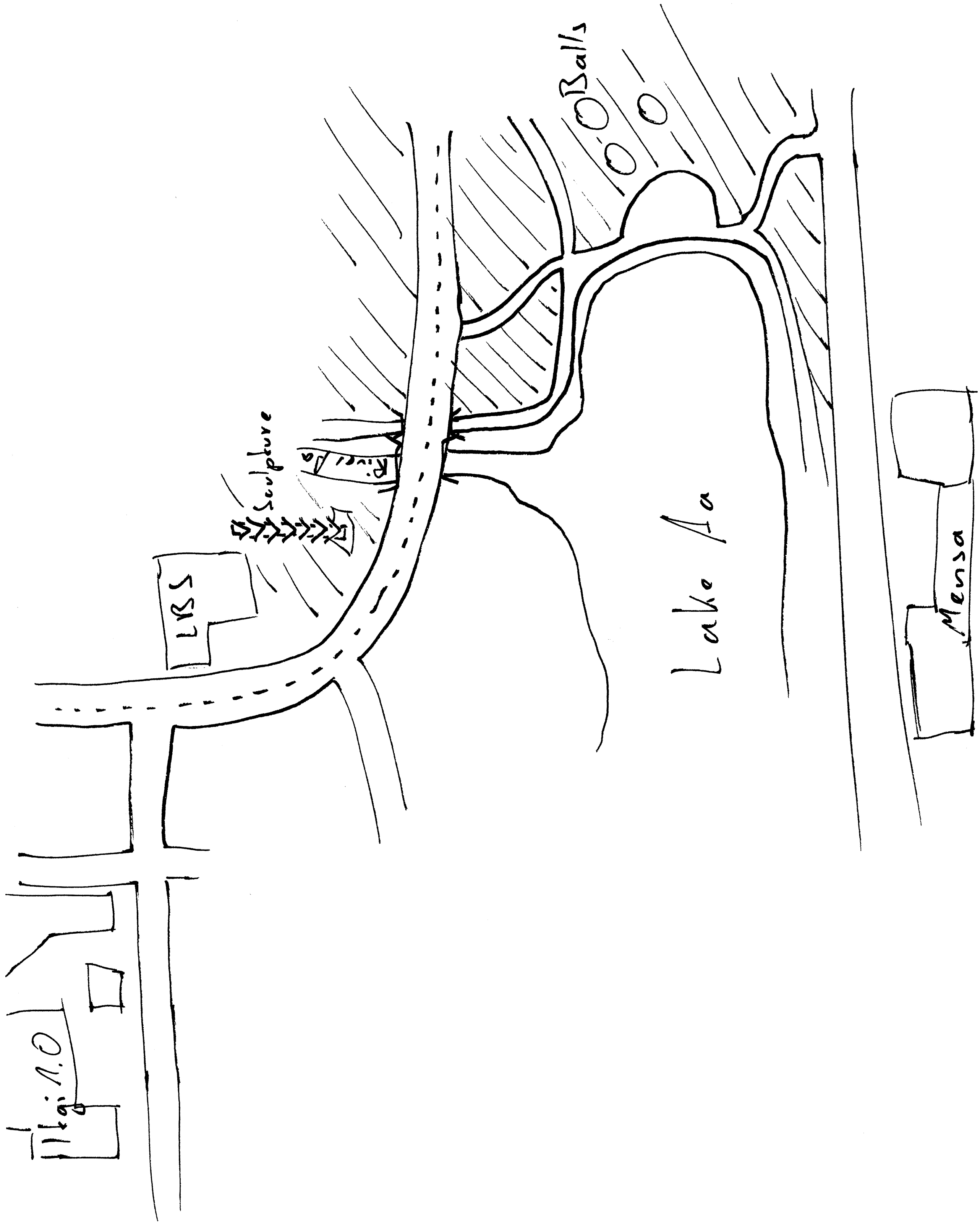
Appendix 16: One sketch map of Location II from formal experiment and for sketch map analysis.



Appendix 17: One sketch map of Location II from formal experiment and for sketch map analysis.



Appendix 18: One sketch map of Location II from formal experiment and for sketch map analysis.



Student Declaration

I declare that the submitted work has been completed by me the undersigned and that I have not used any other than permitted reference sources or materials nor engaged in any plagiarism. All references and other sources used by me have been appropriately acknowledged in the work. I further declare that the work has not been submitted for the purpose of academic examination, either in its original or similar form, anywhere else.

Declared in Münster ……………………….
(date)

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(signature)