

2017

Sketch Recognition and Interpretation Using a Web-Based PGIS Framework for Urban Planning

Mohammadi, Ehsan

Mohammadi, E. (2017). Sketch Recognition and Interpretation Using a Web-Based PGIS Framework for Urban Planning (Doctoral thesis, University of Calgary, Calgary, Canada).

Retrieved from <https://prism.ucalgary.ca>. doi:10.11575/PRISM/27798

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Sketch Recognition and Interpretation Using a Web-Based PGIS Framework for Urban Planning

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

GRADUATE PROGRAM IN GEOMATICS ENGINEERING

CALGARY, ALBERTA

JANUARY, 2017

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ABSTRACT

Internet and web mapping technologies have provided the public with a new understanding of maps and how they can participate in different types of activities. Access to these technologies offers opportunities for the provision of services that utilize users' tacit knowledge to enhance the quality of engagements. This has led to the advent of applications that rely on users' knowledge. However, participation in planning and decision-making using mapping technologies used by GIS and urban planning experts can be difficult and problematic for lay people as it requires expert knowledge. To address this issue, and other associated limitations (such as: validating the users' input, defining the implication of planning based on users' input and so on), this research investigates the difficulties and limitations related to participation and offers a solution based on semantics that models urban feature relationships to help recognize and validate users' contributions collected as a set of sketches in an urban context. This methodology aims to help community members to engage in participatory GIS activities with minimal cognitive effort. The overall process requires an approach to help participants convey their cognitive maps in a valid and logical way that matches with standard urban patterns generally, or for an application specifically. Developing an ontology to model urban entities and their relationships is crucial for this matter. Utilizing spatial reasoning to check and validate logical

relationships between sketches and existing features based on the developed ontology for the domain is also essential.

In this thesis, the main objective was to overcome the aforementioned difficulties of user interaction with a PGIS system. To achieve the objective, an ontology was developed to present the semantic, topological and geometric relationships among the urban planning entities. Then, spatial reasoning rules were applied to recognize and validate users' input and give them feedback based on the nature of their input. Finally a web-based system called PYPsketch for participatory GIS was developed. The user interface of the system was also evaluated in terms of urban feature recognition.

*To my Father **Ata**, and the memory of my beloved Mother **Ozra**.*

No son ever had better parents.

ACKNOWLEDGEMENTS

I started my research under supervision of Dr. Andrew J.S. Hunter and finished it under supervision of Dr. Xin Wang. I express my special appreciation and thanks to both. You have been tremendous supervisors for me. I would like to thank you for all your patience, trust and encouragement during my research.

I would also like to thank my committee members, Dr. Rob Feick, Dr. Dan Jacobson, late Dr. Danielle J. Marceau, Dr. Derek Lichti, and Dr. Steve Liang. Your brilliant comments and suggestion helped me a lot to revise this work more profoundly.

I also would like to thank all my colleagues and group members at GIScience Group of the Department of Geomatics who helped me a lot during my PhD program, especially: Stefan Steiniger, Ali Mousavi, Coral Bliss Taylor, and Ebrahim Poorazizi. Your friendship is invaluable for me.

Finally, a special thanks to my family. I am grateful to you beyond words. Your encouragement, sacrifice and support gave me the courage to travel this road. Without your support I was not able to accomplish it.

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LIST OF ABBREVIATIONS

2D	Two Dimension/Dimensional
3D	Three Dimension/Dimensional
AR	Augmented Reality
DC	Disconnected
DE-9IM	Dimensionally Extended-9 Intersection Model
EC	Externally Connected
EPSG	European Petroleum Survey Group
EQ	Equal
FOSS	Free and Open Source Software
GIS	Geospatial Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HCI	Human Computer Interaction
IoT	Internet of Things
ISK	Indigenous Spatial Knowledge
NTTP	Non-Tangential Proper Part
NTTPi	Non-Tangential Proper Part inverse
OGC	Open Geospatial Consortium
PDA	Personal Digital Assistant
PGIS	Participatory GIS
PO	Partially Overlapping

PPGIS	Public Participation GIS
PYP	Plan Your Place
RCC8	Region Connection Calculi 8
RDF	Resource Description Framework
REST	REpresentation State Transfer
SDI	Spatial Data Infrastructure
SOA	Service Oriented Architecture
TPP	Tangential Proper Part
TTPi	Tangential Proper Part inverse
UCD	User Centered Design
UGC	User Generated Content
UI	User Interface
UID	User Interface Design
URL	Uniform Resource Locator
VGI	Volunteered Geographic Information
VRML	Virtual Reality Modeling Language
WIMP	Window Icon Menu Pointer
XML	eXtensible Markup Language

In a Participatory GIS (PGIS) activity, local residents and laypeople provide much of the information about the environment/locality they are coming together to discuss. The information is best captured using tools that are accessible and usable for a diverse range of people. An objective of a PGIS activity is to provide appropriate tools and technologies to facilitate the participation of all stakeholders as much as possible. Tools and technologies commonly used to capture and render the participant's spatial knowledge include: sketch maps, 3D models, aerial photos, satellite images, web-maps, GPS and GIS (Rambaldi et al., 2006b). Sketching as a participatory tool is a general approach that allows people to express their knowledge, ideas and designs in different fields including the field of spatial knowledge, regardless of their level of education, background, race, or age. However, understanding and interpretation of sketches requires knowledge of the domain to which sketches refer, the entities of the domain, and the rules and conditions that apply to those entities. Domain entities, and the relationships between them (i.e. the domain ontology) must be clear in order to interpret a sketch effectively.

1.1.Motivation

The requirement for integrating sketching into participatory activities was mentioned during “Plan Your Place” (PYP) workshops and meetings. PYP was an initiative conducted at the

University of Calgary by Geomatics, Transportation, and Urban Planning Departments to study the requirements for an efficient framework to help local residents to participate in decision making processes in their communities. This initiative led to a group of workshops and meetings during which a framework for participatory planning platform was proposed; identifying: legal framework, functional objectives, and technical implementations as the main components. The structure of this framework is shown in figure 1.1.

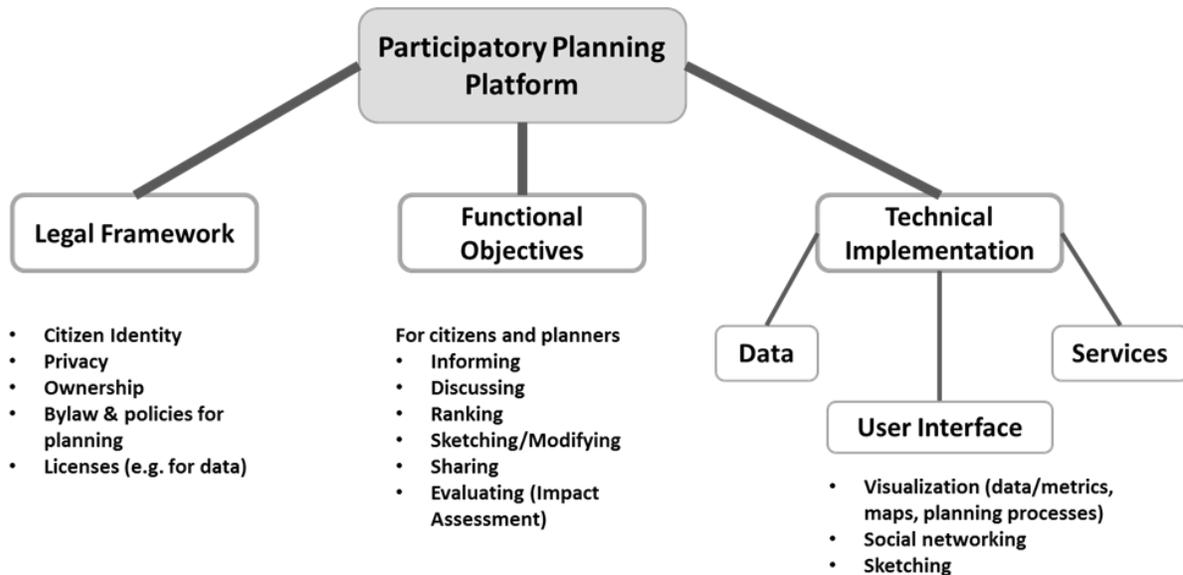


Figure 1.1 The proposed framework for a participatory planning platform

During eleven different meetings and workshops, PYP could attract and engage a large number of people from City of Calgary to define the problems in the City in terms of transportation and land use issues. The last four workshops focused mainly on Glamorgan

Community in the west section of City of Calgary, in which local residents gathered to talk and brainstorm on the problems in their community and find solutions for those problems. They found free sketching on printed maps a convenient practice to convey their thought, ideas, solutions and contributions. Figure 1.2 shows an example of the sketches made by residents during these workshops.

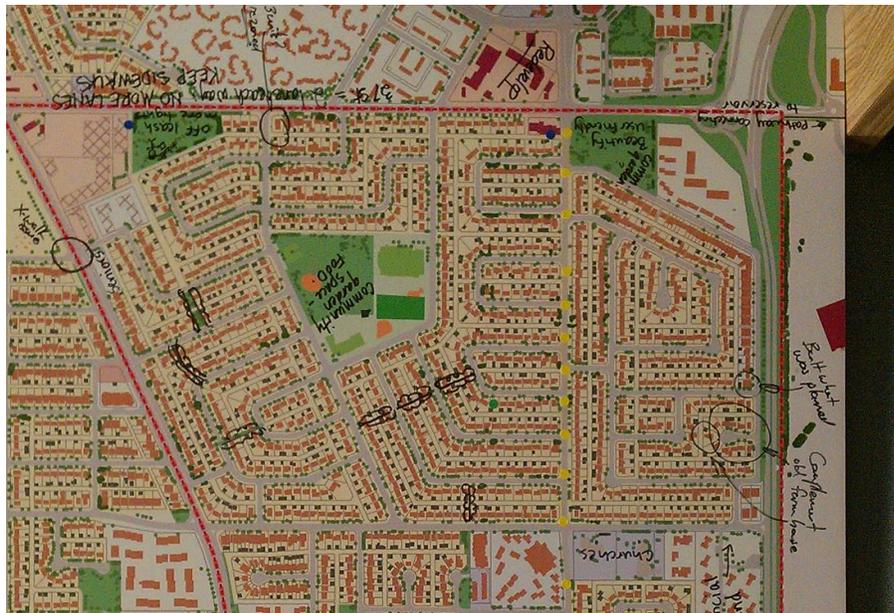


Figure 1.2. An instance of sketches on a printed map made by local residents to identify problems and propose solutions

During these workshops and meetings and based on the ongoing conversations and brainstorming sessions, the idea of rich experience in participatory GIS was developed in which the process of participation is facilitated and consolidated by additional analyses, feedbacks, and

supports. The additional information produced from the interaction of the participants were intended to inform them on the type and logic of their sketches based on existing semantics and illustrate the implications of new designs.

To complete this idea, this research proposed taking an approach in which participants could have access to a platform with a simple and easy to use interface, backed with intelligent algorithms to provide feedback to the participants on their sketches (we named the platform PYPsketch). The feedback is in the form of recognizing the sketches as objects in the domain of urban planning based on standard rules defined generally or specifically for a community.

1.2.Problem Statement and Research Objectives

1.2.1. Problem Statement

In PGIS, participants prefer to have direct interaction with maps to express their ideas, highlight the problematic areas and suggest solutions. Their interaction is mainly in the form of sketching, captioning and push pinning on a map canvas. Although on a catalog map all of these interactions are performed with just a pen and interpretations and recognitions are made manually, we propose the same approach for digital online maps in which interpretations and recognitions are performed automatically.

To pursue this idea for online map-based PGIS platforms we realized the following problems:

1. Graphical User Interfaces (GUI) usually become a maze if they are not simplified for general users. Finding the appropriate tool for interaction among tens of tools makes it difficult for laypeople to have easy interaction with the system, especially when it comes to drawing features in urban planning context where each feature may have its own corresponding sketching tool. Also the sketches require recognition and validation based on existing standards; and the implications of plans based on those sketches should be realized.

2. Even if the sketch is done with the appropriate tool, it may not be validated based on the logical and semantic rules between urban features. Recognizing a sketch based on existing rules and validating them is usually performed manually. However, there is no strict ontology which clearly defines urban entities and their semantic, topological and geometric relationships.

3. Inferring the relationships and recognizing objects automatically, depends majorly on spatial reasoning. Spatial reasoning rules need to be extended to cover all the semantic and topological relationships between entities, especially from human cognition point of view in which terminologies and perceptions may be different from those in professions and literature.

4. User-centered interfaces should be designed to take the burden of interaction from users to computers through understanding and analyzing the interactions. The results should lead to recognizing the correct geometry of the sketch and the feature type it represents.

Based on these problems and issues, the objectives of this research were defined. The overall framework within which this research is developed is that of an information system. Information systems deal with two complementary but distinct paradigms: behavioural science and design science. Behavioural science investigates theories that explain human behaviour impacted by the design of a system, while design science looks for approaches to accomplish a task more efficiently and effectively (Hevner et al., 2004).

This research focuses predominantly on design science aspects of an information system and attempts to make the process of participation in a PGIS activity more efficient and effective by identifying and utilizing the methods that help to recognize, interpret, and validate participants' sketches in the domain of urban planning.

Since a sketch is a visual representation of something, it is important to consider its perception and interpretation (MacEachren, 2004). Although sketching has a high potential to become a common mode of interaction, it has not been given this role yet (Blaser, 2000). One

reason for this is the lack of intelligent algorithms required to distinguish and interpret sketches (Casella et al., 2008; Hammond et al., 2010).

Today, users' interaction with spatial information via GIS is not much different from that found in other application domains. That is, a user typically has to rely on keyboard, mouse, and occasionally a digitizing tablet to interact with the computer system. Many common tasks are executed via pull-down menus, buttons, or dialog boxes. While this form of interaction has its benefits for some applications, they have serious limitations when more complex and less sequentially structured processes or information are involved, as is often the case when sketching (Egenhofer, 1997). Relying on traditional modalities to solve such complex tasks frequently leads to unintuitive and cumbersome interaction procedures, which generally result in the need for high levels of training. The main reason for this limitation is that pointing and typing are inadequate and not flexible enough to deal with interrelated information frequently encountered in today's information systems (Egenhofer, 1997). To solve these issues, this research borrows principles from "Quality of Experience" (Alben, 1996) research to investigate sketching tools for people with no, or limited background in the use of spatial information and GIS, so that they may express their ideas and designs effectively. Therefore, the ultimate purpose of this research is to facilitate the participation process in PGIS — based on Shneiderman and Plaisant's rules (Shneiderman and Plaisant, 2005), and Tognazzini's (Tognazzini, 1993) and Rams' (Kemp and

Ueki-Polet, 2009; Lovell, 2011) principles which mainly are about intuitiveness of the interface to increase the effectiveness and efficiency of the system — to provide natural interactions between a user and the computer within the domain of participatory planning for community and neighbourhood design and development.

1.2.2. Research Objectives

The primary objective of this research is to enhance public engagement in their community development by facilitating the process of participation using effective and efficient approaches. The effectiveness of the approach refers to the accuracy and the efficiency refers to easy-to-use and fast approaches versus approaches that require education, experience and expertise. This work focuses on enhancing effectiveness and efficiency of participation by employing interaction principles, sketch recognition algorithms, and ontologies for spatial features in the urban design domain. To achieve the primary objective, the following sub-objectives need to be addressed:

- Investigate how people sketch, and study the components of sketches and develop an approach to recognize and validate sketches in urban domain.

- Investigate urban entities and how they are logically and semantically related to each other in a standard urban pattern and develop an ontology to model the semantic, topological, and geometric relationships between entities.
- Develop and extend spatial reasoning methods to infer and recognize objects based on the rules (defined in the ontology) that govern semantic, topological and geometric relationships between objects in an urban environment.
- Design a sketch recognition framework to recognize the geometry of the sketch and interpret and validate the feature type of the sketch.

1.2.3. Research Questions

Based on research objectives, the central question to be addressed is: What is the requirement of an effective and efficient participatory GIS approach? In other words, what approaches should be considered to bring intelligence in terms of feedback and support so users can easily interact (assuming sketching as the major mode of interaction) during participation activity?

These questions can be further broken down into the following sub-questions:

- How people perceive their environment in terms of semantic relationships between components and entities of the environment and how effectively those

perceptions can be converted to digital maps and recognized and validated in context of urban planning?

- What are the spatial entities and objects in the urban planning domain, and what are the logical (e.g. semantic, topologic, and geometric) relationships between them and how can we model those relationships?
- What spatial and non-spatial rules govern the relationships between urban entities and how these rules can be used in spatial reasoning process to simulate human qualitative reasoning?
- How can we enhance the efficiency (time and energy) and effectiveness (more accurate results) of interaction in the sketching process?

Examining these questions will address the primary research objective in the following ways:

- Define sketch components and parameters that affect the geometry of a sketch and bridge the gap between human cognition and spatial data employing the context and semantic of the sketch.
- Define and develop a complete and sound ontology of spatial features and entities for the urban planning domain and the relationships between entities including semantic, topological, and geometric relationships.

- Define spatial reasoning methods and develop new spatial reasoning concepts to cover the rules and relationships between urban entities.
- Design and develop an efficient and effective participatory GIS platform to facilitate participation for average people by integrating spatial reasoning in the process of participation.

The objectives and questions of this research can be viewed within Hevner’s design science research framework illustrated in figure 1.3, where the components of a research program are outlined (Hevner et al., 2004).

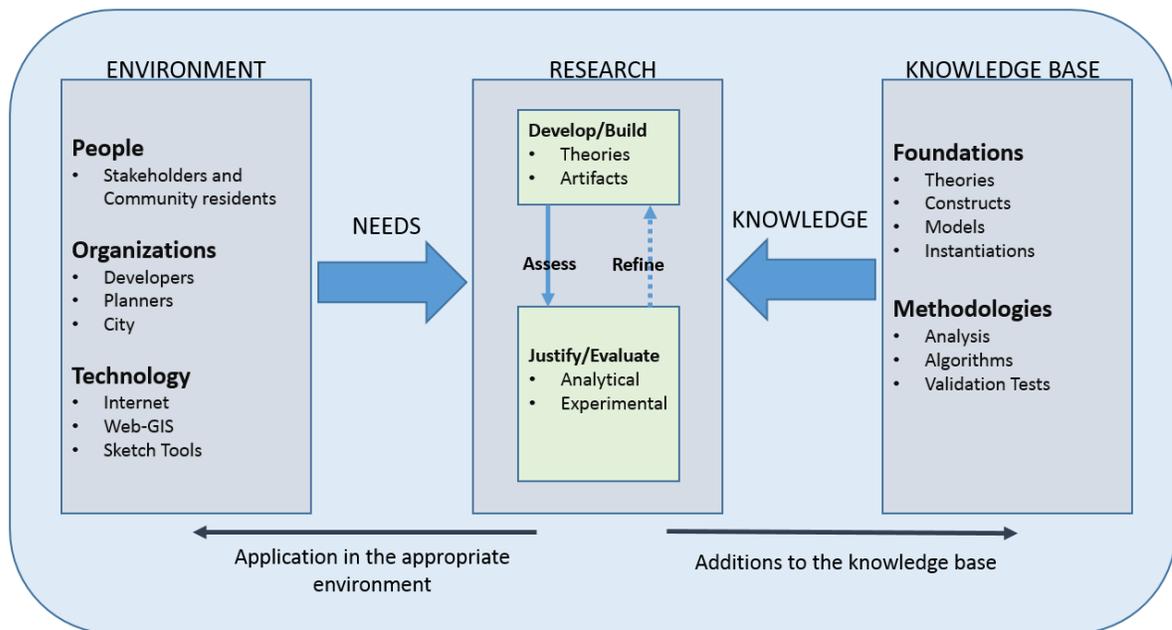


Figure 1.3. Information System Research Framework

According to this framework and based on the objectives of this research, the problem to deal with is to enhance the participation in an urban planning activity. The environment refers to stakeholders and laypeople or community residents, who are interested in the development of their community. Stakeholders include residents, community members, developers, planners, city managers, and decision-makers, who are responsible for development of a city. Technology includes the Internet, Web-GIS, and user interfaces that provide the infrastructure necessary for online participation. The knowledge base for this research consists of all analytical theories, models, ontologies and algorithms that help us understand online sketches produced by participants contributing to a planning engagement process.

Based on the mentioned framework this research addresses participation problems encountered by community residents and urban planners in interacting with online platforms through the design, implementation, and testing of an intelligent sketching tool based on the use of existing knowledge about urban typologies and patterns. The results of this research are intended to enhance both users' experience, and the existing knowledge on human computer interaction.

1.3. Research Scope, Assumptions, and Limitations

The strength of this research is that it seeks to find a way to enable laypeople (e.g. non-experts in urban planning) to participate in the practice of local urban planning. The goal is to improve how computers understand what a user is sketching, rather than requiring the user to sketch in a way that the computer understands (Sezgin et al., 2006).

By integrating an urban planning domain ontology, we hypothesize that the expressiveness of a sketch has been increased. By adopting a user-first philosophy to human computer interaction it is expected that the goals of effectiveness and efficiency will release users from a maze of menus, toolbars, and complicated commands (Cai and Yu, 2009).

The scope of this research is restricted to participatory GIS activities in which the scenario is addressed generally (e.g. which part of your community is problematic? Or what do you like/dislike about your community? Or provide a plan for this vacant area in your community) and community residents can participate by sketching dominant geometric objects found in urban areas (e.g., roads, parks, pathways, bridges, and so on). The canvas used in this research is a two dimensional Cartesian plane, and entities beyond this canvas are not considered (e.g., three dimensional objects, or spatio-temporal features). Communities in City of Calgary are used for the initial implementation and testing; and online maps are employed which adopt a bird's eye perspective, versus worm's eye view (oblique view).

This study assumes that free sketching on computer screen is the most convenient tool for average people to interact with a personal computer, however with the advent of touch screen technologies using fingers to interact with a computer screen is even more convenient than using a mouse, but both follow the same interaction principles. This assumption makes the backbone of user interface design. Also this research assumes that users have the minimum knowledge of dealing with web mapping systems.

A limitation of this research is the accuracy of existing sketch recognition algorithms. Rather than considering one threshold value (i.e. a parameter that distinguishes entities, for instance if the distance between two end points of a polyline is smaller than a threshold it can be considered as the boundary of a polygon), I propose that employing a range of values together will improve recognition. Taking this approach, sketch algorithms make use of the concept of probability to identify a sketched object.

Another limitation is the incompleteness of urban planning ontologies and their ability to adapt to variations observed when categorizing urban planning objects from different geographic locations. The more complete urban planning ontology the better results achieved. Also beside general patterns seen in a city, sometimes specific rules may apply to an urban feature depending on the application (e.g. recognition of indoor pathways versus outdoor pathways). In these cases, the relationship between entities (e.g. relationships between pathways and buildings and indoor

areas vs. outdoor areas) should be modeled comprehensively in the ontology to make the recognition possible.

Additionally, interpretation of perceptually meaningful results can be difficult as users draw sketches in an abstract way that may be geometrically or semantically far from the real objects they portray (Eitz et al., 2012). The major reason returns to the fact that people's perception of their environment is a cross section image rather than a bird's eye view that is used in maps.

Also, the implementation in this study is limited to one case study of City of Calgary.

Although the methodology can be used for any area with appropriate ontology, tests are conducted just for City of Calgary. The other limitation in this study is the nature of sketched objects; only simple objects are considered. However, implementing the same system for detecting complex objects can be considered as the extension of this study and is suggested for future work.

In addition, this research is biased by the knowledge and experience of the author on Geomatics and GIS, as solutions to the problem of enhancing participation for urban planning in this research is sought through Geomatics approaches; including: user interface design for GIS applications, spatial reasoning solutions, and adding semantic relationships for urban entities into ontology for sketch recognition purposes. The same goals can be pursued by experts from other fields of study with their own specific perspective employing different methodologies.

This research looks for increasing the ease and richness of experience of interaction with a PGIS platform (our platform is named PYPsketch) for average people (i.e. with no specific knowledge in GIS) to participate in decision making in their communities. Similar studies can be conducted from Social Science, Computer Science, Anthropology, Artificial Intelligence, Urban Planning, and other fields' perspectives.

1.4.Contributions

This research contributes to knowledge by developing a framework to bridge the gap between human cognition of the urban environment (e.g. cognitive maps) and digital maps that are used for decision making. For this purpose the developed framework should be able to minimize the cognitive burden on users and utilize intelligent algorithms to understand and interpret the interaction of users with the computer in the scope of knowledge provided to the system. The knowledge is structured in the form of ontology to model logic, semantic and rules on urban entities. Urban patterns provide the base for the utilized ontology.

In order to fulfill the objectives of this research and answer the fundamental questions, the following contributions were made:

1. A PGIS framework is developed based on participants' requirements for a comprehensive and rich experience in a PGIS activity.

2. An ontology is developed to identify urban entities and model their semantic, topological and geometric relationships.

3. Spatial reasoning methods were investigated and new rules were introduced to help realize how urban features relate logically to each other.

4. An online PGIS platform (PYPsketch) was developed and tested to recognize the geometry of the sketch (utilizing several interactive parameters) and its feature type in urban domain.

Finally the outcome of this research can be seen from design science perspective as an artifact (sketch recognition for urban planning) that facilitates users' participation in planning of their environment by combining two major components: geometry recognition and feature recognition.

1.5.Organisation of Dissertation

Chapter Two (Background) presents an extensive literature review covering the different aspects of this work, including: Participatory GIS, User Interface Design, Sketch Recognition, Urban Planning and Cognitive Maps, and Spatial Representation and Reasoning. The purpose of chapter tow is to provide the framework within which this research sits, starting with a review of Participatory GIS as the basic engagement platform, followed by user interface design to apprise

platform design. Sketch recognition, as the fundamental interpretation algorithm in this research, is explored in some depth. Urban planning and cognitive maps, as the domain within which this research stands, is briefly described, and finally spatial representation and reasoning rules and algorithms are summarized.

Chapter Three (Methodology) focuses on the implementation and design of the framework. In particular, this chapter summarizes on how all components of this research from spatial reasoning to urban planning are brought together to design the framework and utilize an intelligent tool for sketch recognition and interpretation.

In Chapter Four (Results) the results obtained in this research and how they meet the research objectives are discussed. This chapter provides analysis on geometrical aspects of the algorithms and the reliability of the spatial reasoning and ontology for sketch recognition.

Chapter Five (Conclusions) provides an overview of the empirical findings and discusses the study's contributions, along with recommendations for future areas of research.

In this chapter the different fields of study that create the structure of this thesis are reviewed and presented. The overall picture of this thesis depicts a Participatory GIS framework designed to give online access to members of a community. From this perspective, Participatory GIS is one of the building blocks of this research.

Although this research can be considered under PGIS category, the main outcome of it is to develop intelligent algorithms to provide efficient and effective interaction between participants and participatory interface. In other words, this research studies the field of Human Computer Interaction (HCI) in order to design a simple and efficient interface, so users can easily interact with the platform. User Interface Design (UID) will be reviewed for this purpose.

The intelligent platform that this research focuses on should be able to recognize the interactions of the users. The interactions are represented as sketches on the canvas of a map (on computer screen) and are subject to recognition, interpretation and validation. The recognition of the sketches requires algorithms that can distinguish between the sketches. The domain is that of urban planning. So both sketch recognition and urban planning deserve investigations.

The correct recognition and interpretation of sketches requires a thorough understanding of the domain (e.g. urban planning), its entities and the rules between these entities. Ontology and

spatial reasoning are discussed for this purpose. Ontology models the entities and their relationships and spatial reasoning examines the rules between entities and makes inferences.

The rest of this chapter provides a literature review and background on the aforementioned fields: Participatory GIS, User Interface Design, Sketch Recognition, Urban Planning and Cognitive Maps, Ontology, and Spatial Reasoning. Figure 2.1 shows a schema of these fields shaping the structure of this research.

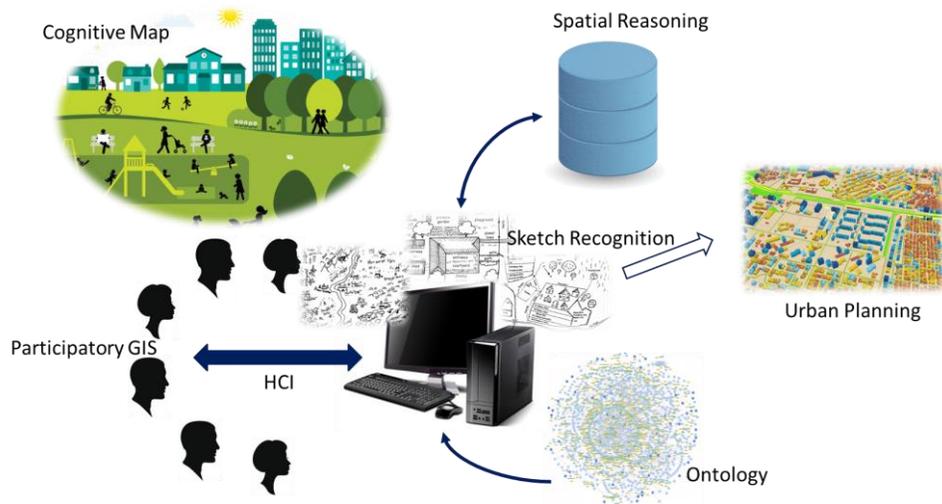


Figure 2.1. Fields shaping the structure of this research

2.1. Participatory GIS

2.1.1. Introduction

Although Participatory GIS (PGIS) started in the late 1980s, it has changed dramatically due to the advent of spatial information technologies (e.g. GIS, GPS, Remote Sensing and Internet)

(Rambaldi et al., 2006b). PGIS arises to overcome two major limitations of traditional GIS: type of information fed for decision making and limited sources of that information (Dunn, 2007). New technologies made it possible to combine spatial information systems with community-centered initiatives to enable underprivileged groups to participate in socio-economic decisions (Rambaldi et al., 2006b). PGIS combines geospatial information technologies and tools such as sketch maps, 3D models, aerial photos, satellite images, GPS, and GIS to render participant's spatial knowledge in the form of virtual, or physical 2D or 3D maps. These maps are used for spatial learning, discussion, information exchange, analysis, decision-making, and advocacy. PGIS helps disadvantaged people (e.g. indigenous groups who have been sidelined, or illiterate community members) to improve community empowerment and cohesion, innovation, and social change (Fox et al., 2006) through the generation, management, analysis, protection, and communication of spatial information.

Through generations indigenous knowledge is passed down by stories, songs, folklore, proverbs, cultural values, and agricultural practices. However, much of these knowledge has some embedded geographical context with local geographical environment at the center (Dunn, 2007). The same fact applies for modern world urban knowledge as everyday interaction with our environment results in knowledge and information with geographical or geospatial

component. Thus, GIS plays an important role in collecting those information and knowledge through participatory activities, based on the following facts (Sieber, 2006):

1. Most information contains a spatial component (e.g. address, postal code, coordinates).
2. Use of spatial information leads to better policymaking.
3. Output of spatial visualization conveys ideas and convinces people of the importance of those ideas.

However, there are some other important factors that should also be considered for a successful practice; such as: data accessibility, development practices, and evaluation strategies.

PGIS methodologies attempt to provide easy access to spatial information technologies for different groups in society to generate, manage and use their own Indigenous Spatial Knowledge (ISK) in different contexts, such as: preserving good governance, collaborative research, managing conflicts amongst local communities, raising social awareness, and so on (Fox et al., 2006). It is important to note that PGIS builds on local ISK, and the intention of ISK custodians is generally to share their knowledge with others. In PGIS the focus is on the process that leads to outcomes such as improved quality of life, while traditional GIS usually emphasizes the final outcomes (e.g. maps, charts, and reports); so effective participation and communication are key to successful PGIS practice. There are different ways that participation can take place in a community (Sieber, 2006):

1. GIS can be utilized by communities to apply it in daily practices and associated trainings.
2. Communities can participate in inputs and outputs used mainly in developing countries for spatial knowledge production and verifying outcomes of participation.
3. Community mapping can be accomplished to empower communities to make their voice heard.

PGIS as a practice is founded on three major concepts (i.e. three Ts)(Robert Chambers, 2006): Transparency, Time and Trust. Transparency is about accountability and clarity of communication methods. Time refers to the duration to establish a trustful relationship between employed technologies and communities. Finally, trust refers to the quality of the relationships between different groups and people engaged in the activity. Based on these concepts, this research focuses on decreasing the time required for people to understand the PGIS tools by providing a user-friendly, intelligent and efficient platform.

Access to and understanding of local peoples' perspective and knowledge of spatial information is a major focus of facilitators, since local people may use different means to express their spatial knowledge of their local environment (Carton, 2002; Rambaldi, 2005). However, local people's spatial knowledge becomes more valuable as they have better understanding of their environment. Collated indigenous knowledge can be used to support a range of purposes, including: social mapping, health mapping, education, water and sanitation, land use, farm

mapping, and so on (R. Chambers, 2006). Verplanke et al. (Verplanke et al., 2016) summarizes five prevailing and persistent principles in participatory spatial information handling as: access, intellectual ownership, trust, validation, and application. These principles form a logical structure of participatory approaches. Their study investigates the shared and competing perspectives of PGIS on these principles and suggests that people and society achieve:

1. Access to data through openness, and access to methods through inclusiveness and complexity.
2. Ownership of data through process and attribution, and ownership of methods through technology and training.
3. Trust in data through accuracy and precision, and trust in methods through feedback and usability.
4. Validation of data through quality, and validation of methods through application and results.
5. Application of data through use, and application of methods through purpose.

PGIS can be employed at different scales from local to global. This research concentrates mainly on community and neighbourhood scale with special attention to urban planning. Al-Kodmany (Al-Kodmany, 2000) provides detailed reasons for making GIS technology available and accessible at the neighbourhood level. These reasons include:

1. A GIS that maps local areas in detail plays an important role in restoring the importance of local neighbourhoods in the process of problem solving and decision making;
2. GIS is becoming an important tool for engaging residents in neighbourhood planning. Citizen's knowledge, experience, creativity and participation are essential to creating successful solutions for existing urban issues;
3. Since GIS technology is a powerful visualization tool, it can be used in a pro-active way to prevent social turmoil and misunderstanding that often occurs when public agencies make changes to a neighbourhood without securing residents' opinions. Local government planners can use GIS technology to get citizens involved early in land-use planning; and
4. A GIS can promote small changes in a community that, taken together, can have substantial impact.

Sieber (Sieber, 2006) provides a detailed discussion on four major themes that should be considered in participatory GIS review. Based on her work these themes are:

- Place and People: PGIS is illustrated as a highly localized activity, influence by culture and socio-political conditions. These specifications leads to consideration of following parameters:

- Context: factors that influence the condition of participation; such as: laws, culture, politics, history of the community, city, region, or nation.
- Stakeholders and Other Actors: stakeholders are those people who are affected by, bring knowledge or information to, and possess the power to influence a decision or program.
- The Public: general public who are not stakeholders.
- Technology and Data: PGIS facilitators should consider technology and data in terms of appropriateness, accuracy, access, ownership and representation. For this matter the following parameters should be considered:
 - Extent of GIS Technology: GIS technologies should fit with participants' goals by providing malleable and active tools. Also the design of these technologies should match with the learning curve of users. Finally, an effective application depends on understanding the place of technology in the process in terms of how much technology is required and when it should be brought.
 - Accessibility of Data: Access to the data is of huge concern in participatory applications. Level and amount of access to data is of huge importance especially for decision making purposes. Most spatial data created in participatory activities are generated by participants or public sectors, however

the following parameters should be considered about data: openness, privacy, security, and fiscal responsibility.

- Appropriateness of Information: Accuracy and appropriateness of information for a particular participatory application is of great concern as they influence the outcomes of decisions and policies.
- Representation of Knowledge: The type of representations of knowledge, the fact that indigenous knowledge is also integrated, and the format of transformation of knowledge to digital products is of the concern of participatory applications.
- Process: three main organizational processes are considered:
 - System Implementation and Sustainability: adoption of spatial technologies by non-profit organizations and marginalized groups which means internal decisions by organizations to acquire, install, implement, and maintain GIS and its applications towards the intended goals.
 - Participation and Communication in the Policymaking Process: participatory activities are considered as a ladder of enhancing participation and influence in public policymaking. Based on the ladder model participatory GIS activity can range from tokenism (e.g. counting the likes on a Web-GIS platform),

to collaboration (e.g. based on a GIS platform), to having control on changes by citizens. However, participation depends on who defines it at what scale and for what goals. In such model, improving the participation of the community from cooperation to community control is desired.

- Decision Making Structures and Processes: Participatory activities adds value at different stages of decision making process, making complex decisions more transparent and objective.

- Outcome and Evaluation: Participatory GIS activities have become expansive and reaching the ends is not guaranteed any more. Thus outcome and evaluation of a participatory GIS needs to be considered as much important as the process:

- Goals and Outcomes: Participatory GIS is all about empowerment of people in decision making. Output of such activities may be a map clarifying an issue or increasing social capacity and democracy through participation in decision making. However, the main goal is to increase positive impacts in the face of possible negative consequences.

- Measurement and Evaluation: Participatory GIS activities can be measured and evaluated on their effectiveness. Some researches argue that

evaluation of such activities should be measured on their appropriateness for a particular activity, their adaptability to local conditions and fitness to current capacity and goals.

The power of PGIS is in the data collected through participation which highly depends on the tools that provide purposeful functions to participants. Harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals is the main concept related to PGIS, Public Participatory GIS (PPGIS) and Volunteered Geographic Information (VGI) (Goodchild, 2007). Therefore, it is worthwhile to investigate studies that have used different sort of tools for similar applications. Designing tools for PGIS is closely related to the concept of participatory design. In participatory design the aim is to work collaboratively with the users throughout the design, and involve the users in every stage of the design process. Participatory design can be viewed as a 'democratic version' of User Centered Design (UCD). Participatory design requires a higher level of engagement from users, and the education of both designers and users to achieve a common understanding of the required product and to ensure its success.

Three main characteristics of participatory design should be considered when developing new tools (Dix, 2009): 1- Focus should be on the improvement of the work environment, so the evaluation is inherently context oriented and not system oriented; 2- The collaboration with the users should be at the center of the process and they should be involved throughout the design

process; 3- The process should be iterative, and in each stage the proposed design should be negotiated with the users.

Beside the characteristics of participatory design the suitable methods should also be considered. These methods include: Brainstorming: a process in which the participants in a meeting suggest ideas to solve a specific problem. Storyboarding: a way for participants to describe their work practices and communicate them to the designer. Paper and pencil exercises: exercises in which the participants are asked to describe their work environment and workplace using paper and pencils. Workshops: Workshops are critical to the process of knowledge construction. Although these characteristics and methods are general, they can be adopted accordingly for PGIS activities. For instance, a PGIS session should focus on the local environment and people can gather for this purpose and describe their concerns and ideas during workshops or brainstorming sessions.

It is the facilitator's responsibility to enable local people to engage in the map producing process, through the development of participatory tools (R. Chambers, 2006). To this end, this research focuses on providing efficient tools to enhance and encourage public participation in urban planning scenarios.

2.1.2. Types of PGIS Studies

PGIS can be studied from many different perspectives, including: case studies and applications of PGIS; integration of multiple tools used in practice; theoretical development; ethical considerations; or potential pitfalls of PGIS practices (Robert Chambers, 2006), to name a few. Case studies in PGIS practice can be separated in two groups based on the emphasis of the study: tool-based case studies, and issue-based case studies. Tool-based studies have included the assessment of map-based multimedia information systems, community information systems, participatory 3D modelling, or participatory orthophoto mapping (R. Chambers, 2006); while issue-based case studies have addressed specific concerns such as the documentation of the history of first nations in BC, Canada (Candler et al., 2006), or monitoring slum areas in Addis Ababa, Ethiopia (R. Chambers, 2006).

Considering the first category of PGIS studies, a broad range of high- and low-tech tools and methods are available to PGIS practitioners, including: ephemeral maps, sketch mapping, scale mapping, PGIS spatial analysis, participatory 3D modelling, photomaps, and mobile devices (e.g. Tablets, Smart Phones, PDAs, and GPS receivers) for data collection (Budhathoki and Haythornthwaite, 2013; LAQUES, 2006; Lunch, n.d.; Rambaldi et al., 2006b, 2006c); In the same way that participation may vary, the tools and technologies to engage people may also vary (Dunn, 2007). In other words, tools should be incorporated within the context of use (Sieber,

2001). From this perspective, this research can be classified in this category, which aims to develop high-tech tools for participants.

The advent of new technologies such as Web 2.0, handheld smartphones, Geo-Web, and Geosocial media has completely changed the way people can be engaged in PGIS activities.

Berdou (Berdou, 2013) suggests that advances in open source software have addressed the key developmental and democratic challenges of participatory activities through the power of technology, bottom up collaboration and transparency. In his work the significance of blending participatory mapping with technology-driven information generation is highlighted. New technologies have facilitated participation by providing: support for faster and cheaper data collection, support for data exchange over a variety of channels and networks, and support for improved data generation, aggregation and publication.

With this regard, Brovelli et al. (Brovelli et al., 2015) celebrate a revolutionary era for PGIS with the rise of Web 2.0 and access to mobile sensors. They also propose a completely “Free and Open Source Software” (FOSS) architecture to capture users’ data directly from field.

Current trend also shows the integration of free and open source software and web 2.0 technologies and their abilities to create new and innovative tools such as geosocial media to collect user-generated content (UGC) in PGIS and VGI applications (R. Feick and Robertson, 2015; Rob Feick and Robertson, 2015; Hall et al., 2010; Robertson and Feick, 2015; Zhang and

Feick, 2016). However Verplanke et al. (Verplanke et al., 2016) predict that low technologies still will be around at least for near future for PGIS application.

PGIS consists of many different aspects. Some of these aspects include: PGIS research directions and advantages (Elwood, 2006a), the role of stakeholders and their behaviour and relationships (R. Chambers, 2006; Rambaldi et al., 2006a); power relationships and disadvantaged groups (Elwood, 2006a; Rambaldi et al., 2006a; Tamang, 2005); the role of free and voluntary participation (Tamang, 2005); the role of underprivileged groups (e.g. children and women) in PGIS; and the role of good governance in encouraging people to use participatory practices. In next sections some of these aspects will be discussed considering high participation from community members as the main concern of this research.

2.1.3. Importance

Considering democratic aspect of PGIS on empowerment, local and indigenous spatial knowledge is as equally valuable and legitimate as that of experts (McCall and Minang, 2005). Elwood (Elwood, 2008) indicates that local data users experience difficulties with local government data resources with respect to accessibility, quality, and usefulness. These difficulties have roots in resource constraints, knowledge systems, and socio-political positions of local groups.

Local data suffers from data development, dissemination, and administration challenges. The major reason is that most data are implemented by SDIs and SDIs are mostly based on national rather than local context. Different types of spatial knowledge (expert, sectoral, tacit and community) are strategic resources in urban planning and management. PGIS is a major approach for eliciting various types of spatial knowledge through providing a platform for knowledge integration and informing local action and public policy (Pfeffer et al., 2013).

However, Sanderson and Kindon (Sanderson and Kindon, 2004) argue that rather than eliciting local knowledge, participatory activities should “produce knowledge specific to their process and participants”.

It is important to consider both local and official knowledge in a participatory activity since the interrelationships between local and official knowledge may be concealed if researches force to juxtapose these two types of knowledge (Elwood, 2006b).

Pfeffer et al. classifies different methodologies through which different types of spatial knowledge can be produced (Pfeffer et al., 2013):

1. The process through which knowledge is generated.
2. The purpose for which knowledge is generated.
3. The adoption of tools such as GIS, location based mobile devices, web-mapping services and Web 2.0 applications.

Their work emphasizes on the role of participatory processes, purpose of participation and available tools that can be adapted for spatial knowledge production.

Although PGIS focuses on providing access to appropriate tools and platforms to provide every member of a community a voice on their living environment in practice it suffers from some vulnerabilities. The issues related to PGIS may affect it from many perspectives; including: accessibility, different groups' interest, need for specific expertise, the relation of power, the outcome of participation and so on. The next section looks at some of these issues.

2.1.4. Vulnerability

Elwood (Elwood, 2014) brings some questions about the societal and scholarly practices and implications of geospatial data and technologies raised by critics of GIS. They believe that geospatial data, technologies and visualization is biased based on the interests of particular institutions or social groups. This critical perspective also includes new generations of geospatial information systems.

In the mid-1990s, GIS was criticized for some aspects, including: access, representation, expertise and power. PGIS tried to respond to some of these critiques, however, they are still valid (Elwood, 2006a) because:

- “Participatory GIS interventions in the technologies and social/political practices of GIS directly address many of the central concerns of the GIS critique; these interventions introduce their own contradictions with respect to knowledge, access, representation and power.

- The technical and political contexts in which participatory GIS is undertaken have themselves shifted a great deal in the past decade, further exacerbating some contradictions.”

Three main types of interventions tried to alter GIS and PGIS, to enable more equitable access to GIS and digital spatial data (Elwood, 2006a):

- Some PGIS interventions concentrate on altering the research, planning and decision making processes in which GIS is used, to try to make these GIS applications inclusive of a greater diversity of people, places and priorities.

- Other reconstructions of GIS target software and database, seeking ways to extend and diversify the forms of spatial knowledge that may be included and represented in a GIS, and to adapt the technology to foster broader access by diverse institutions and social groups.

- Other technology-focused reconstructions of GIS have sought ways to alter the digital practices used in GIS software and databases to represent and analyze spatial knowledge.

In another work Dunn (Dunn, 2007) provides contextual place of PGIS and its different meanings and discusses conflicts and opportunities embedded in PGIS as well as issues related to accuracy and representation for indigenous spatial knowledge. She also elaborates the importance of scale, questions about Web-based PGIS and issues on evaluation and sustainability of PGIS applications. Her work can be summarized in following terms:

- Conflicts: participation in collecting GIS information and knowledge does not necessarily empower those engaged or affected by the decision making. MacEachren (MacEachren, 2000) suggests a four step process to overcome this conflict: assessment, problem definition, decision making, and follow-up.
- Accuracy: PGIS does not want to privilege on type of information to another and wants to give equal validity to all type of information.
- Scale: many projects are local, so difficulties may raise about extending the findings both spatially and among organizations. Scaling up is concerned about linking

information from different scales and relating local knowledge to social understanding (Stonich, 2002).

Other major concerns are also brought by other researchers on other aspects related to participatory GIS activities. McCall and Minang's (McCall and Minang, 2005) major concerns in this regard are: data reliability of user-generated content, social exclusion due to dependence on technology and the interpretation and implications of digital maps. They argue that technological developments of knowledge production have not fully addressed important issues related to accountability, empowerment, control and use of knowledge. Their research seeks the answer to question on how different types of spatial knowledge can be produced or made more visible, used and exchanged for urban planning purposes. They classify spatial knowledge and major actors in producing these type of knowledge in four major categories shown on table 2.1.

Table 2-1. Types of knowledge and main actors

Types of knowledge	Main actors
<i>Tacit knowledge</i>	<i>Individuals with experience (experts, communities and citizens)</i>
<i>Community knowledge</i> <i>Context-embedded knowledge: community based and social</i>	<i>Community knowledge spread by social networks</i>
<i>Sectoral knowledge</i> <i>Context-embedded knowledge: technical, economic and political</i>	<i>Professional knowledge belonging to sector professionals and political networks</i>
<i>Expert knowledge</i> <i>Codified knowledge (analytical, regulatory, standards, etc.)</i>	<i>Academically and professionally taught and diffused</i>

The usefulness of data also depends on other factors including: timeliness, reliability, accessibility and ability of the actors to understand them. In PGIS activities equal attention should be paid to the context of participatory as well as the limitations set by social and political structures and relations between the actors. Although PGIS activities open up new opportunities for public to engage in urban analysis and changes the socio-political construction of spatial knowledge; they may be affected by uneven development for data production and uneven access by public.

Brown and Kyttä (Brown and Kyttä, 2014) present their views on the key issues and research priorities in a PGIS for land use planning. From their perspective the key issues are: 1- conceptual and theoretical foundations of participatory mapping, 2- the diversity of definitions and approaches to participatory mapping, 3- the spatial attributes measured in participatory mapping, 4- sampling, participation, and data quality, 5- relationships between participatory mapped attributes and physical places, and 6- the integration of participatory data into planning decision support. They also define the top research priorities as: 1- understanding and increasing participation rates, 2- identifying and controlling threats to spatial data quality, 3- improving public participation, and 4- evaluating the effectiveness of Participatory GIS. These priorities give the guideline for this research.

García-Nieto et al. (García-Nieto et al., 2015) show that high influence stakeholders and low influence stakeholders have different perception of the issues in PGIS activities (e.g. ecosystem services) and suggest that complex issues be handled with transdisciplinary methods.

The work of Verplanke et al. discusses the inter-connected memes of technological advances, the significance of localness in local spatial knowledge, and the consequence of ethics by which PGIS and VGI can strengthen each other. Their work mentions that PGIS has evolved from a useful collection of tools to a more holistic practice (Verplanke et al., 2016).

Quality of data collected in PGIS activities plays a major role in the outcome of the process (Brown and Kyttä, 2014; Furtado et al., 2016; Verplanke et al., 2016). The quality of participatory data is highly related to sampling design and participation rates. There are actually two important metrics to measure the data quality: sufficiency of spatial data for meaningful analysis, and the inclusion of the participants that are affected by decision making (Brown and Kyttä, 2014).

Besides the concerns mentioned, a main challenge in the recognition of PGIS applications is the lack of effective administrative structure for executing the decisions reached in PGIS practices (Rambaldi et al., 2006a). Some studies such as Brown (Brown, 2012) suggest that PGIS has not dramatically enhanced the public impact on the process of decision making mainly due to social and institutional constraints.

Participation, like development, means vastly different things depending on who defines it and uses it, and to what end, where, when and how. In order to avoid pitfalls of participatory activities, six key questions should be considered as checklist (Rocheleau and Slocum, 1995):

- Why is this participatory process needed? What ends does it serve?
- What are the relations of power at play in different social scales?
- Who is involved? Who is in control of the process?
- What is the best time frame for the process and plans and actions to

follow?

- What are the appropriate spatial and organizational scales for analysis?
- How should a participatory process proceed?

In addition, PGIS has been used less frequently for local community planning vs. for large-scale planning (Al-Kodmany, 2000). The reasons can be described in terms of:

1. A lack of local data;
2. Local land-use maps are usually only viewed as being useful during emergency events (such as natural disasters or traffic management during emergency service events);
3. Existing maps provided by governments do not provide necessary detail, or do not match community requirements.

Another vulnerability is that PGIS looks to implement a bottom-up approach for planning to give precedence to the opinion of the residents of a community, rather than top-down approach, which is usually mandated by government. Questions about access, control and ownership of geospatial information and output is of crucial importance to PGIS. These factors depend on cultural, institutional and locational framings, objectives of participatory, user characteristics, and political embeddedness (Dunn, 2007).

2.1.5. Evaluations

Evaluation of a participatory GIS activity is of major importance to measure the success of the activity. Different researchers and critiques have used various criteria to evaluate and assess the success of PGIS. McCall and Minang (McCall and Minang, 2005) use ‘good governance’ as a mean to evaluate the process of Participatory GIS. The aspects of good governance and criteria used include:

- Legitimacy and Participation: including representation and involvement of actors, and involvement of actors in decision making.
- Empowerment of Actors.
- Ownership of Spatial Knowledge and Process: by providing access to Geo-Information and GIS to all actors and use of Geo-Information for decision making.
- Respect for Local People and Their Knowledge:
- Equity-Governing and Governed.
- Effectiveness and Competence.

Dunn (Dunn, 2007) suggests that success of PGIS applications should be evaluated and assessed through follow-up studies:

- Social cost-benefit analyses (Jordan, 2002).
- Systematic social-behavioural research (Nyerges et al., 2002).

- Meeting criteria for good governance (McCall and Minang, 2005).
- Economic analytical approach (Tulloch and Epstein, 2002) for efficiency,

effectiveness and equity brought by the process.

In other study, Brown and Fagerholm (Brown and Fagerholm, 2015) review and evaluate Participatory GIS approaches for ecosystem services. The mapping of ecosystem services puts emphasize on the spatial relationships between landscape characteristics and their effect on human wellbeing. They conclude that the best practice for participatory mapping of ecosystem services is multi-dimensional, requiring consideration of the type of ecosystem services being mapped, the importance of spatial validity for decision making, and the importance of participation to build social capital, which implies lots of trade-offs in the process of participation.

Parker's (Parker, 2006) work identifies the mapping process critical to the definition and understanding of community mapping and emphasizes on the importance of three major themes: inclusion, transparency, and empowerment in providing insight into particularities and commonalities of community maps and the relationships between these maps and power in a community. He provides a matrix of 8 classes to evaluate the success of PGIS based on access and participation (table 2.2).

Table 2-2. Matrix of the 8 classes of access and participation and their effect on success of participatory GIS

	No or Low Levels of Access	High Levels of Access
No or Low Levels of Participation	<p><i>TYPE I</i></p> <p><i>Successful: Least Likely</i></p> <p><i>Unsuccessful: Most Likely</i></p>	<p><i>TYPE II</i></p> <p><i>Successful: More Likely</i></p> <p><i>Unsuccessful: Somewhat Likely</i></p>
High Levels of Participation	<p><i>TYPE III</i></p> <p><i>Successful: Less Likely</i></p> <p><i>Unsuccessful: Somewhat Likely</i></p>	<p><i>TYPE IV</i></p> <p><i>Successful: Most Likely</i></p> <p><i>Unsuccessful: Less Likely</i></p>

2.1.6. Similar Studies

In this section we summarize some of the similar studies, which were conducted by other researchers. One such study (Kubota et al., 2012) shows the application of PGIS in regional urban development and solving regional problems. Another study (Bugs et al., 2010) combines new technologies to enhance the participation in such activities by analyzing the impact of collaborative Web 2.0 tools applied to PGIS applications in urban planning actions. In this study (Bugs et al., 2010) a Web mapping service is developed which enables users to explore different geospatial data layers and comment on them. This service aims to promote communication among users and decision makers and was easy to use for non-experts in City of Canela, Brazil. Tools such as geovisualization, email, maps with sketches, georeferenced comments, and online

forums are used. Pros and cons of using these tools in other platforms, such as: London Profiler, Map Hackney, Orange County Interactive Mapping, Virtual Slaithwaite, Argumentation map, and WikiMapia are also given.

In his study Hanzl (Hanzl, 2007) emphasizes providing a communication platform to reduce the barrier of non-professionalism, allowing for distant contacts and enabling participatory process management. This study also discusses the role of vision and city models in perception process and investigates different formats, tools and communication forms for participatory urban planning, including: XML, 3D VRML, Collaborative Software, Games, PPGIS, Planning Support Systems, Forums and Chats, Email, Text, Illustrations, Downloadable Data, and Augmented Reality (AR) Systems.

Toker (Toker, 2007) studies the importance of participation as well as urbanism and sustainability in community design. He also provides a comprehensive list of all professionals of architecture and planning in the community design field.

Kahila et al. (Kahila and Kyttä, 2006, 2009) introduce SoftGIS as a tool that aims to build a bridge between residents, researchers and urban planners by promoting the participation and collaboration of citizens. This study uses Web mapping technologies to interact with users and gather user responses/experiences with respect to safety, urban mobility and green environment issues, in the form of questionnaires.

McCall and Dunn (McCall and Dunn, 2012) explore the potential contributions of participatory geospatial tools towards spatial planning, with great attention to good-governance criteria. However, there are some other studies that use a Web-based PGIS framework for a diversity of planning and decision making analysis, such as (Mekonnen and Gorsevski, 2015) for offshore wind suitability analysis which gathers public preferences on evaluating the importance of three different decision alternatives. The platform in this study contains different components including forums, spatial maps and a decision-making module, all integrated in a Web-based platform. The most important criteria implemented for decision making in this study are: bird habitat, fish habitat, sport fishery effort, commercial fishery effort, and distance from utilities, population density, distance from waterways and distance from shore. Participants can explore the maps and data, vote for the sites they prefer and get engaged in discussion about their votes. The final decision is made based on the number of votes.

In an interesting study Brown and Pullar (Brown and Pullar, 2012) compare the result of participation between two modes of point and polygon. In their study participants give value to four criteria of interest (Aesthetics, Recreation, Economic, and Biological) either by drawing points or polygons. Both points and polygons are used to create heat maps; density of point propagation and density of polygon intersections were used for this purpose. This study emphasizes the importance of using points and polygons for collecting area attributes as well as

the importance of understanding the strengths and limitations of each of these spatial features in PGIS activities. A similar study (Brown and Reed, 2012) uses PGIS to investigate the structure and distribution pattern of human perceptions of landscape including the human attribution of place values, perceptions, and preferences.

Drakou et al. (Drakou et al., 2015) propose an open-access interactive platform for participatory mapping to assess, quantify, map and communicate ecosystem services. Their research reveals the requirements for open access data sharing and usability of information for different needs. In their work developing an appropriate tool is an ongoing process. Darvill and Lindo (Darvill and Lindo, 2015) have used PGIS methods to map 16 cultural and ecosystem indicators across 7 stakeholder groups for an area of lacking data. They have asked participants to draw polygons representing ecosystem services use and have detected hotspots from overlapping areas. They have demonstrated an effective free tool to visualize the results of stakeholders' participation.

Understanding the scope of PGIS and how it fits in this research is crucial as this research concentrates on indigenous, local, non-expert, and average participants with little or no knowledge of GIS. In the next section the necessity of having a good interface design will be discussed, as it fills gaps of knowledge between participants and experts and facilitates the interaction of participants with PGIS platforms. By following interface design principles, we

tend to design tools that are easy to use and understandable for most participants and stakeholders.

2.2. User Interface Design

Because GIS is a popular tool both in private and public sectors, investigating the interactions of humans with such systems becomes important. Human-Computer Interaction (HCI) is concerned with the design, evaluation, and implementation of interactive computing systems for human use and its surrounding phenomena (Haklay and Skarlatidou, 2010). In essence, HCI is based on different disciplines, including: Computer Science, Ergonomics, Cognitive Psychology, Sociology, Anthropology and Ethnography, Linguistics, Artificial Intelligence, and Engineering (Haklay and Skarlatidou, 2010). The major focus of HCI is on User Interface issues.

User Centered Design (UCD) is the core concept in HCI and emphasizes the concepts of usefulness and usability. UCD is both a philosophy of design and a framework for application development which puts the users at the center of the development process. Nielsen (Nielsen, 2003) defines usability as ‘a quality attribute that assesses how easy user interfaces are to use’. Usability concerns with the effectiveness of the interaction between humans and computers and can be evaluated in terms of: learnability, efficiency, memorability, error rate and user satisfaction (Haklay and Skarlatidou, 2010). Different researchers have developed their own sets

of rules of Interface Design evaluations. For example, Norman (Norman, 2002) describes the rules of UCD as: Use both knowledge in the world and knowledge in the head; Simplify the structure of tasks; Make things visible: bridge the gulfs of execution and evaluation; Get the mapping right; Exploit the power of constraints, both natural and artificial; Design for error; When all else fails, standardize. Shneiderman and Plaisant (Shneiderman and Plaisant, 2005) identify eight “Golden Rules” for interface design from a Human-Computer Interaction (HCI) perspective: Strive for consistency; Cater for universal usability; Offer informative feedback; Design dialogs to yield closure; Prevent errors; Permit easy reversal of actions; Support internal locus of control; and Reduce short-term memory load. Tognazzini (Tognazzini, 1993) has also outlined principles of design for graphical user interfaces. These principles can be summarized as: 1) Consistency; 2) Unity; 3) Simplicity; 4) Using real world metaphors; and 5) Developing techniques for user testing. As cited by Kemp and Ueki-Polet (Kemp and Ueki-Polet, 2009), Dieter Rams has also developed principles for good design, which state that User Interface Design must: 1) be innovative; 2) make a product useful; 3) be aesthetically pleasing; 4) make a product understandable; 5) be unobtrusive; 6) be honest; 7) be long-lasting; 8) be thorough down to the last detail; 9) be environmentally friendly; and 10) must be designed as minimally as possible. A more comprehensive framework was offered by Gould and Lewis (Gould and Lewis, 1985) indicating the following as principles of User Interface Design: Early focus should be

made on uses and tasks; Empirical measurements should be performed; and design should be iterative (containing the cycle of: design, test, measure, and redesign).

In general we can summarize these rules as: simplicity and minimalist design of the interface; effectiveness and efficiency of the tools; and human-understandable approach to design. Special requirements of GIS and different mediums of interaction (e.g. desktop vs. Web GIS; monitor screen vs. mobile screen; personal vs. public applications) increase the need for accurate and comprehensive interface design and usability testing of such systems (Haklay, 2006; Haklay and Tobón, 2003; Haklay and Zafiri, 2008; Nivala et al., 2007, 2008; Nivala and others, 2007; Nivala and Sarjakoski, 2003).

In addition, the interaction between humans and GIS systems involves creating spatial cognition, which deals with the way GIS systems intend to represent geospatial data, how these representations are perceived by humans, and how connections are made between human mental maps and computer representations of space (Clare Davies et al., 2010). Representation of space on computers and for different devices (e.g. screens, tablets and smartphones) requires a comprehensive understanding of cartographic principles and rules (Jones, 2010). Digital maps employ these principles and rules to create spatial representations that match human understandings of space.

The number of users and their interactions (Multi-user, Collaborative, and Participatory GIS) is another issue that should be considered for interface design, as well as the mode of interaction (which is especially important for Web-based applications). These modes include: face-to-face interaction, asynchronous interaction, synchronous distributed interaction, and asynchronous distributed interaction (Haklay, 2010).

The User Interface (UI) is the conceptual link between human intention and what a computer can offer, above and beyond human capability (Gould, 1994; Wardlaw, 2010). Command lines and Graphical User Interfaces (GUI) are two main modes of interface between users and computers. Using command line mode, users should know the syntax of the command, but using GUI is much easier since the elements are obvious. Basic elements of GUI are windows, icons, menus, and pointers.

Guidelines to design effective GUI applications indicate the following rules: Be consistent in design components (e.g. color, layout, fonts, ...); provide obvious and immediate feedback for actions; inform the user clearly about the completion (success or failure) of a process; prevent errors by creating good conceptual models; permit easy reversal of actions; make the user feel in control; reduce short-term memory load; and strive for universal usability by catering the interface to users of all levels of technological ability (Wardlaw, 2010).

There are other challenges when designing a user interface for a group of users. These challenges include: designing and assessing interfaces for collaborative tools (Fuhrmann and Pike, 2005), information visualization and universal usability (Plaisant, 2005).

Human vision is the dominant sense, although we receive information from the world around us in various sensory modalities; including: taste, sound, smell, and feel. So, interfaces that attend to vision are more noticeable. Visual interaction between humans and computer systems dates back to Sutherland's Sketchpad in the early sixties (Sutherland, 1964). Today, there are many different types of tools that help users to draw and sketch as a means of interacting with a computer. A sketch is essentially an accumulation of strokes. Freehand sketching is a familiar, efficient, and natural way of expressing certain kinds of ideas, particularly in the early phases of design (Sezgin et al., 2006). Sketching is a universal form of communication. Since prehistoric times, people have rendered the visual world in sketch-like petroglyphs, or cave paintings (Eitz et al., 2012).

Sketch recognition and interpretation is an essential part of this research, which intends to investigate methodologies to render the spatial model of a user's mental map into a computer understandable format.

Freehand sketches play an important role in fields such as spatial cognition where sketch maps are used to depict people's mental model of space. However, there are many other application domains that use sketching, such as architecture and animation (Egenhofer, 1997).

Despite decades of graphics research, sketching is still the most common mechanism used by people to render visual content (Eitz et al., 2012). However, sometimes designers sacrifice the utility of freehand sketching for other capabilities (Sezgin et al., 2006)(e.g., separate tools for drawing points, lines, and polygons).

Therefore, the purpose of this research is to develop tools to recognize and interpret users' sketches into comprehensible designs, employing rules of human-computer interaction to facilitate users' interactions, and utilizing ontology to empower the system's overall capability to understand users' design intentions.

2.3. Sketch Recognition

The word "sketch" in urban planning refers to a picture drawn by a specialist that shows the proposed or future condition of an urban location (Figure 2.2). Here in this research, by "sketch" we mean a drawing made by people (usually non-specialists) on a map in the form of points, lines, or polygons (Figure 2.3).

Sketching has a key role in concept design and visual thinking (Tovey et al., 2003). In the design process, the designer attempts to give external definition to an imagined design.

Sketching is the language for handling different design ideas. Johnson et al. (Johnson et al., 2009) studies sketch-based design tools comprehensively in his work and offers that sketching is an effective approach in design practices. In their view, sketching is an iterative process of problem-framing and exploring solutions. Tovey et al. (Tovey et al., 2003) describe that sketching can be used for different purposes including: generating concepts, visualizing problems, facilitating problem solving, facilitating perception, representing artefacts, and revising ideas. In their work they also categorize type of sketches based on the complexity into following classes: level 1- Monochrome line drawing (no shading, no color, no thickness), level 2- Monochrome line drawing (no shading, no color, variable thickness), level 3- Monochrome with rough shading, level 4- Line and shading (may include color and graduation), and level 5- Color illustration (including: color, shading, shadows, annotation, and dimensions).

Many studies suggest sketching as the integral part of next-generation of Human Computer Interaction (Bimber et al., 2000; Johnson et al., 2009; Plimmer and Apperley, 2004) and some suggest sketching interfaces as a more human oriented interface design (Landay and Myers, 2001). Some other studies even suggest using sketched interfaces rather than formal diagrams for interface design itself (e.g. sketched menus, buttons, boxes ...) and found it was preferred by

users (Plimmer and Apperley, 2004). SILK (Landay, 1996; Landay and Myers, 1995, 2001) is such a tool that gives designers a lot of flexibility for utilizing sketches to design user interfaces.

Many different researchers have dedicated considerable time to the topic of sketch recognition, including: Sezgin et al. (Sezgin et al., 2006), Paulson & Hammond (Paulson and Hammond, 2008), Apte et al. (Apte et al., 1993). Many algorithms and tools (e.g. PaleoSketch and SketchREAD) have also been developed in different domains, and for different purposes. Eitz et al. (Eitz et al., 2012) conducted the first large-scale exploration of human sketching, and analyzed the distribution of non-expert sketches of everyday objects. In their research, a large database of 20,000 unique sketches distributed over 250 categories were analyzed to discover how human beings draw objects, and they subsequently compared performance of human recognition against computer recognition. Sezgin et al. (Sezgin et al., 2006) attempted to combine the flexibility and ease of use of paper and pencil with the processing power of a computer, with a design objective of producing a user interface that felt as natural as paper, but was smarter, in that the system used multiple sources of information to identify generic shapes drawn by a user. The basic concept in their research was the process of converting the original digitized pen movements into geometric objects.

PaleoSketch (Paulson and Hammond, 2008) is a system designed for accurate primitive sketch recognition. Primary features such as: lines, polylines, circles, ellipses, arcs, curves,

spirals and helixes are the main geometric objects identified by this system. Apte et al. (Apte et al., 1993) has also designed a system to recognize multi-stroke sketches. The basic shapes covered in their research include: rectangles, ellipses, circles, diamonds, triangles, and lines. Wenyin et al. (Wenyin et al., 2001) have also covered shapes such as: triangles, rectangles, ellipses, straight lines, and arrowheads during the development of their recognition algorithms.

SketchREAD (Alvarado and Davis, 2004) is capable of recognizing free hand-drawn diagrammatic sketches from multiple domains. This system can be applied to a variety of domains by providing structural descriptions of the shapes in that domain. Wenyin et al. (Wenyin et al., 2001) have designed a system to recognize drawings through imprecise stroke approximation. The output of this system is organized in a hierarchical structure that includes syntactic and semantic information, as well as raw data. Here, raw data represents the geometrical aspect of the sketch, while syntactic information describes the relationships between different parts of a sketch with each other; and finally the semantic aspect is the final recognition of the object, not as a geometry feature, but as an example of a feature in a particular domain.

Fernández-Pacheco et al. (Fernández-Pacheco et al., 2009) have designed an agent-based solution for free-hand sketch recognition which consists of three different agents for three different stages of recognition: basic agents to recognize and classify simple strokes; primitive agents for finding the syntactic meaning of strokes, and combined agents for obtaining the

semantic meaning of groups of strokes. Arvo and Novins (Arvo and Novins, 2000) uses a more advanced methodology, which combines recognition and morphing in order to transform users' sketches into final shapes. Fonseca et al. (Fonseca et al., 2002) have used Fuzzy Logic to recognize geometric shapes interactively. Shpitalni and Lipson (Shpitalni and Lipson, 1997) used a method based on linear least squares fitting to a conic section equation, to help classify sketch strokes and identify lines, elliptical arcs, and corners. In Ding et al. (Ding et al., 2005) an algorithm is presented to recognize composite shapes from a sketch, which can be used to infer complex shapes composed of more than one primary shape. Field et al. (Field et al., 2011) have designed the Mechanix system, which is a sketch recognition application that compares sketches with pre-designed sketches to facilitate the process of marking assignments.

Jan and Schwering (Jan and Schwering, 2015) have designed SketchMapia; an online tool that considers topology, orientation, and alignment to recognize a freehand sketch and combine it with metric maps. Their system integrate data from different sources including cognitive maps of users and official metric maps.

Hu et al. (Hu et al., 2015) have designed a multi-stage collaborative 3D GIS which employs online communication and sketching to produce 3D models to support public participation. Their platform provides synchronous and asynchronous collaboration functionalities.

In order to classify the aforementioned methods and algorithms we can group them into the following categories:

1. Domain dependent (sketches interpreted as objects of a known domain) vs. domain independent algorithms (sketches interpreted as primary geometrical elements, or as any object imaginable);
2. Image-based (image analysis) vs. geometry-based (coordinate analysis) algorithms; and
3. Precise (geometry important) vs. imprecise (concept important) methods.

2.3.1. Sketch Recognition in Geospatial Domain

People's interest in GIS increases the need for user-friendly, easy-to-learn and intuitive interfaces (Schlaisich and Egenhofer, 2001). GIS applications are widely used to query and analyze spatial data and considering the lack of training for most users, the need for more intuitive interfaces becomes more important. Free sketching helps by providing intuitive interface for general users. The power of sketching in human communication arises from the high bandwidth it provides (Oviatt, 1999). On the other hand, other interfaces such as menus and toolbars frequently prevents the speech-like flow of interaction.

Furtado et al. (Furtado et al., 2016) investigate how the interaction design of a PGIS favors the user's perception about their empowerment level. Their research indicates that in order to empower the user experience, a PGIS system should have the following characteristics: building user capacity, interaction (including: content interaction based on information, multimodal interaction based on the device, and social interaction based on user's motivation), and context of interaction.

In the geographic domain, researchers have investigated the role of sketch maps for different purposes. Blaser (Blaser, 2000) studied people's sketching habits in GIS, and concluded that sketching is an appropriate modality for interaction with a computer where one wants to describe and capture object configurations in a spatial environment. Blaser (Blaser, 1997) analyzed traditional and alternative user interaction methods and explored the potential of a sketch-based user interface with a focus on applications in GIS. Studies by Egenhofer (Egenhofer, 1996, 1997) suggested a new method of spatial querying, in which queries are built up using user sketches. In addition to these studies, research by Yin et al. (Yin et al., 2010), and Richter et al. (Richter et al., 2012) have evaluated the spatial reasoning ability of GIS systems using sketches drawn by users.

Schlaisich and Egenhofer (Schlaisich and Egenhofer, 2001) investigates the preferences of users when they have the choice of sketching and talking, and finds that sketching cannot replace verbal description and vice versa. Forbus et al. (Forbus et al., 2001) describes four dimensions of

sketching as: visual understanding, conceptual understanding, language understanding, and drawing. They apply free sketching (nuSketch) for military planners who design an operation. The sketches are created on layers over maps. Drawings are interpreted as military elements based on their characteristics (e.g. for adding regions, curves drawn are taken to be the boundary of a region and are closed and filled with appropriate texture).

Forbus et al. (Forbus et al., 2004) describe techniques that were developed to enable software to perform human-like reasoning about sketch maps. They describe the use of qualitative topology and Voronoi diagrams to construct spatial representations, and explain how these facilities are combined with analogical reasoning to provide a simple form of enemy intent hypothesis generation in a military scenario. They claim that qualitative spatial reasoning is essential for working with sketch maps. Haarslev and Wessel (Haarslev and Wessel, 1997) offer a sketch-based query language for finding spatial constellations of objects. Their system combines querying (spatial and topological) with deductive spatial reasoning to detect constellations.

While currently we can build software that enables sketching in a limited way, the state of the art is far from creating systems that have the depth and flexibility of a human. Challenges that arise with this are: Integrated compositional semantics (i.e. the ability to combine visual and conceptual understanding in a compositional way to decode complex sketches), user-extensible

visual symbologies (i.e. being able to interactively specify the domain semantics of a new symbol, and having the software to recognize it through normal interactions), and visual analogies (i.e. being able to compare sketches) (Forbus et al., 2001).

2.4. Urban Planning and Cognitive Maps

Spatial cognition field of research includes the contrast between human understanding (cognition) of real world space and space on computer screens. Spatial cognition mainly deals with the challenge of representing geographic space on a screen. How human understand the space and the way the space is imagined and navigated has an important role on using related technologies. To this end one of the major questions in spatial cognition is how people make connection between screen and geography spaces (C. Davies et al., 2010) under the shade of main differences such as point of view (worm's eye vs. bird's eye view) and reference frame (e.g. top of the screen as north in computer maps). This fact becomes more important when we need to make a connection between human cognition and real world for urban planning purposes.

Urban planning is a continuous succession of phases as there is no final state for a city. These days most cities suffer from ugliness, dirt, smoke, heat, congestion, and chaos (Lynch, 1960). The images that citizens hold in their mind from issues and palatability are important, since they

are a way to understand a city and its future changes. These images are so important that any spatial behaviour would be restricted or impossible without it (Kitchin and Blades, 2002). Gould and White (Gould and White, 2002) emphasize on the role of cognitive maps in spatial behaviour while Stea and Blaut (Stea and Blaut, 1973) and Hart and Moore (Hart and Moore, 1973) study how humans learn space and develop cognitive maps from their living environments.

Cognitive map refers to an individual's knowledge of spatial and environmental relations recorded in mind as a set of images. Cognitive maps describe: how people learn new environments; how they find their way through familiar environments; how they draw sketch maps from memory; how they give verbal route directions; and how they make decisions about their environments (Kitchin and Blades, 2002). Cadwallader (Cadwallader, 1976) suggested that cognitive maps affect at least three types of spatial decisions: first, the decision to stay or go; second, the decision of where to go; and third, the decision of which route to take.

There are different factors that may affect cognitive map knowledge. These factors include: function of the areas in a city, order of the areas and their clarity and continuity, identity of the areas that distinguish them from other areas, and appeal, which refers to the appropriateness and harmony of an area (Greene, 1992). That is why the way that Europeans learn their way round a typical European city with an irregular street pattern may be very different from the way a person in North America learns a city based on a regular grid pattern.

The creation of cognitive maps is a mutual process between the observers and observed environment (Lynch, 1973). Due to humans' adaptability, people can distinguish different parts of a landscape and assign meanings to each part. The physical space of a city is learned through time in three ways (Briggs, 1973): 1. By direct interaction with the city structure through different sensing modalities; 2. From abstract and symbolic representations of the city using media such as maps, photographs, videos and audio; 3. By inferring from experiences in other spatial locations. Two important measures of space that are perceived qualitatively rather than quantitatively in the human mind are distance and direction.

The relationship between cognitive distance and real distance is examined in many studies (Briggs, 1973; Cadwallader, 1973, 1976; MacEachren, 1980). Distance is a parameter that is distorted cognitively and parameters such as travel time, familiarity with the space, attractiveness of the space, and the length of residence, affect its distortion.

Orientation is also an important factor that ties cognitive maps to the spatial environment (Downs and Shea, 2006) and requires knowledge about your position and immediate surroundings. This knowledge is called topographical orientation (Griffin, 1948).

Connecting cognitive maps to GIS maps is an interesting field of study. Medyckyj-Scott and Blades (Medyckyj-Scott and Blades, 1992) study the aspects of GIS design to represent human cognitive maps. MacKay (MacKay, 1976) compares hand-drawn maps with physical maps of

American cities with different patterns. The study found that hand-drawn maps are like physical maps. In a study, Lloyd (Lloyd, 2000) argues that cognitive maps can be simulated by neural networks, and locations of cities are distorted in the human mind with the same amount of error in the corresponding neural network.

Hayward and Tarr (Hayward and Tarr, 1995) explore the commonalities between linguistic and visual representations of space, and conclude that the structure of space represented linguistically may be determined by the structure of space represented visually. Kulhavy and Stock (Kulhavy and Stock, 1996) find that individuals assign meanings to spaces based on their interpretation of that space.

2.5. Spatial Reasoning and Ontology

Cognitive maps, as human knowledge of large-scale environments, describe how people imagine or perceive their environments. This knowledge of large-scale environments can be presented via different distinct, but interacting, levels with their own ontologies, including: sensory, control, causal, topological and metrical levels (Kuipers, 2000). Map sketching can be thought of as a way of expressing our cognitive maps using appropriate tools at each of these levels.

Individual objects are the primary building blocks of a sketch. Therefore, knowledge about the type of objects in a sketch and its relationship to other objects reveals part of a sketch's meaning (Blaser, 2000). Since all sketches in this research belong to the same domain (i.e. urban objects), it is possible to define a set of object classes that covers most cases. An object class is defined as a category of objects with similar characteristics. In order to have a comprehensive definition of objects and their relationships with each other, and the meaning that they convey, this work requires the study of ontology and reasoning in the domain of urban planning ontology.

2.5.1. Ontology

Ontology can be studied from two major perspectives: Philosophical and Computational. In this research the computational sense of ontology is reviewed. Ontology is defined as “explicit specifications of conceptualization” (Gruber, 1993). While each of the terms in the definition requires their own comprehensive definition, the backbone of an ontology consists of a generalization/specialization hierarchy of concepts (i.e. taxonomy) (Staab and Studer, 2013). In other words, ontology conceptualizes and represents the objects, concepts, and other entities and the relationships among them, which exist in some domain of interest.

Ontology uses a set of axioms (e.g. reflexive, irreflexive, symmetric, asymmetric, transitive, intransitive, and so on) to model the relationships between entities and facilitate reasoning.

Reasoning is required to check the quality of an ontology and to exploit the structure of ontologies (Staab and Studer, 2013).

Ontology has been discussed in Geographic Information Sciences (GIScience) by many researchers, such as Fonseca et al., Frank, and Smith and Mark (Fonseca et al., 2002; Frank, 2003; Smith and Mark, 1998). Within GIScience, an ontology may have many applications, including: 1) a standardization procedure for easy translation between different information (Smith and Mark, 1998), 2) a systematic approach to capture the universal concepts and meanings that define a geographic domain (Frank, 2003), and 3) a framework of design for data models and information systems to make them better equipped for handling geographic concepts (Fonseca et al., 2002).

The third application category of ontology explained by Fonseca et al. (Fonseca et al., 2002) is suitable for this research to define geo-spatial entities along with their concepts and attributes, and their relationships with other entities. Given the ontology, different sources of knowledge can be combined to produce a hierarchy of successively more abstract interpretations of a sketch. Thus, a comprehensive ontology provides a concrete base for interpreting spatial reasoning in sketching.

Spatial reasoning is at the heart of this research, to help make clear inferences from sketches. Spatial features and phenomena obey rules that spatial reasoning tries to affirm and explore. The

collection of these rules helps to define the knowledge base of our domain. It is important to have both qualitative and quantitative aspects of spatial reasoning in mind, since both play critical roles when dealing with spatial phenomena (Worboys and Duckham, 2004). However, human cognitive maps are usually based on qualitative reasoning rather than quantitative.

2.5.2. Spatial Reasoning

Spatial Reasoning mostly deals with human understandings of space in terms of qualitative criteria rather than accurate quantitative criteria. Spatial reasoning has a close connection with ontology. Relationships between spatial objects, and how humans perceive and describe these relationships, can be modeled with ontological means.

Defining and conceptualizing relationships (e.g. semantic, topologic, and geometric) between urban entities through an ontology can assist the design of more intelligent tools for collecting local knowledge using participatory activities. These relationships can be general (e.g. general relationships between urban entities), or specific to a particular application (e.g. specific to transportation). Using ontology to check and validate the relationships between entities can enhance the outcome of participation and guarantee the quality of participation based on the approved standards. Although, imposing a top-down approach in participation may be accomplished by modifying the ontology, it is not the intention of this research.

Relationships between spatial features are usually modeled using topological concepts. RCC8 (Region Connection Calculi) and DE-9IM (Dimensionally Extended – Nine Intersection Model) are two common models used for this purpose. These models describe numerous qualitative relationships between features. However, they are not yet exhaustive standards, and not yet capable of modeling complex relationships such as parallelism of two linear features (e.g. major roads).

Qualitative spatial representation and reasoning address many different aspects of space, including: topology, mereology, mereotopology, orientation, shape, size and distance (Cohn and Renz, 2008). In the following sections each of these aspects are described.

2.5.2.1. Topology

The topological properties of features can be expressed using three distinct vocabularies: OGC's Simple Features topological relations (Battle and Kolas, 2011); Egenhofer's DE-9IM model (Egenhofer, 2015; Egenhofer and Herring, 1990); and RCC8 (Randell et al., 1992). Simple Features topological relations include equals, disjoint, intersects, touches, within, contains, overlaps and crosses. The DE-9IM model uses the concept of interior ($^{\circ}$), boundary (∂), and exterior ($'$) of features to describe their topological relationships. The matrix given in figure

2.4 presents the topological relationships that can be modeled by DE-9IM between two entities X and Y.

$$\begin{bmatrix} X^\circ \cap Y^\circ & X^\circ \cap \partial Y & X^\circ \cap Y' \\ \partial X \cap Y^\circ & \partial X \cap \partial Y & \partial X \cap Y' \\ X' \cap Y^\circ & X' \cap \partial Y & X' \cap Y' \end{bmatrix}$$

Figure 2.4. DE-9IM Matrix

A large number of researchers utilize the primitive connectedness relationship $C(x,y)$ of Clarke (Worboys and Duckham, 2004) as a basis for qualitative spatial reasoning. The overall method is called Region Connection Calculus (RCC) and RCC8 is an extension of this method. RCC8 uses the concept of connection between regions (Randell et al., 1992). The connection relation is reflexive and symmetric and describes 8 possible relations between two dimensional regions. Using RCC8, the following topologies can be described (Bittner and Stell, 2000; Cohn et al., 1995; Cohn, 1996, 1997; Cohn et al., 1997; Cohn and Hazarika, 2001; Cohn and Renz, 2008; Kontchakov et al., 2014): disjoint (DC: Disconnected), meet (EC: Externally Connected), overlap (PO: Partially Overlapping), equal (EQ: Equal), inside (NTTP: Non-Tangential Proper Part), contains (NTPPi: Non-Tangential Proper Part inverse), covers (TPPi: Tangential Proper

Part inverse), and covered by (TPP: Tangential Proper Part). Figure 2.5 illustrates the possible RCC8 concepts for two regions: *a* and *b*.

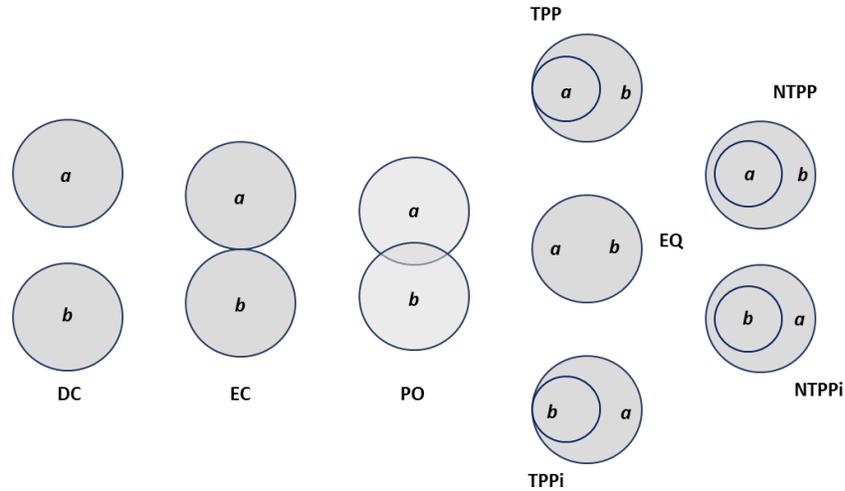


Figure 2.5. RCC8

Although these models can represent most planning topological relations, they lack some essential relations that are required in many urban planning applications. The importance of these “missing” relations limits the usefulness of PGIS applications when attempting to interpret local spatial knowledge. For instance, designing new road networks requires sharing interchange locations which will affect the arrangement of house clusters. Putting all these relationships together is beyond the capabilities of the aforementioned models.

2.5.2.2. Mereology

Mereology is concerned with the theory of parthood (Cohn and Renz, 2008). Mereology is simply an attempt to set out the principles underlying the relationships between a whole and its constituent parts (Varzi, 1996). Mereology can be defined by the following proper axioms for the Parthood predicate, P:

P1: P_{xx} ; every entity is part of itself (reflexive).

P2: $P_{xy} \wedge P_{yx} \rightarrow x=y$; if x is part of y and y is part of x then x and y are equal.

P3: $P_{xy} \wedge P_{yz} \rightarrow P_{xz}$; if x is part of y and y is part of z then x is part of z (transitive).

2.5.2.3. Mereotopology

Mereotopology can be viewed as a combination of mereology (the concept of parthood) and topology (the concept of connection) (Cohn and Varzi, 2003a; Düntsch and Winter, 2004; Varzi, 1996, 1998, 2007). Although this view is subject to debate, there are some pure mereotopological axioms that can be described based on parthood and connection concepts (assuming parthood as P and connection as C):

- P-reflexive: every entity is part of itself.
- P-antisymmetry: two distinct (disconnected) entities cannot be part of each other.
- P-transitivity: any part of a part of an entity is itself part of that entity.

- C-reflexive: every entity is connected to itself.
- C-symmetry: if an entity is connected to a second entity, the second is connected to the first.
- Monotonicity: every entity is connected to those entities to which its parts are connected.

Mereotopology supports some useful concepts (Varzi, 1996), including: Proper Part, Overlap, Underlap, Over-Crossing, Under-Crossing, Proper Overlap, and Proper Underlap.

Mereotopology can overcome some of the limits of mereology when connection between entities plays an important role (Cohn and Varzi, 2003b).

2.5.2.4. Distance and Size

The concept of distance is crucial in human understanding of space and reasoning about entities. Distance can be considered either as absolute or relative (Cohn and Renz, 2008).

Conceptually, distance is usually thought as one dimensional, while size is of higher dimension (Cohn, 1996).

Qualitative reasoning using distance is investigated in different studies. Frank (Frank, 1992) studies the deduction of the distance and direction from A to C, given the distance and direction

from A to B and B to C. Worboys (Worboys, 1996) argues that contextual knowledge of a space is a key feature in understanding of human estimation of distance in that space.

The concept of proximity or nearness is also a vague concept which affects human perception of their environment. Worboys (Worboys, 2001) suggests three different methods to unlock the concept of nearness and how people perceive distance between features in an environment.

These methods are: nearness neighborhood regions with broad boundaries; fuzzy nearness and distance measures; and higher-valued logics where conflicting views may be represented.

2.5.2.5. Direction and Orientation

Direction relations describe the orientation relationships between two objects and can be described by three basic concepts: the primary object, the reference object and the frame of reference (Cohn and Renz, 2008). In human cognition, these relations are perceived as three basic types of reference: egocentric, fixed, and global (Kitchin and Blades, 2002; Stea and Blaut, 1973).

In order to find the direction relation of a primary object with respect to a reference object, we require some type of frame of reference. In order to define direction relationships, different qualitative direction calculi are defined in literature pertaining to each types of references.

Freksa (Freksa, 1992) and Zimmermann and Freksa (Zimmermann and Freksa, 1996) study the qualitative spatial reasoning based on orientation between a point and a vector. Based on their study, 15 different relations can describe the directional relationship between a point and a vector. Figure 2.6 illustrates these relationships.

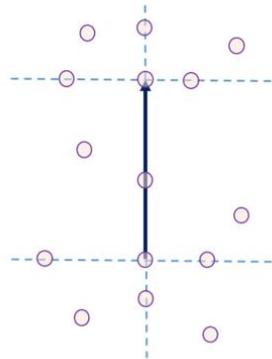


Figure 2.6. Relations between a point and a vector

Moratz et al. (Moratz et al., 2000) study the qualitative relations between two oriented line segments and identify a set of 24 atomic relations. These relationships consider the direction of each segment and create a 4 character value based on the location (right, left, on) of the start and end point of each segment to the other one. (e.g. As shown in figure 2.7 if the start and end points of segment A are to the right of segment B and start and end points of segment B are to the right of Segment A the relationship can be described as A rrrr B).

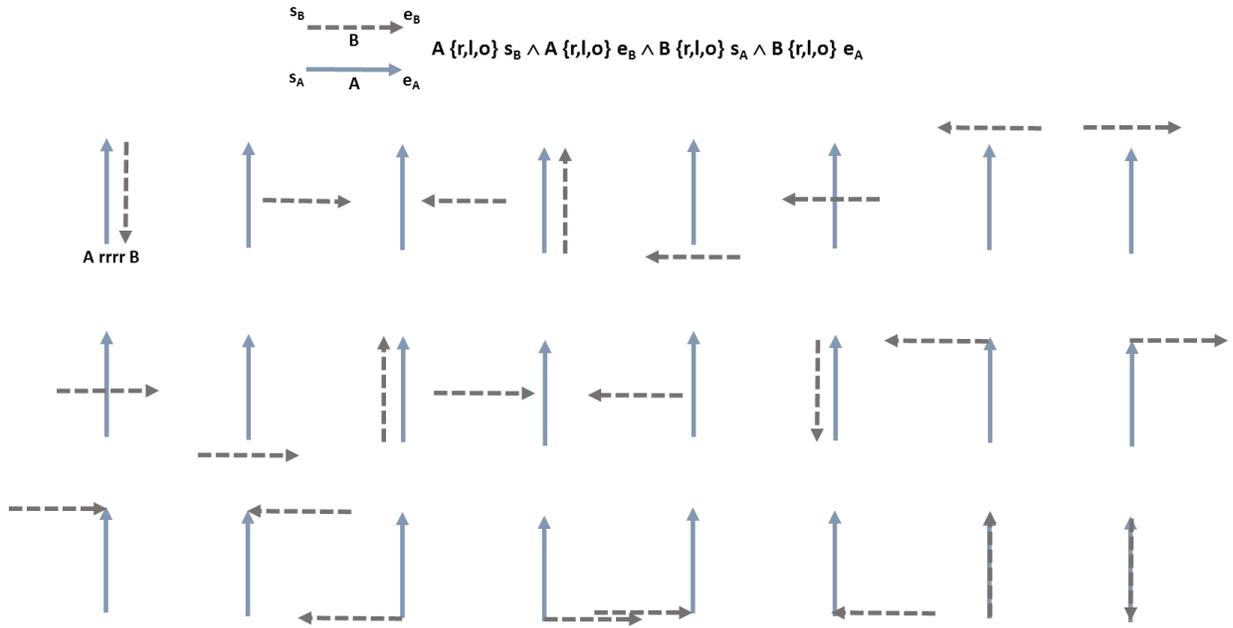


Figure 2.7. A set of 24 atomic relations between two oriented line segments (vectors)

Schlieder (Schlieder, 1995) develops a calculus which describes the relation between three points by qualitative values of anticlockwise (+), collinear (0), and clockwise (-) orientations. For three points A, B, and C if traversing from A to B to C is an anticlockwise traverse the value of the calculus will be positive (+), otherwise it will be negative (-) and if three points are on a line the value will be zero (0). Based on this work some 14 relations between two oriented line segments can be described, if collinearity is not taken into account. Figure 2.8 illustrates these relationships.

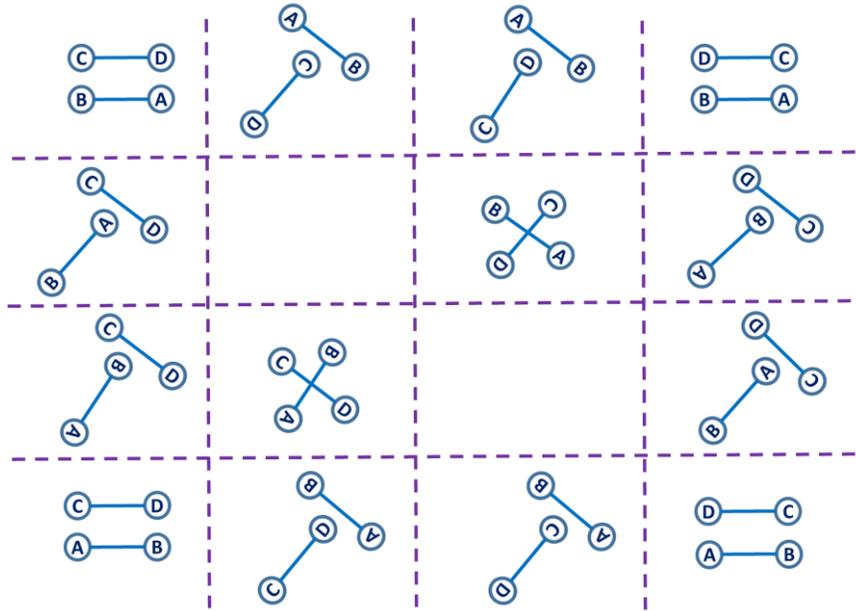


Figure 2.8. Schlieder's 14 line segment relations

Frank (Andrew, 1991), Frank (Frank, 1992), and Frank (Frank, 1996) study the deduction of distance and direction from A to C, given the distance and direction from A to B and B to C based on human understanding of cardinal directions of North, East, South, and West.

2.5.2.6. Shape

Shape is an important feature of an entity, although it is very complex and hard to describe qualitatively (Cohn, 1997; Cohn and Hazarika, 2001; Cohn and Renz, 2008). From a topological point of view, some quick statements can be made about the shape of an entity: whether it is simple or complex, weakly connected or strongly connected (Worboys and Duckham, 2004, pp.

113–117), has a hole or an island or not (Worboys and Duckham, 2004, pp. 184–187). Shape of the boundary (rounded or straight) and concavity vs. convexity of polygons can also describe the shape of entities. For some applications, bounding box or convex hull of the entity can also be used to represent the shape of the entity.

This chapter describes the motivation behind this research, the architecture of the developed platform, geometry recognition algorithms, the logical patterns identified between urban entities, the ontology developed for modeling relationships between conceptual entities, feature recognition algorithm, the interface designed for user interaction and finally the designed test to evaluate the output of developed sketch recognition framework.

3.1.Plan Your Place Initiative

The methodology used in this research is the outcome of a dozens of meetings and workshops that were conducted in our research group as “Plan Your Place” (PYP) initiative which led us to investigate the process of participation. The goal of these meetings and workshops were to understand needs and requirements of a functional framework to facilitate participation.

Appendix A shows a complete table of workshops and meetings.

A summary of discussions from meetings and workshops related to this research include:

1. For online participation the following tools are required: ranking, sketching/modifying, evaluating, and sharing of the plans generated by participants.
2. Requirement for a Standard Data Infrastructure (SDI) and web architecture (SOA vs. REST) is identified.

3. Platform Implementation should consider the following milestones with regards to participatory activities in the proposed platform:

- a. Informing, discussing, ranking, and mapping
- b. Evaluation of current conditions and proposed plans
- c. Development of sketching tools

4. Web-based process tools should include:

- a. A set of core tools for assessment of existing conditions and future developments
- b. Tools to be integrated into sketch functionality
- c. Three types of tools for: Connectivity, Visualization, and Evaluation

During the workshops the types of actions and use cases were established to be performed by public through a participatory web-based planning platform. User actions can be viewed as a collection of functional requirements for the platform (representing one component of the software development framework). Technical requirements of the platform led us to realization of components of our framework; including: 1- The legal environment within which the system must function, 2- Functional objectives of the framework, and 3- The technical implementation.

The legal component contains a set of constraints for platform development and its functionality: citizen identity (to avoid fraud), privacy, ownership (of information provided),

bylaw and regulations (where and when participation is sought), and licenses (for software and data that will be used).

Functional objectives component of the framework establishes the use cases in detail: participators should have access to documents relevant to planning process and proposals (e.g. maps, 3D visualizations, text document, images, and tables). Participants may also inform authorities of what they like or dislike in a community. They may use other social networking capabilities to leave comments, post documents (e.g. photos, videos, or audio files). They should be able to discuss the development options or planning proposals. Ranking and voting on planning options and comments by participants is another level of engagement. In order to address the engagement options and help participants to deliver a meaningful participation experience, the platform must incorporate design capabilities, such as: sketching of new ideas, and modification of existing proposals. And finally the platform should provide the participants with tools to evaluate the plans based on some descriptive metrics; such as: cost of services per household, walkability, expected transit use, anticipated household travel, distribution of land uses, etc.

The technical component of the framework shows what is required to implement the platform based on functional objectives and legal framework; these components include: Data, User

Interface (including: visualization, social networking, and sketching and evaluation functions), and Services.

This research focuses on developing appropriate sketching tools to help participants engage in a meaningful approach to the process of planning in their communities. Beside the mentioned scenarios in which a sketching tool can be used to provide new plans for the community of interest, these tools can also be utilized in following scenarios:

Define locations in your community/city that:

1. Requires development or redevelopment.
2. Should be preserved (form development, construction, etc.).
3. You like or dislike.
4. Are problematic (e.g. from aspects such as: noise, garbage, traffic, crime, etc.) or unsafe.
5. Were affected by the recent natural disaster (e.g. flood, earthquake, landslide, tsunami, volcano eruption, tornado, and so on).
6. Should be considered specifically (e.g. as downtown of the city).

PGIS applications provide opportunities for residents of communities to share their ideas, concerns and opinions about how their environments should be planned and developed or what is desirable/undesirable in their communities. In order to fully explore the opinions of participants,

data collection tools should check the compatibility of contributed ideas and diagrams against standards or defined patterns, to validate the contributions and to provide feedback about the implications of a particular contribution. To this end, PGIS tools should be equipped with spatial reasoning logic that extracts and validates relationships between entities created during a mapping and planning activity. Figure 3.1 illustrates the workflow of participation and the desired feedback provided to the participants in terms of geometry and feature recognition.

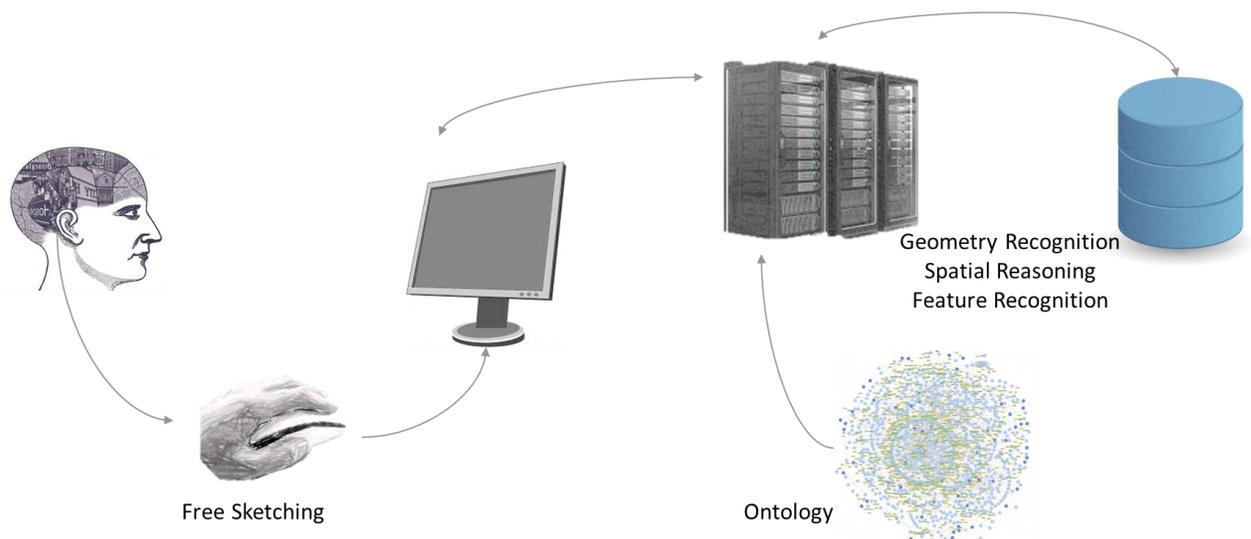


Figure 3.1. Participation workflow

This chapter is organized to show how different components (including: user interface design, ontology, spatial reasoning, and architecture) are deployed to create a platform (named

PYPsketch) capable of recognizing and interpreting the drawings and sketches of the users. In next sections the architecture of the PYPsketch platform and its components are elaborated.

3.2.Architecture

PYPsketch is based on client-server architecture. A web browser on the client side interacts with the user and collects the interaction in the form of map coordinates (longitudes and latitudes). Other parameters are also collected from the client side (e.g. zoom level). The collected input is sent to the server side where most of the analysis is performed on the input data. From this perspective, the architecture of PYPsketch platform is thin-client/thick-server.

The client has the duty of collecting the user's interaction, mostly through mouse events (e.g. mouse-down, mouse-move, mouse-up, and mouse-click). The client also provides context to the user in the form of tile maps equipped with base-layers to give the user a better context of the environment. The cartography of the layers and the precision of data play vital roles in the user's perception.

On the other hand, the server has the duty of analyzing the user's data and providing reasoning based on the ontology fed to it. The ontology is in the form of an XML (RDF) file containing tags, attributes, and content. Using RDF format, an ontology sentence in the form of

“subject-predicate-object” is converted to XML tags and contents. Properties in the ontology can be converted to attributes of tags.

The XML (RDF) file is provided to the server side. This file can vary based on the relationships that are valid for different contexts. So local relationships can easily be modeled as different ontology files. This feature makes PYPsketch flexible and scalable for a variety of applications.

The RDF file is then parsed as entities with properties and functions on the server side. One of the essential properties of each entity is the geometry type. When the geometry of the sketch is detected in the first part of recognition algorithm, the analyzer filters the ontology and fetches just those entities that match with the geometry type of the sketch.

The predicate in each ontology sentence should have an equivalent function on the server side; either a spatial function or a non-spatial function. Otherwise, that specific relation cannot be validated between the subject and the object.

Besides the functions on the server side, we need some base-layers against the features of which each sketch is examined. The features in these base-layers play the role of objects against subjects or vice versa.

So, when a sketch enters the analysis process it is examined against features from base-layers that fall in the bounding box of the sketch. The examinations are based on the functions declared

in the ontology. Most of these functions are topological in nature. So if the sketch satisfies the same relationships that are provided in the ontology for a specific subject, the subject will be chosen as a candidate feature for the sketch. Figure 3.2 represents the architecture of the PYPsketch platform.

In the next section geometry recognition is discussed as the first step of the proposed sketch recognition algorithm.

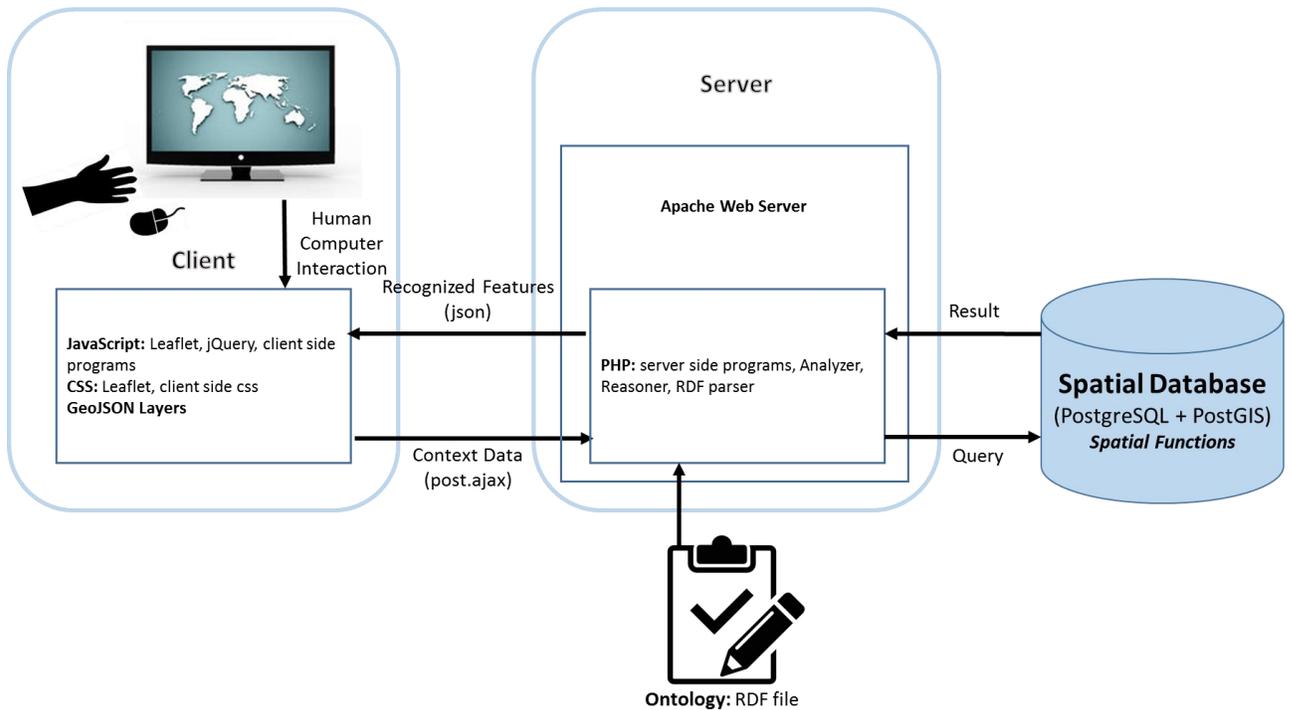


Figure 3.2. Architecture of PYPsketch platform

3.3.Geometry Recognition

During the interactions between users and the PYPsketch platform, several variables work together to facilitate geometry recognition. These variables include: zoom level, tolerance, vertices, length, distance, area, distance tolerance, area tolerance, and line-polygon criteria.

Zoom level returns to the scale of the map, extension of visible area on the map and level of details shown on the map. The higher the zoom level, the more details are shown and the less area is covered. The movement of the mouse also creates smaller/shorter sketches on higher zoom levels than on lower zoom levels. Figure 3.3 shows the downtown of City of Calgary at different zoom levels.



Figure 3.3. Calgary downtown at 3 different zoom levels

Lower zoom levels correspond to smaller scales and the higher zoom levels correspond to larger scales. The relation between zoom level and approximate scale is shown in table 3.1.

Table 3-1. Relation between Zoom Level and Scale

Level	~Scale	Level	~Scale	Level	~Scale	Level	~Scale
<i>0</i>	<i>1:500 million</i>	<i>5</i>	<i>1:15 million</i>	<i>10</i>	<i>1:500,000</i>	<i>15</i>	<i>1:15,000</i>
<i>1</i>	<i>1:250 million</i>	<i>6</i>	<i>1:10 million</i>	<i>11</i>	<i>1:250,000</i>	<i>16</i>	<i>1:8,000</i>
<i>2</i>	<i>1:150 million</i>	<i>7</i>	<i>1:4 million</i>	<i>12</i>	<i>1:150,000</i>	<i>17</i>	<i>1:4,000</i>
<i>3</i>	<i>1:70 million</i>	<i>8</i>	<i>1:2 million</i>	<i>13</i>	<i>1:70,000</i>	<i>18</i>	<i>1:2,000</i>
<i>4</i>	<i>1:35 million</i>	<i>9</i>	<i>1:1 million</i>	<i>14</i>	<i>1:35,000</i>	<i>19</i>	<i>1:1,000</i>

Tolerance is a selectable variable between 0 and 10 that affects other variables such as distance tolerance and area tolerance. This variable can be changed by the user for testing purposes.

The **vertices** variable shows the number of points in a sketch. If the sketch is done slowly there will be more vertices than when the sketch is done fast; so two equal sketches with different speed of drawing may have different number of vertices. The **length** variable refers to the overall length of the sketch and the **distance** variable is the distance between the first and the last point of a sketch. **Area** refers to the area of the concave hull containing the whole sketch.

Distance tolerance is a variable that works as a threshold to decide about the distance between the first and the last point of a sketch. If the distance between the first and the last point of a sketch is less than the threshold the sketch can be considered as a closed sketch (i.e. polygon), otherwise it will be recognized as an open sketch (i.e. polyline). The distance tolerance should be dependent on the user's eye resolution and since the user may work on different zoom levels, distance tolerance should be dependent on zoom level too. Through the tests we found that distance on screen is a function of 2 powered by zoom level. The relation between distance (both in longitude direction and latitude direction) and zoom level is illustrated in figure 3.4. In this figure a line on longitudinal direction from (50N, 113W) to (50N, 114W) and another line on latitudinal direction from (50N, 114W) to (51N, 114W) are measured on the screen at different zoom levels. The ground length of the first line is 71.47kms and the second line 111.2kms.

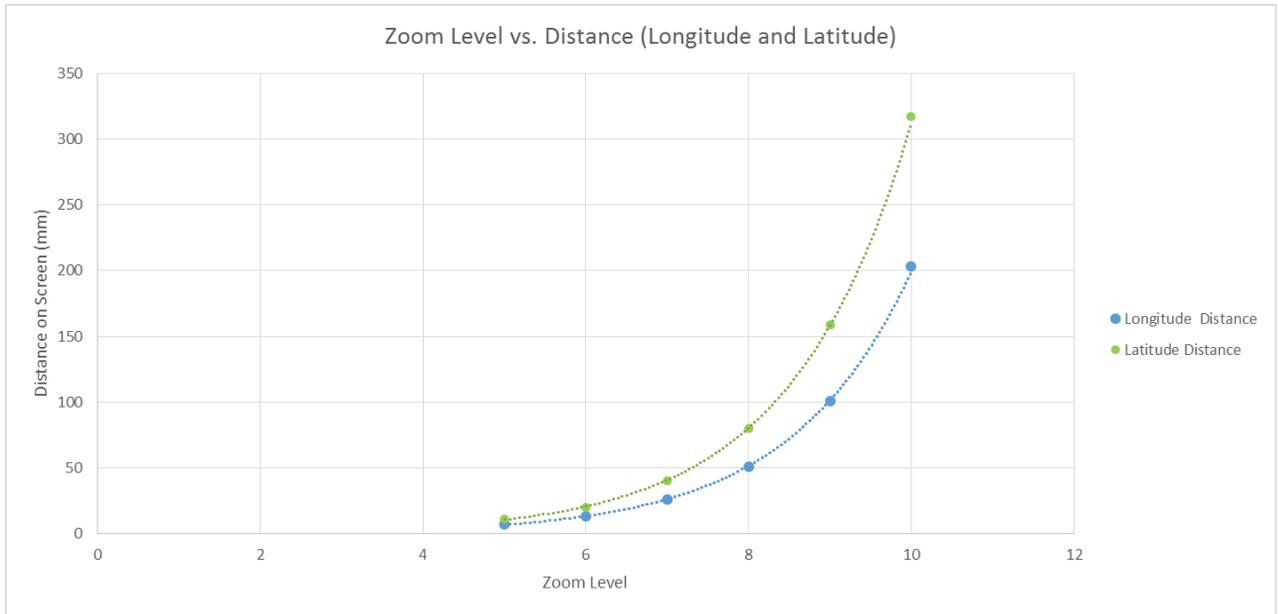


Figure 3.4. Relation between zoom level and distance on screen

The best curve that fits the latitude distance on screen as a function of zoom level comes as:

$$screen\ distance\ (mm) = 0.231 e^{0.676\ zoom\ level} \quad R^2=0.9997$$

Similar equation for longitude distances can be described as:

$$screen\ distance\ (mm) = 0.357 e^{0.676\ zoom\ level} \quad R^2=0.9997$$

These equations can be averaged as:

$$screen\ distance\ (mm) = 0.294 e^{0.676\ zoom\ level}$$

To convert the distance from screen to ground we can use this average equation considering the average distances on the ground which is $0.5(71.47+111.2) = 91.335$

So the relation between screen distance, ground distance and zoom level can be described as:

$$\text{screen distance (mm)} = \text{ground distance (km)} \frac{0.294 e^{0.676 \text{ zoom level}}}{91.335}$$

The importance of all these conversions is in that people usually perceive what they see on the map rather than actual ground distance; so it is important to find a relationship between what people perceive at different zoom levels to what actually is on the ground.

In order to define a distance tolerance function we know that on tile maps that are used on web-mapping applications, the size of the tiles doubles from one zoom level to another; thus the distance tolerance should be in reverse proportion with 2 powered by zoom level and if we assume zoom level 12 as the base of our measurements it should have reverse proportion with 2 powered by “zoom level - 12”. In order to give the testing participants flexibility to manipulate the “distance tolerance” we enter a tolerance variable (a value between 0 and 10) to the equation that can be changed by the user. Since tolerance can directly change the “distance tolerance” variable it should be in direct proportion. The following equation uses these concepts to find the value of distance tolerance:

$$\text{Distance Tolerance} = \frac{200 * \text{Tolerance}}{2^{(\text{Zoom Level}-12)}}$$

The value of 200 as coefficient in the equation helps to produce values from 0 to 2000 meters (on the ground) on online maps which is correspondence to the values between 0 and 14 centimeters on computer screens. In other words, the maximum distance tolerable to distinguish

between line and polygon is 14 centimeters if the zoom level is set to 12 and tolerance is set to its maximum value of 10. Figure 3.5 shows a 3D plot of distance tolerance as a function between tolerance and zoom level.

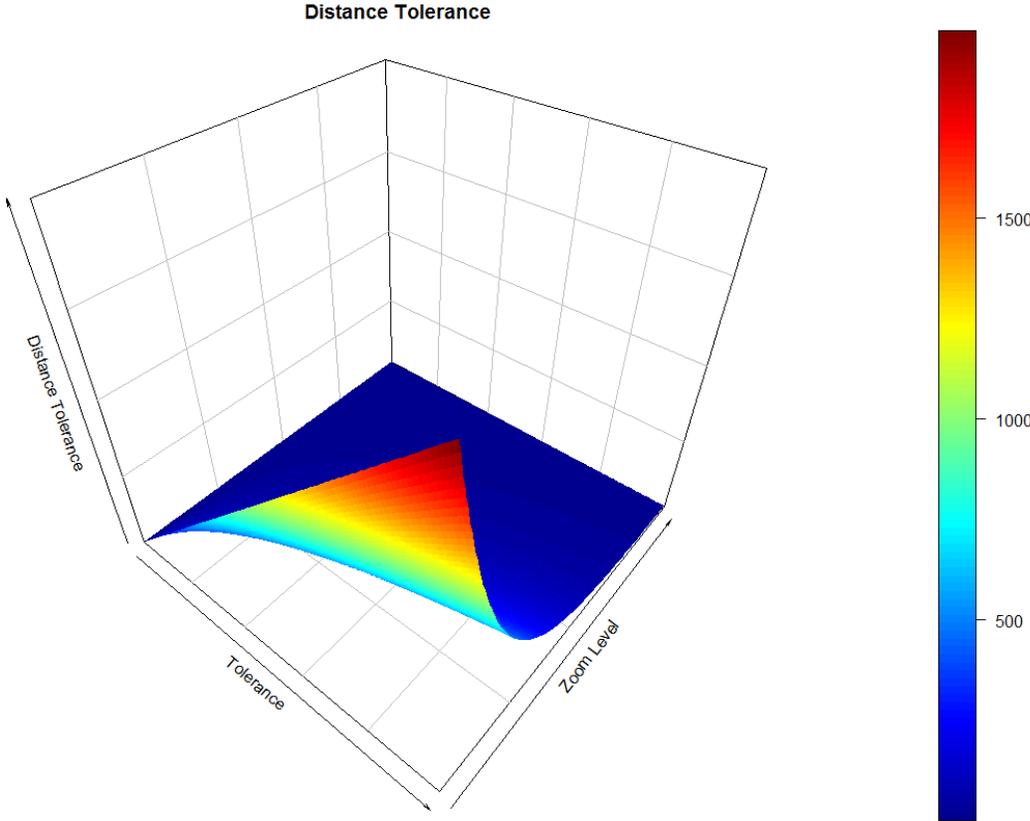


Figure 3.5. Distance tolerance as a function of tolerance and zoom level

It is important to note that the distance tolerance value should be changed based on the latitude of the location when using WGS84 Web Mercator (EPSG: 3857) coordinate system for online maps. Figure 3.6 depicts how distance changes between two points that are 1 degree away from each other at different latitudes. Our test area was located approximately on 51° north, but for other regions this value should be adjusted for the latitude as well.



Figure 3.6. The L shaped Objects are 1 Degree Wide in both Directions

The effect of different distance tolerance can be seen on figure 3.7 where two sketches with the same shapes are recognized differently based on the distance tolerance: one as a polyline and the other one as a polygon.

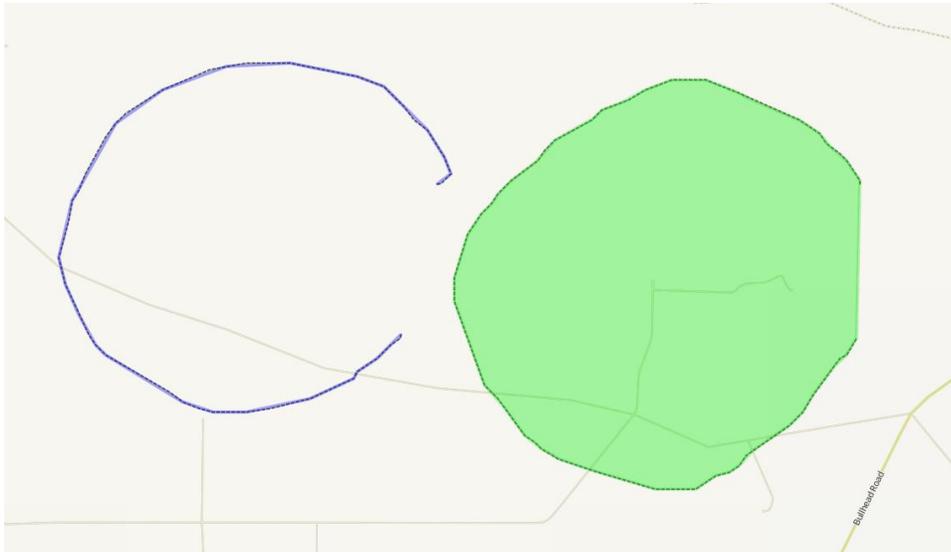


Figure 3.7. The effect of distance tolerance on geometry recognition on similar sketches (right is recognized as polygon and left as polyline)

Area tolerance is a variable that works as a threshold to determine whether a sketch is a point or a polygon. If the area of a sketch is less than this value it is recognized as a point; otherwise it is recognized as a polygon. The following equation shows how area tolerance is calculated:

$$\text{Area Tolerance} = \frac{2400 * \text{Tolerance}}{2^{(\text{Zoom Level}-12)}}$$

Area tolerance is also a variable that changes reversely with 2 to the power of “2 times zoom level”. Figure 3.8 shows area tolerance as a function of zoom level and tolerance in a 3D model. This tolerance value covers areas between 0 and 25000 square meters (25000 square meters on the ground is almost correspondent to a rectangle of 2mm by 3mm in zoom level of 12 which is the lowest zoom level tested in this research).

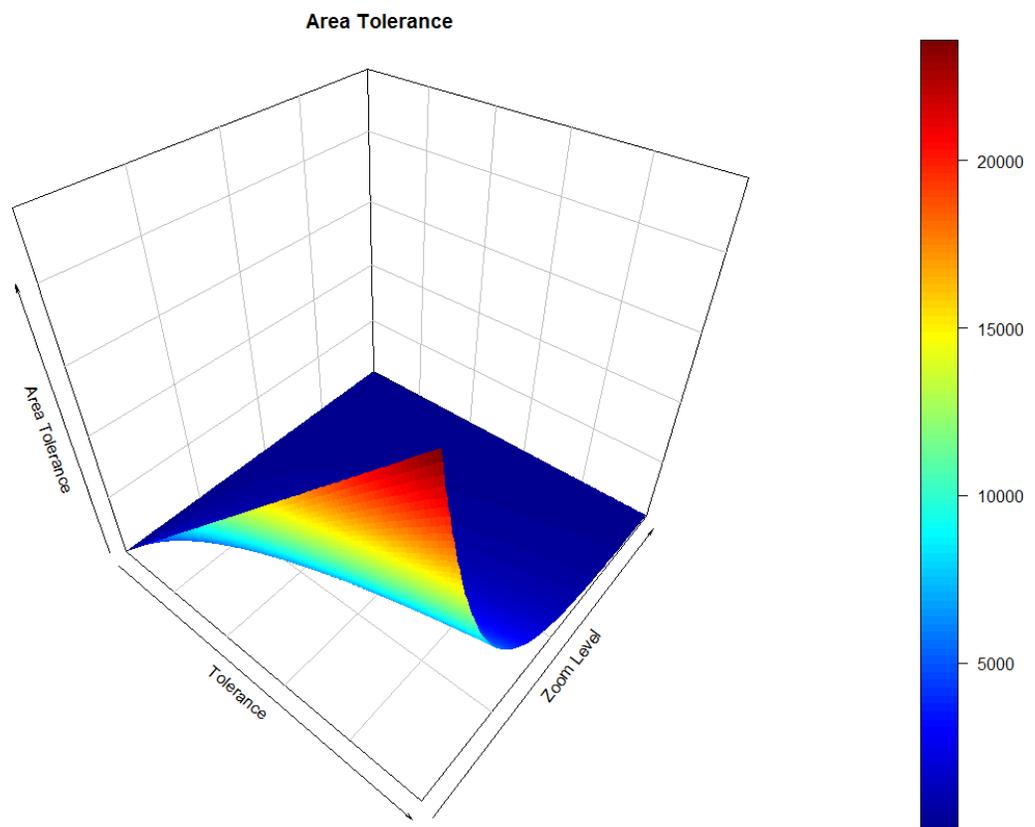


Figure 3.8. Area tolerance as a function of tolerance and zoom level

The effect of different area tolerance can be seen on figure 3.9 where two sketches with the same shapes are recognized differently based on the area tolerance: one as a point and the other one as a polygon.

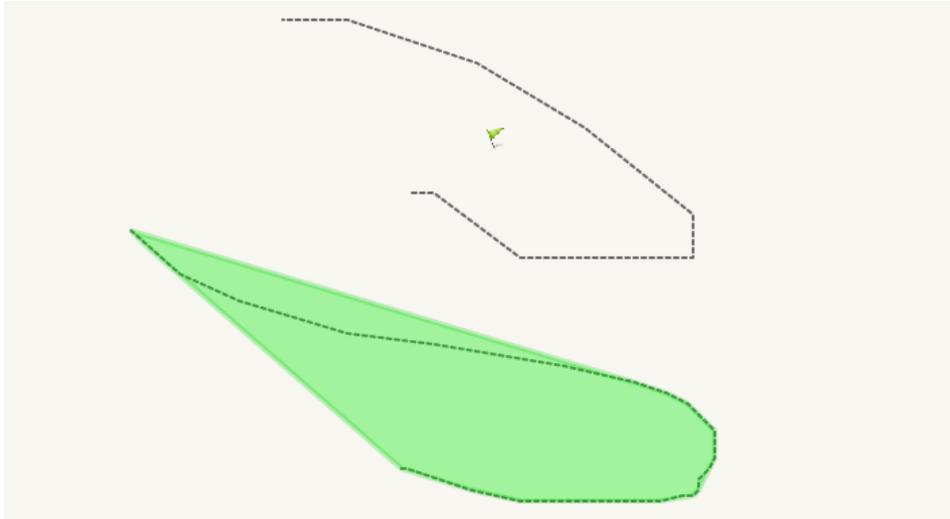


Figure 3.9. The effect of area tolerance on geometry recognition of similar sketches (top as point and bottom as polygon)

Line-Polygon criteria is a variable that distinguishes a polyline from a polygon. This criterion takes into account the length of sketch, number of vertices, area that sketch occupies, and the zoom level of the map. The following equation shows how line-polygon criteria is calculated:

$$\text{Line - Polygon Criteria} = \frac{\text{Length} * \text{Vertices}}{(\text{Area} + \varepsilon) * 2^{(\text{Zoom Level} - 12)}}$$

Where $\varepsilon=1.00$

This criterion is used with distance tolerance for geometry recognition purposes. If for a sketch the distance is more than the distance tolerance and line-polygon criteria is less than 0.25, then the sketch is categorized as polyline. The value of 0.25 is achieved based on some preliminary tests. Two lines with similar lengths may have different number of vertices, since vertices can increase as the shape of the line becomes complicated.

In the Line-Polygon Criteria equation the ε parameter is a small value used to avoid dividing by zero when the area of the shape is equal to zero.

In figure 3.10 the right-most sketch has a higher value for this criteria compared to two left sketches, so it is recognized as a polygon rather than a spiral polyline. This criterion is useful for recognizing the sketch of people who tend to draw a polygon by filling the inside of it rather than by drawing the boundary of it.



Figure 3.10. The effect of line-polygon criteria on geometry recognition

The algorithm to recognize the geometry works as follows: based on the number of vertices in the drawing, it is distinguished if the sketch is a “Point” or not. If this value is less than 3 the interaction is just a click which means the sketch is just a point. However if this value is equal or more than 3 other parameters such as distance between first and last point in the sketch, area of the sketch and density of the points in the sketch should be considered. Smaller areas than area tolerance and smaller distances than distance tolerance can also lead to recognition of the sketch as a point. But if the distance is still smaller than the distance tolerance but area is bigger than area tolerance the sketch is recognized as polygon, otherwise as point. The line-polygon criteria can be used to decide if a dense sketch is a polygon or not. The geometry recognition algorithm flowchart is represented in figure 3.11.

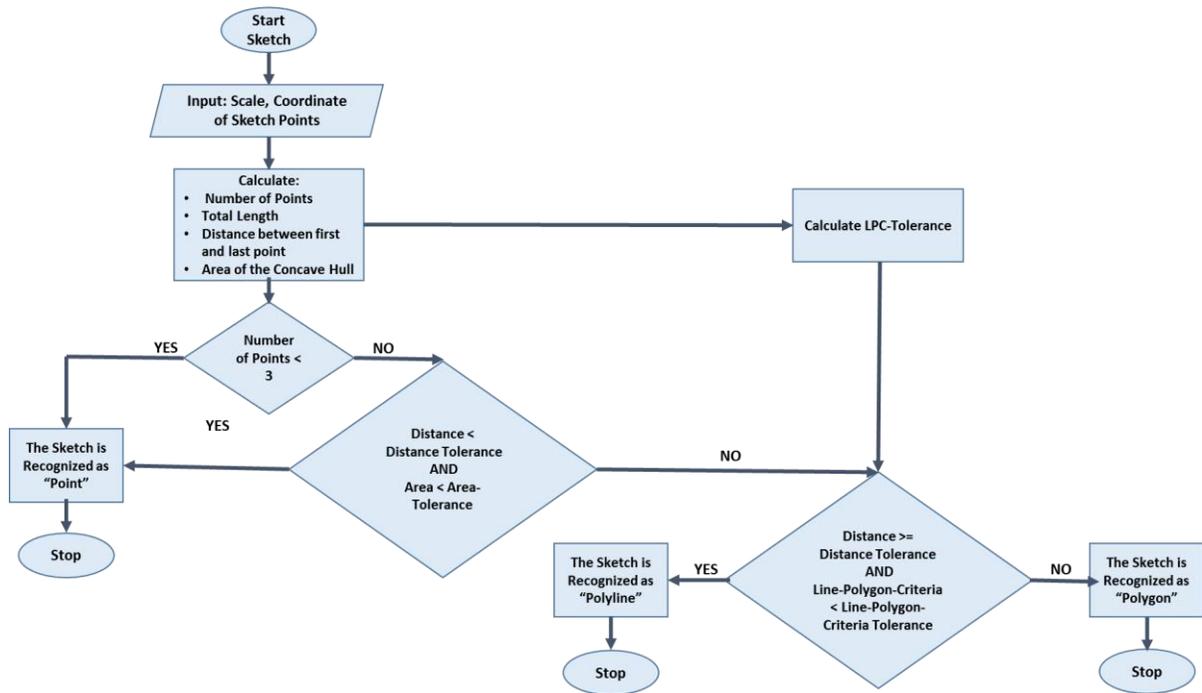


Figure 3.11. Geometry recognition algorithm

Besides the type of geometry, the urban feature types also need to be recognized. For this purpose, an understanding of urban feature types and their relationships with other features is required. “A Pattern Language” book by Christopher Alexander (Alexander et al., 1977) is considered as the main source for this purpose. Based on Alexander’s book, 253 different patterns can be considered for urban planning at different scales and levels of detail. 94 of these patterns illustrate relations between public space urban features that are common in towns. The

rest of the book studies patterns in buildings and construction, which are not of interest of this study.

Urban patterns were studied in detail with a focus on spatial aspects, to find the geometrical, topological and semantic relationships that help establish the ontology for this study. A summary of these patterns is provided in the next section. These patterns are general patterns that may not necessarily be required in a specific community or city, but it shapes the overall structure of planning that other specifications may occur in. For example, it provides the general aspects of a major road, but if a road in some community is restricted by its distance from a hospital, new specifications should be considered and added to ontology accordingly.

3.4.A Pattern Language

The first pattern is **Independent Regions**, which refers to autonomous areas with natural and/or geographic boundaries containing populations between 2 and 10 million, with their own economy and government.

Inside Independent Regions the population is distributed in **Towns/Cities** to create self-sufficient areas. Cities should have proper interlocking connections with rural lands through **City-Country Fingers**. Inside Independent Regions, **Farmlands** and **Agricultural Valleys**

should be protected from any developments. Countries should be connected to cities by **Lace of Country Streets**. In order to support the even distribution of towns, **Small Towns/Country Towns** with self-contained economies should be preserved. Cities need to have access to **Countryside**. Countryside includes: farmlands, parklands, forests, deserts, grazing meadows, lakes, and rivers.

A city is made of (mosaicked by) a large number of **Subcultures** which are relatively small in size, each occupying an identifiable place and separated from other Subcultures by a boundary of non-residential land. The **Subculture Boundary** can be natural (e.g. wilderness, farmland, water) or man-made (e.g. railroad, major road, park, school or housing). **Workplaces** should be scattered with short walking distances from homes, children and families. Each city should have one **Center (Magic of the City)** for each 300'000 people, with distributions proportional to the density of the population. Towns should be divided into **Local Transport Areas** of about one to two miles across surrounded by a ring road. There should be minor local roads and paths for internal movement within the local transport areas.

Communities can give people a voice and let them participate in the government of their area. Communities should be adjacent sharing natural, geographic or historical boundaries. Communities can also be divided into small identifiable **Neighborhoods**. Neighborhoods should

be protected from heavy traffic by preventing major roads from passing through. Each Neighborhood should have a strong **Boundary** to maintain its identifiable character.

Different transportation modes should be connected together in a **Web of Public Transportation**. Public transportation must be able to take people from any point to any other point with the means of **Mini-Buses**. High speed **Ring Roads** should be designed in a way that never splits a community, to allow local people access to the countryside without crossing the road, and to make neighborhoods sound proof. Also, high speed roads should lie tangent to each local transport area in a way that ensures local areas are not bounded at least from one side. The roads should also be shielded to protect the neighborhoods from noise. The public transportation needs **Interchanges** to function properly. Interchanges should be surrounded by workplaces and houses. Their interior should be kept continuous and their exterior should be connected by pedestrian networks.

Education should be decentralized by **Networks of Learning** from schools to many places in the city. Shops in cities should locate themselves where they are needed in a **Web of Shopping** with the idea that each unit of shopping has a certain catch basin.

In an urban area, the majority of buildings should be kept **four stories** high or less. Not more than 9 percent of the land in any given area should be used for **Parking**. Major roads should not intersect each other; instead a system of **Parallel Roads** should be designed to carry traffic to the

ring roads. **The Sacred Sites** should be preserved in any place either big or small, in towns or in the countryside. **Water Bodies** should be given access, however a belt of common lands should be preserved immediately beside the water. Cities should be designed to preserve the **Life Cycle** by providing for a balance of people at every stage of life. Environments should be built for both **Men and Women**.

On the boundary of each community closest to the nearest major urban center is the **Eccentric Nucleus**. Around each nucleus are **Density Rings**. These rings represent change in the density of the population from the nucleus. **Activity Nodes** should spread over communities. These nodes should be connected to each other by walking paths. Beside Activity Nodes, each Subculture needs a center for its public life called the **Promenade**; a place where people can go to see other people. Local shopping centers should grow in the form of short pedestrian **Shopping Streets**, at right angles to major roads and the opening of these roads, with parking behind the shops. **Night Life** in a city is composed of amusements, services, hotels, and bars that are open at night. These types of evening centers should be distributed evenly across the town.

A **Mix of Households** is preferred for a community including: one-person, families with children, and group households. Houses have different **Degrees of Publicness**. Some are on the quiet side, some are on busy streets and some are more or less in between. Also houses should form a very rough but identifiable **Clusters** of 8 to 12 households around some common land or

path. **Row Houses** are also essential along pedestrian paths that run at right angles to local roads and parking lots. **Housing Hills** or apartments are essential in areas that people for any reason would like to live in high densities with 30 to 50 household per acre. Besides different type of houses **Dwellings for Old People** should be considered in every community to keep old and young people in touch, and to prevent older people from becoming isolated.

Work Communities are collections of smaller clusters of workplaces with their own courtyards. **Industrial Ribbons** should be placed in the boundaries between communities. A **University** should be considered as a marketplace of higher education, open to people of all ages. Each community should have a **Local Town Hall** to allow local government and control by inhabitants. The Local Town Hall should host **Community Projects** for political works, trial services, researchers, and advocacy groups. Establish frequent **Marketplaces**, each one with many smaller autonomous and specialized shops, rather than modern supermarkets. **Health Centers** should be decentralized to be accessible by people. The separated areas should be filled with **Housings** to make more lively communities.

Looped Local Roads provide access to houses but prevent fast through traffic. **T-Junctions** reduce the chance of accidents and are recommended for road intersections. Local roads should turn into **Green Streets** where the through traffic is closed. **Networks of Paths and Cars** is a place where urban life occurs. The roads and pedestrian paths systems should be kept separate,

but meet frequently at focal points. The boundary of a community, a neighborhood, or a precinct should have a **Main Gateway** where the major entering paths cross the boundary. **Road Crossings** should be kept safe and marked for pedestrians who want to cross to the other side. However pedestrian paths along a road carrying fast traffic should be **raised**. Building independent systems for **Bike Paths and Racks** can also be considered as a solution for the problem of conflict between cars and bikes, however it may be less desirable. Extra safe paths also should be developed for **Children in the City**.

Each community or neighborhood should contain some public open land such as: **Carnivals, Quiet Backs, Accessible Green Areas, Public Squares, High Places/Landmarks, Raised Platforms for Dancing, Pools and Streams, Birth Places, and Holy Grounds** where people can relax, rub shoulders and renew themselves.

Each house cluster or work community should have some common areas such as: **Common Lands, Connected Playgrounds, Public Outdoor Rooms, Grave Sites, Still Waters, Local Sports, Adventure Playgrounds, and Animal Stables** to provide relaxing environment for local people and pets.

There are other patterns that concern the different types of houses, such as: **The Family House Clusters, Houses for Small Families, Houses for Couples, and Houses for One Persons**. Others concern workplaces: **Self-Governing Workshops and Offices, Small Services,**

Office Connections, Teenage Societies, Shopfront Schools, Children’s Home. While other patterns deal with local shops and gathering places; such as: **Individual Owned Shops, Street Cafes, Corner Groceries, Beer Halls, Traveler’s Inns, Bus Stops, Food Stands, and Public Sleeping Places.**

Reviewing these patterns exposes a great amount of geometrical, topological, and semantic properties (emphasized by underlines) of individual urban features (emphasized by bold fonts) and their mutual relationships with other features. Some of these relationships are explicit and can be extracted easily (e.g. communities share same boundaries or a bridge crosses a river), while others are implicit or require more investigation (e.g. even distribution of schools in a town).

Extracting the properties of urban features and their relationships creates the backbone of the ontology in this study. The ontology includes 94 different urban entities with their geometric, topologic and semantic relationships. The ontology is then used for reasoning for feature recognition.

3.5. Ontology

The creation of an ontology requires the definition of its components. Components of ontologies include: Classes, Objects, Attributes, Relations, Rules, and Axioms. In this research, primary geometrical types (e.g. point, polyline, polygon), and urban feature types (e.g. road, school, bridge) at different scales (e.g. small, medium, and large) represent classes containing samples or objects of the classes (e.g. Peace bridge in Calgary). Classes are composed of attributes and functions in the forms of relations with other classes, rules, or axioms. Relations, rules and axioms are used to define the hierarchy of the classes and organize them in a superclass-subclass network.

The relationship between two classes can be modeled using “subject-predicate-object” expression. The subject denotes the resource, while predicate expresses the relationship with object or behaviour of subject. Each object or subject can possess as many properties as possible. The fact that properties can be added helps us to put constraints on objects (e.g. a house is a polygon at small scales, but a point at large scales).

The relationships modeled in ontology include: geometric, topologic, and semantic relationships. Geometric relationships model the relation between the entity and one of the basic geometrical components (e.g. point, polyline, or polygon). Topologic relationships model the

spatial logic and relationship of the subject and object in the statement, and semantic relationships model the meaning and logic behind the existence of the entities. For example, in the triple statement of “A house is inside a Community” we can detect the following components: “A house” as subject, “is inside” as predicate, and “a community” as object. “A house” is geometrically a polygon, so is “a community”. “is inside” indicates the topological relationship, while the whole concept of “a house being inside a community” is the semantic, as for instance, a house cannot be outside a community or on its boundary in an urban structure of interest. Figure 3.12 illustrates how top level classes of entities are related to each other ontologically to shape the relationships between these concepts. Each urban feature at any scale has a geometry. Urban features are related to each other by semantic or topologically.

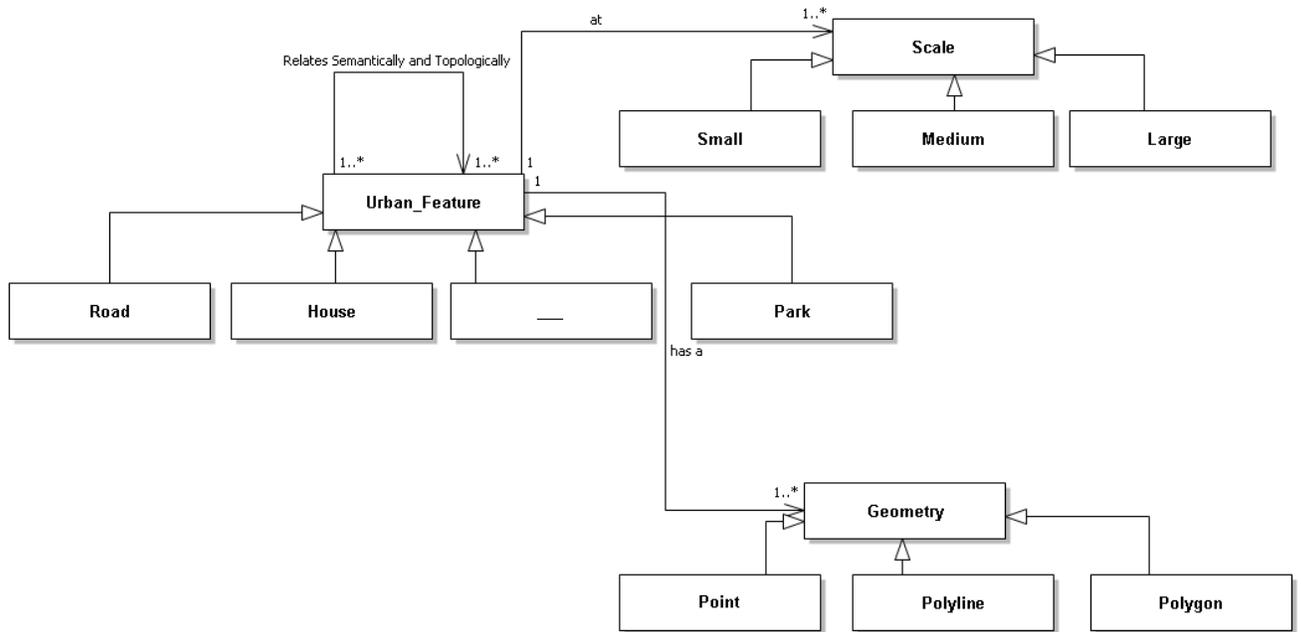


Figure 3.12. Application Ontology

Utilizing Protégé software entities and their relationships were brought together to create the ontology (i.e. knowledge base) of urban features. The result is exported as an RDF file, which is essentially an XML file that can be easily read and parsed for information extraction.

In order to recognize the feature type, the relations between the sketch and other features are compared to the relations that are given in the ontology and if these relations match appropriately with one or more features in the ontology, the sketch will be recognized as either subject or object of the class for which it provides a match.

3.6. Spatial Reasoning

Some of the major concepts that play a role in the proposed ontology include: scale, conceptual hierarchy, topological relationships, and attributes. The topological relationships between objects of different classes are the heart of reasoning; in order to match any sketch with a pattern we need to confirm if these topological relationships also exist. It is crucial to acknowledge that one spatial reasoning rule alone cannot distinguish an object from other. A group of rules should work together to help recognize an object.

Complex relationships can be decomposed into basic relationships and used in spatial reasoning process. The spatial reasoning engine of PYPsketch application relies on PostGIS functionalities. In this section some of the major topological methods that are used to examine the relationships between a sketch and other features are investigated. These functions include: Contains, Contains Properly, Covers, Covered By, Touches, Crosses, Overlaps, Within, Within Distance, Fully Within Distance, Equals, Intersects, Disjoint and Relate. Although the output and process of functions may differ based on dimensional considerations and definition of point, line, and polygon, the functionality of each method is described in the following section:

- First object **contains** second object if and only if no points of the second object lie in the exterior of the first object, and at least one point of the interior of the second object lies in the interior of the first object.
- First object **contains properly** second object if the second object intersects the interior of the first object but not its boundary or exterior. An object does not contain properly itself, but does contain itself.
- First object **covers** second object if no point in the second object is outside the first object.
- First object is **covered by** second object if no point in the first object is outside the second object.
- One object **touches** another object if the geometries of both objects have at least one point in common, but their interiors do not intersect.
- One object **crosses** another object if both objects have some, but not all, interior points in common.
- Two objects **overlap** if the specified objects share some space of the same dimension, but are not completely contained by each other.

- First object is **within** second object if the first object is completely inside the second object.
- Two objects are **within a distance** if the specified objects are within the specified distance from each other.
- Two objects are **fully within a distance** if the specified objects are completely within the specified distance of one another.
- Two objects are **equal** if the specified objects represent the same geometry.

Directionality is ignored.

- Two objects **intersect** if the objects spatially intersect in 2D and returns false if the objects are disjoint.
- Two object are **disjoint** if the objects do not spatially intersect.
- How two object **relate** to each other is a DE-9IM matrix describing the intersection between interior, boundary, and exterior of the specified geometries.

Next section clarifies how a combination of these functions can be used to distinguish some of the topological relationships between two geometries.

First, we investigate topological relationships between two polygons. The assumption here is that polygons are simple (i.e. with no island, with no boundary intersection, without multiple

components) however these rules can be extended to complex polygons and multipolygons.

Topological relationships between two polygons are illustrated in figure 3.13 and the results of

topological functions are presented in table 3.2. The highlights of these relationships are:

- “Disjoint” and “Intersect” are mutually exclusive relationships.
- There is no “Cross” relationship between two polygons.
- “Touch” happens when two polygons share some part of their boundaries but no

interiors.

- A1 contains properly B4, but not B5.
- B3 and B6 have the same relationships with A1. Their DE-9IM matrices are also

the same.

- Except for B3 and B6 which have the same relationships, other combinations can be easily distinguished from each other either using some combination of functions or the “Relate” (DE-9IM) function directly.

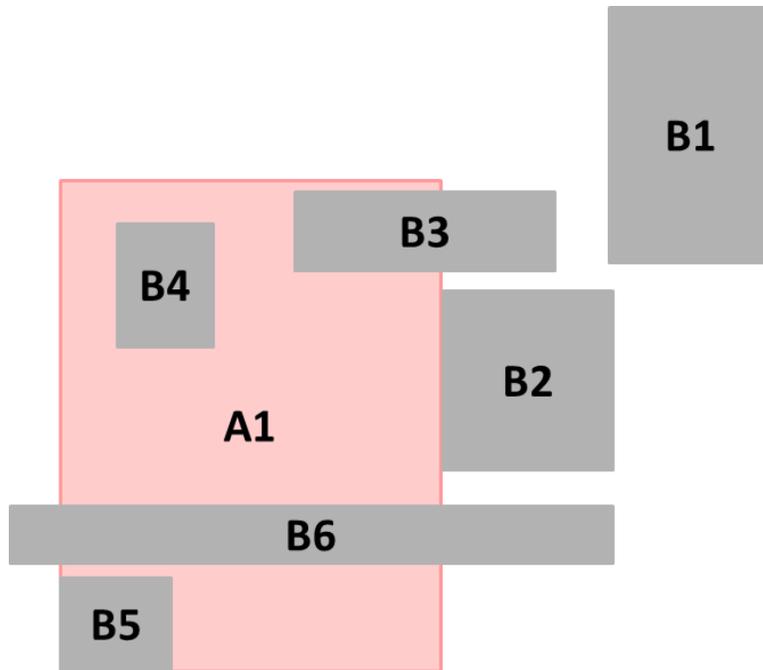


Figure 3.13. Topological relationships between 2 polygons

Table 3-2. PostGIS function results for topological relationships between 2 polygons

Polygon	A1	A1	A1	A1	A1	A1
Polygon	B1	B2	B3	B4	B5	B6
contains	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE
Contains properly	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
covers	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE
covered by	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
touches	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
crosses	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
overlaps	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
within	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
equals	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
intersects	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
disjoint	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
relate	FF2FF1212	FF2F11212	212101212	212FF1FF2	212F11FF2	212101212

Next, we investigate topological relationships between a polygon and a polyline. Here, polygons are assumed to be simple, as are polylines. However, the same rules can be extended for complex geometries. In figure 3.14 topological relationships between a polygon and a polyline are illustrated and the results of topological functions are presented in table 3.3. The highlights of these relations are:

- “Disjoint” and “Intersect” are mutually exclusive.
- A polyline “Crosses” a polygon if it shares some parts with both interior and exterior of the polygon and intersects with its boundary.
- If some part of a polyline is on the boundary of a polygon or its endpoint is on the boundary, then the polyline “touches” the polygon.
- Although the result of functions on different polylines are the same (e.g. B2 and B7 have the same relationships with the polygon, and B3 and B6 also have the same relationships), but the DE-9IM matrix is unique for each relationship.

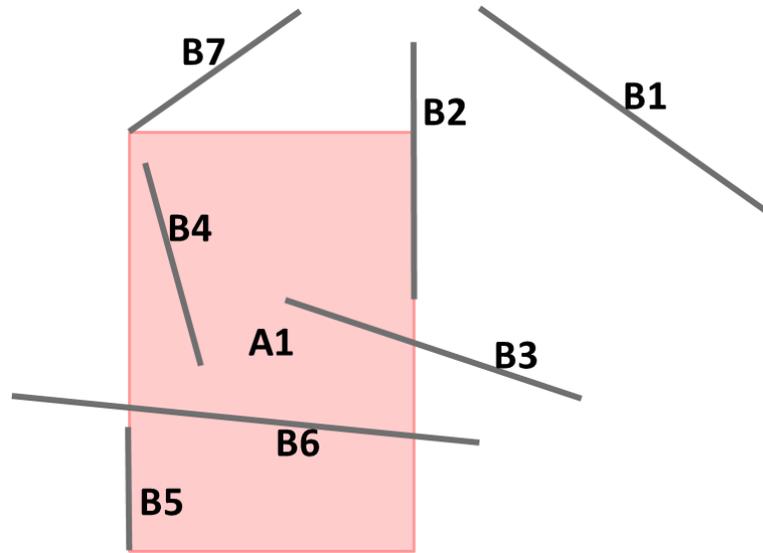


Figure 3.14. Topological relationships between a polygon and a polyline

Table 3-3. PostGIS function results for topological relationships between a polygon and a polyline

Polygon	A1	A1	A1	A1	A1	A1	A1
Polyline	B1	B2	B3	B4	B5	B6	B7
contains	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
contains properly	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
covers	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
covered by	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
touches	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
crosses	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
overlaps	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
within	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
equals	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
intersects	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
disjoint	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
relate	FF2FF1102	FF2101102	1020F1102	102FF1FF2	FF2101FF2	1F20F1102	FF2F01102

Next, we investigate topological relationships between a polygon and a point. The relation between a simple polygon and a simple point is more restricted. A point can be inside a polygon, on its boundary or out of the polygon. In figure 3.15 topological relationships between a polygon and a point are illustrated and the results of topological functions are presented in table 3.4. The summary of these relationships is:

- A point either “intersects” with a polygon or is “Disjoint” from it. Both situations are not possible together.
- A point on the corner of a polygon has exactly same relationships as any point on the boundary of the polygon. Even their DE-9IM matrices are the same.
- A point inside a polygon is both contained (even “Contained Properly”) and covered by the polygon; but a point on the boundary of a polygon is just covered by that polygon.

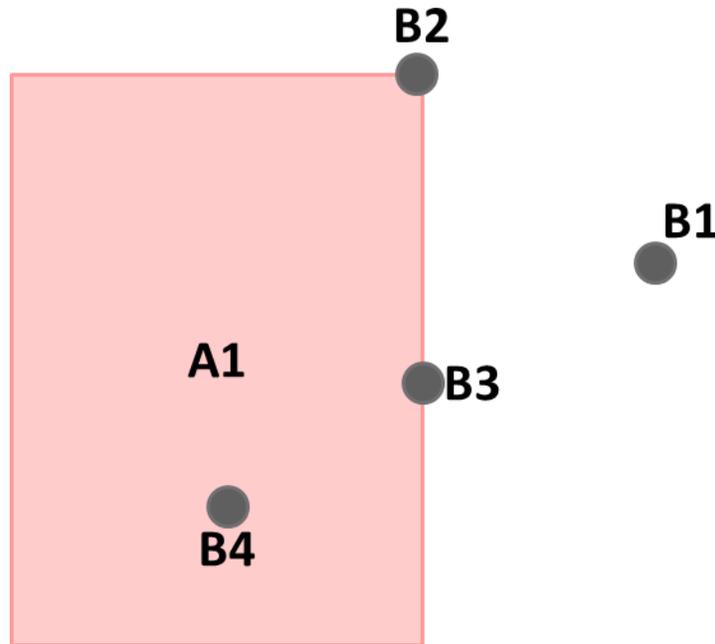


Figure 3.15. Topological relationships between a polygon and a point

Table 3-4. PostGIS function results for topological relationships between a polygon and a point

Polygon	A1	A1	A1	A1
Point	B1	B2	B3	B4
contains	FALSE	FALSE	FALSE	TRUE
contains properly	FALSE	FALSE	FALSE	TRUE
covers	FALSE	TRUE	TRUE	TRUE
covered by	FALSE	FALSE	FALSE	FALSE
touches	FALSE	TRUE	TRUE	FALSE
crosses	FALSE	FALSE	FALSE	FALSE
overlaps	FALSE	FALSE	FALSE	FALSE
within	FALSE	FALSE	FALSE	FALSE
equals	FALSE	FALSE	FALSE	FALSE
intersects	FALSE	TRUE	TRUE	TRUE
disjoint	TRUE	FALSE	FALSE	FALSE
relate	FF2FF10F2	FF20F1FF2	FF20F1FF2	0F2FF1FF2

Next, we investigate topological relationships between two polylines. Two simple polylines can have a variety of relationships with each other. In figure 3.16 topological relationships between two polylines are shown and the results of topological functions are presented in table 3.5. A polyline may be composed of different segments; each segment may have one of the relationships below with other polyline segments. We can summarize these relationships as follows:

- “Intersect” and “Disjoint” relationships are mutually exclusive.
- If a polyline is part of another polyline their relationships are “Contains”, “Contains properly” and “Covers” (B1); but if they just share some parts, their relationship is just “Overlaps” (B6).
- A polyline can “Cross” another polyline (B4).
- If an end point of one polyline intersects with an end point of another one, or some point on the line, the relationship is of type “Touch” (B2 and B5). However, their DE-9IM matrices are not the same.
- Each combination of polylines has a unique DE-9IM matrix, which can help distinguish between the types of relationships.

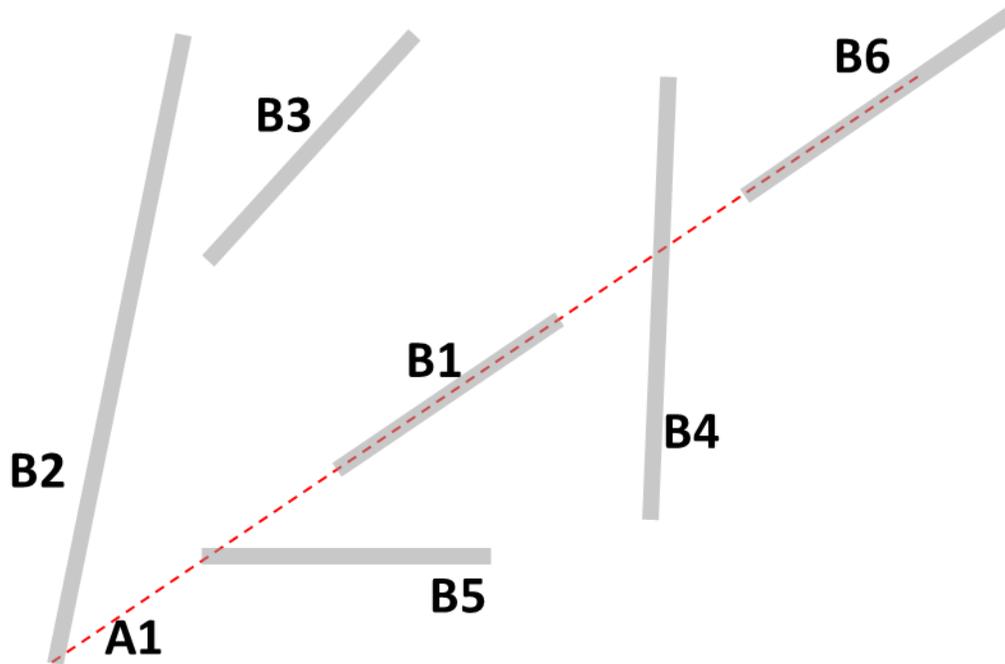


Figure 3.16. Topological relationships between 2 polylines

Table 3-5. PostGIS function results for topological relationships between 2 polylines

Polyline	A1	A1	A1	A1	A1	A1
Polyline	B1	B2	B3	B4	B5	B6
contains	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
contains properly	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
covers	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
covered by	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
touches	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
crosses	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
overlaps	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE
within	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
equals	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
intersects	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE
disjoint	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
relate	101FF0FF2	FF1F00102	FF1FF0102	0F1FF0102	F01FF0102	1010F0102

Finally, we investigate topological relationships between a polyline and a point. In figure 3.17 topological relationships between a polyline and a point are shown and the results of topological functions are presented in table 3.6. These relationships are constrained to just three cases. A point is either on a line, at an end point of a line or out of a line. Topological relations can be summarized as:

- If a point is part of a line it “Intersects” with the line; otherwise, it is “Disjoint” from the line. “Intersects” and “Disjoint” are mutually exclusive.
- If a point is an end point of a line it “Touches” the line and is “Covered” by the line.
- If a point is on the line, but is not an end point of it then the line “Contains” (and “Contains Properly”) and “Covers” the point.
- The DE-9IM matrix for each of these cases is unique and can be used to distinguish the type of topological relationship between a point and a line.

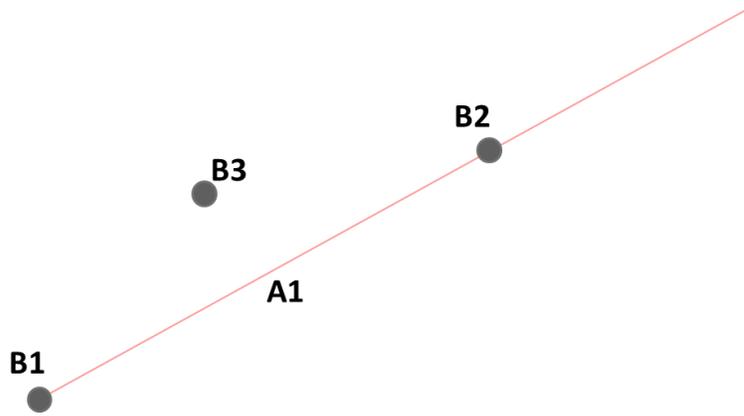


Figure 3.17. Topological relationships between a polyline and a point

Table 3-6. PostGIS function results for topological relationships between a polyline and a point

Polyline	A1	A1	A1
Point	B1	B2	B3
contains	FALSE	TRUE	FALSE
contains properly	FALSE	TRUE	FALSE
covers	TRUE	TRUE	FALSE
covered by	FALSE	FALSE	FALSE
touches	TRUE	FALSE	FALSE
crosses	FALSE	FALSE	FALSE
overlaps	FALSE	FALSE	FALSE
within	FALSE	FALSE	FALSE
equals	FALSE	FALSE	FALSE
intersects	TRUE	TRUE	FALSE
disjoint	FALSE	FALSE	TRUE
relate	FF10F0FF2	0F1FF0FF2	FF1FF00F2

Beside these spatial reasoning rules, in this research some other rules are investigated that can be seen between urban entities. These specific urban relationships are the backbones of patterns

that can be found in a functioning urban area. Some of them may seem to be simple relationships, but to model them more than one operation is required. Following is some of the specific relationships between urban entities:

1. Workplaces should be in 20 to 30 minutes of houses. This relationship is about the **maximum distance** (Hausdorff distance) between two entities or two cluster of entities.
2. A town should **be mosaicked by** communities or subcultures. This relationship means that all communities should be covered or contained by a town area; the intersection of communities are just in their boundaries; and union of all communities should be equal to town area.
3. A town should **be divided into** local transport areas. This relationship is a little bit more complicated since local transport areas can intersect into each other and the union of catch basin of transport areas should cover the whole town.
4. Houses (and common lands) should **create clusters**. “Creating a cluster” is more a statistical function combined with a distance function. However, some entities (including houses and common lands) should be arranged in a meaningful clusters in a city.
5. Common lands should **be around** houses and work places. “Being around some other entity” requires a disjoint relation as well as being covered by a specific buffer from the entity.
6. Major roads should **have parallel** roads in a specific distance to reduce traffic congestion and distribute its volume over the city. Parallel lines in a distance is the type of relationship here. However, being parallel is more a fuzzy concept rather than a crisp one.
7. Shopping streets should **be perpendicular** to major roads. Also being perpendicular is another fuzzy concept between two linear entities.

8. Sidewalks should **be along with** minor roads. “Being along with” is another relationship between two linear entities and requires oriental and distance operations together.

9. Shopping centers should have parking lots **behind**. “Being behind” another entity can be considered as an oriental operation and requires a frame of reference based on the major entity.

10. Local transport areas should **be surrounded by** road rings or a country town should be surrounded by countryside. “Surrounding” or “being surrounded by another entity” is a complex relationship since it can be assumed as a partial surrounding vs. complete surrounding. When an entity surrounds another entity, they are disjoint but surrounding entity’s bounding box contains surrounded entity and they are in a specific distance from each other.

11. The boundary **separates** two communities. Boundary can be considered as an entity which makes separation between two other entities. Boundary can be a road, a pathway, a river, an industrial area, or any other feature.

12. An industrial area can **be part of** a boundary. Being part of another entity is an ontological relationship, however geometrical and topological considerations should be applied.

13. Activity nodes should **be distributed evenly** in a community. This relationship is a statistical operation with many internal parameters, including distance, population and area.

Mentioned items are a few of the specific relationships between urban entities. Modeling these relationships in a spatial reasoning platform requires decomposing the relationships into basic ones and modeling each separately. .

3.7.Feature Recognition

Feature recognition is the step after geometry recognition. At this step we assume that geometry is detected correctly and now we need to recognize the feature type of the sketch.

Although all the urban entities from previous sections were modeled in the ontology, for the test session we chose a limited number of feature types to examine, including: bridge, road, house, park, footpath and landmark. In order to recognize if the object belongs to one of these types, we need to define their ontology thoroughly and for each type define at least one distinguishing property.

So on the reasoning side of the program the sketch is examined against the base-layers with the relationships extracted as predicate. If the relationships satisfy the predicate-object for the sketch it is nominated as the subject and added to the candidate array. If it fails to satisfy any of the conditions, it is added to another array which defines the rejected candidates. Based on the necessity of the conditions, the two arrays can be unified, intersected, or differentiated from each other to give the final candidate(s) as recognized features.

A matrix of reasoning is created for the sketch against the “objects” of the “subject-predicate-object” triple, and all the relations are examined against features from base-layers that fall in the

bounding box of the sketch. Also a dictionary is used to map “objects” to features of base-layers. For example, “river” is mapped to “hydrology”.

The matrix has reasoning predicates as columns and base-layers as rows, and it is filled with true and false values. The last column shows the DE-9IM values as a 9 lettered string. The values in this matrix are finally used to decide the type of sketch.

Besides the reasoning algorithms, some dictionaries are required to map the vocabulary from ontology to the vocabulary used in the reasoning program (figure 3.18).



Figure 3.18. Mutual relation between ontology and reasoning dictionary

The following section elaborates on the ontology and the reasoning details of the test types used for type recognition algorithm.

Bridge

In simple words, a bridge is a polyline feature that crosses a river. So the geometry type is polyline and distinguishing feature from other polyline features is the fact that it crosses a river.

The relationship of a bridge with other entities can be illustrated in figure 3.19.

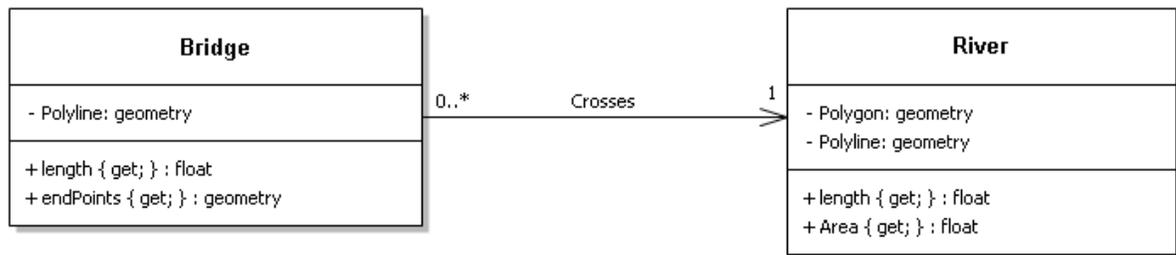


Figure 3.19. Bridge ontology

The ontology is then parsed and stored as a set of “subject-predicate-object” triples. The more human-readable ontology of bridge will be:

Subject	Predicate	Object
Class: Bridge	Is Spatial	Polyline
is Sub Class Of: Urban	crosses	River

In summary a bridge is geometrically a polyline and a distinguishing feature of it is its “crosses River” property. If the sketch is recognized as a polyline, then bridge is among the

candidates, since “isSpatial” predicate and “Polyline” object is part of its ontology. Then the reasoning matrix for the sketch is created. If in the matrix it has “cross” (e.g. ST_Crosses) relationship with “river” (e.g. hydrology), then “bridge” is a candidate for feature type of the sketch and is added to the candidate array and presented to user for confirmation/rejection. Table 3.7 shows the reasoning matrix for a sketch recognized as a bridge and figure 3.20 shows a polyline recognized as a bridge satisfying the values in the matrix.

Table 3-7. Reasoning Matrix for Bridge

	..... ST_Crosses	
addresses		
bikeways		
boundary		
communities		
hardsurfaces		
hydrology	TRUE	
majorroads		
naturalareas		
pathways		
roads		
schools		



Figure 3.20. A Sketch that is recognized as Bridge

Road

In simple words, a road is geometrically a polyline that can intersect with one or more roads but is disjoint from schools or houses. Figure 3.21 shows the relationship between a road and other entities in an urban environment.

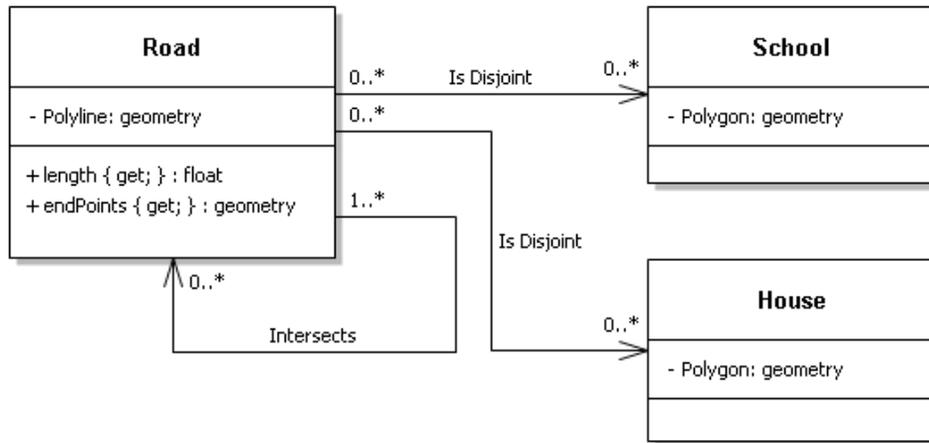


Figure 3.21. Road ontology

The ontology is then parsed and stored as a set of subject-predicate-object triples. The more human-readable ontology of road will then be:

Subject	Predicate	Object
Class: Road is Sub Class Of: Urban	Is Spatial	Polyline
	Intersect	Road
	Is Disjoint From	School
	Is Disjoint From	House

In summary a road is geometrically a polyline that is disjoint from schools and houses. It also may intersect with other roads. Using the same method, if the sketch is recognized as polyline

(“is spatially a Polyline”), then we can create the reasoning matrix for the sketch and if the matrix looks like table 3.8, then “road” is a candidate for feature type of our sketch. Table 3.8 shows the reasoning matrix for a sketch recognized as a road and figure 3.22 shows a polyline recognized as a road satisfying the values in the matrix.

Table 3-8. Reasoning Matrix for Road

	.....	ST_Intersects	ST_Disjoint	.....
addresses			TRUE	
bikeways				
boundary				
communities				
hardsurfaces				
hydrology				
majorroads		TRUE		
naturalareas				
pathways				
roads				
schools			TRUE	

House

The relationship of a house and other urban entities is shown in figure 3.23:

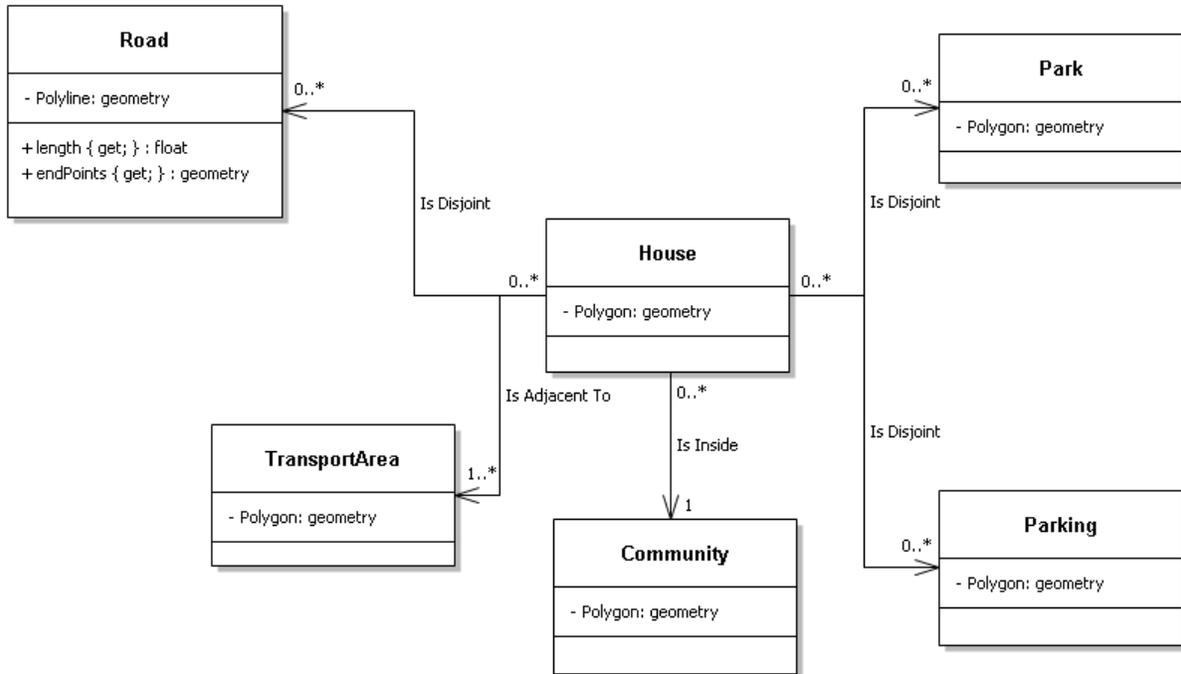


Figure 3.23. House ontology

The ontology is then parsed and stored as a set of subject-predicate-object triples. The more human-readable ontology of house will be:

Subject	Predicate	Object
Class: House is Sub Class Of: Building	Is Spatial	Polygon
	Is Disjoint From	Park
	Is Disjoint From	Major Roads
	Is Disjoint From	Parking
	Is Inside	Community

	Is Adjacent To	Local Transport Area
--	----------------	----------------------

In summary a house is geometrically a polygon that can be adjacent to major roads or local transport systems; is disjoint from parks, parking lots, and rivers; is inside a community and may be alongside country streets. The same logic for the reasoning matrix applies for house. Here “House” is mapped to “Hard Surface” and “Local Transport Area” is mapped to “Major Roads”. Table 3.9 shows the reasoning matrix for a sketch recognized as a house and figure 3.24 shows a polygon recognized as a house satisfying the values in the matrix.

Table 3-9. Reasoning Matrix for House

	..... ST_Disjoint	ST_Within	ST_DWithin	.....
addresses				
bikeways				
boundary				
communities		TRUE		
hardsurfaces	TRUE			
hydrology				
majorroads	TRUE		TRUE	
naturalareas	TRUE			
pathways				
roads				
schools				

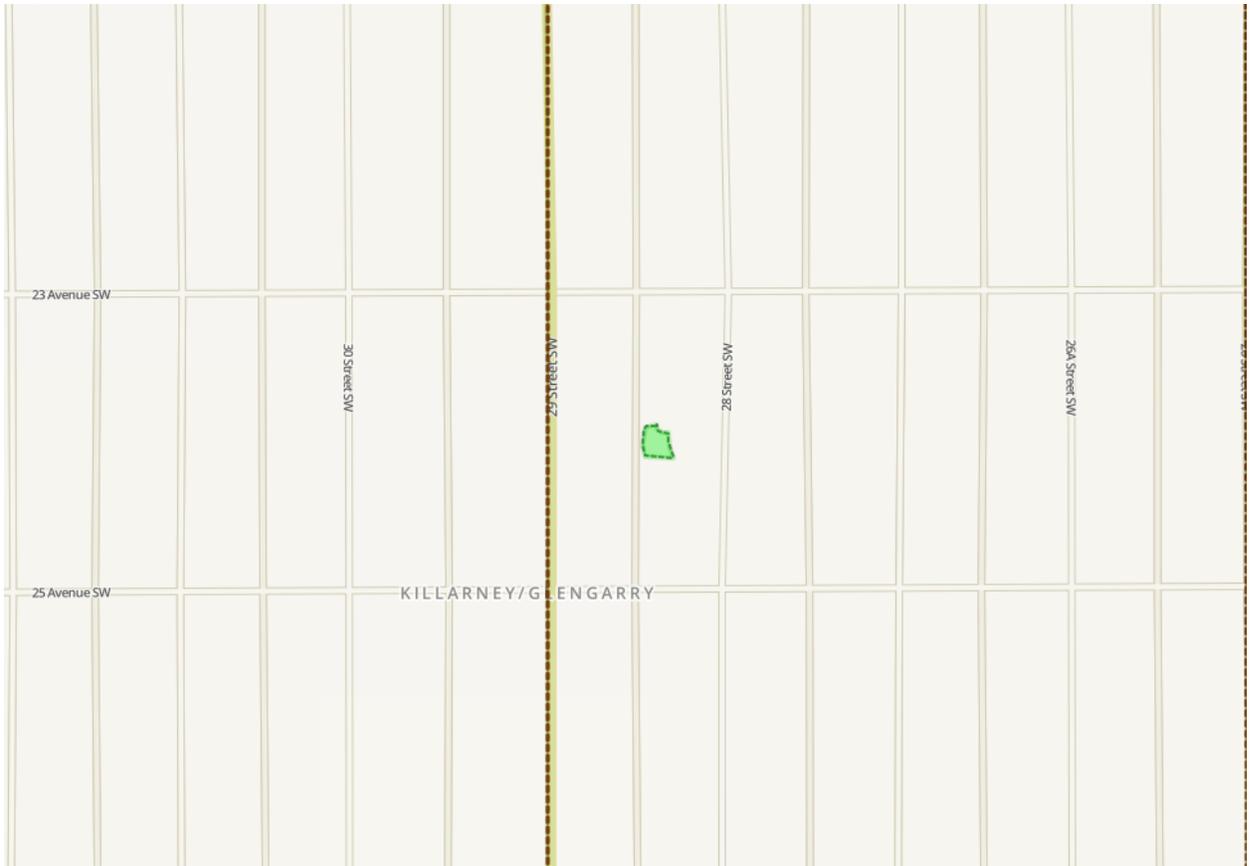


Figure 3.24. A Sketch that is recognized as House

Park

The relationship of a park and other urban entities is shown in figure 3.25.

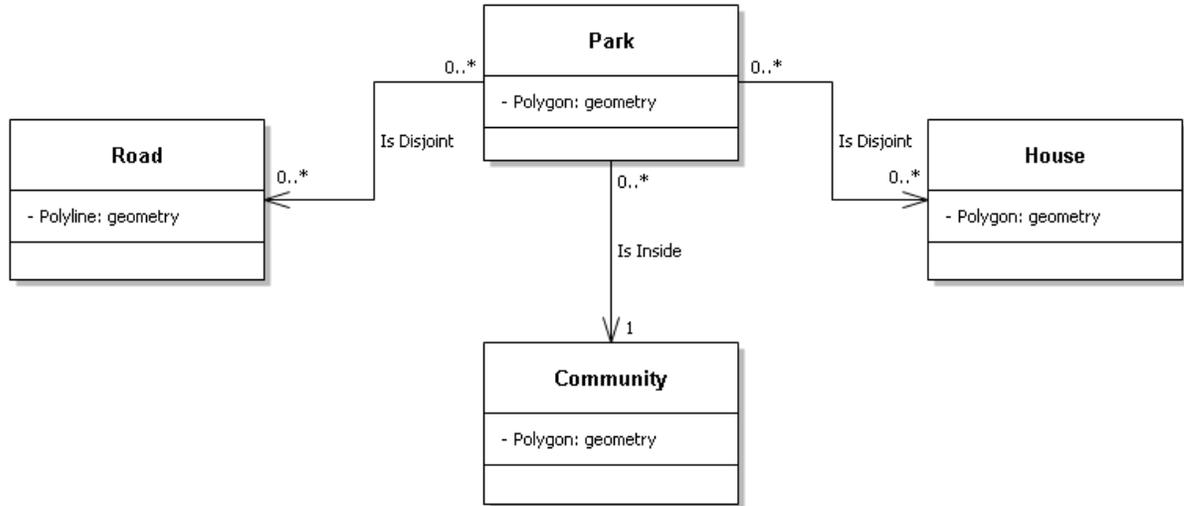


Figure 3.25. Park ontology

The ontology is then parsed and stored as a set of subject-predicate-object triples. The more

human-readable ontology of park then will be:

Subject	Predicate	Object
Class: Park is Sub Class Of: Urban	Is Spatial	Polygon
	Is Inside	Community
	Is Disjoint From	Major Roads
	Is Disjoint From	House

In summary, a park is geometrically a polygon that is disjoint from houses and major roads and is inside a community. Table 3.10 shows the reasoning matrix for a sketch recognized as a park and figure 3.26 shows a polygon recognized as a park satisfying the values in the matrix.

Table 3-10. Reasoning Matrix for Park

	.....	ST_Disjoin	ST_Within	ST_DWithin	.....
addresses		TRUE			
bikeways					
boundary					
communities			TRUE		
hardsurfaces					
hydrology					
majorroads		TRUE			
naturalareas					
pathways					
roads					
schools					



Figure 3.26. A Sketch that is recognized as Park

Footpath

A footpath is related to other urban entities as shown on the diagram of figure 3.27.

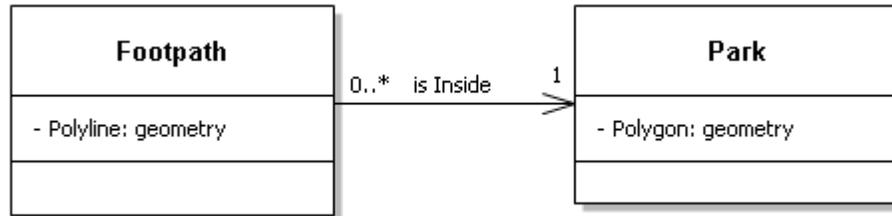


Figure 3.27. Footpath ontology

The ontology is then parsed and stored as a set of subject-predicate-object triples. The more human-readable ontology of footpath will be:

Subject	Predicate	Object
Class: Footpath is Sub Class Of: Urban	Is Spatial	Polyline
	Is Inside	Park

In summary, a footpath is geometrically a polyline that is inside a park. Being inside a park can be assumed as a distinguishing property from other polyline features for footpath. Table 3.11 shows the reasoning matrix for a sketch recognized as a footpath and figure 3.28 shows a polyline recognized as a footpath satisfying the values in the matrix.

Table 3-11. Reasoning Matrix for Footpath

	..... ST_Within		
addresses			
bikeways			
boundary			
communities			
hardsurfaces			
hydrology			
majorroads			
naturalareas		TRUE	
pathways			
roads			
schools			



Figure 3.28. A Sketch that is recognized as Footpath

Landmark

The relationship of a landmark and other urban entities is shown in diagram of figure 3.29.

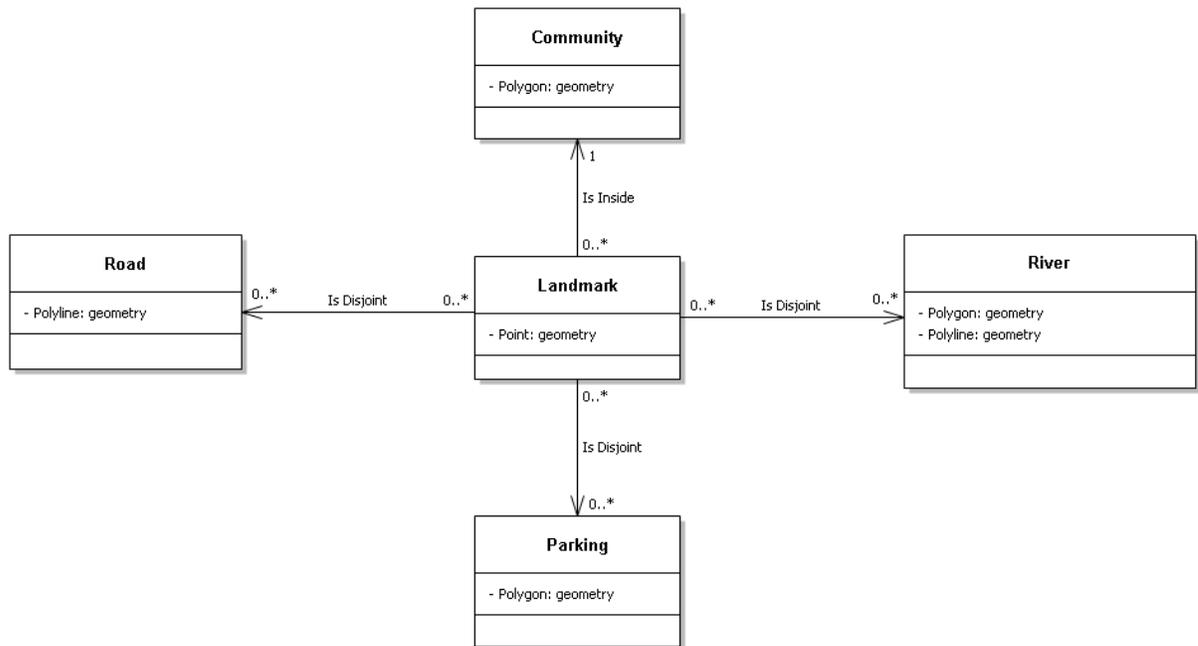


Figure 3.29. Landmark ontology

The ontology is then parsed and stored as a set of subject-predicate-object triples. The more human-readable ontology of landmark then be:

Subject	Predicate	Object
Class: Landmark is Sub Class Of: Urban	Is Spatial	Point
	Is Inside	Community
	Is Disjoint From	Major Roads
	Is Disjoint From	Parking
	Is Disjoint From	River

In summary a landmark is geometrically a point that is disjoint from parking lots, rivers and major roads; and is inside a community. Table 3.12 shows the reasoning matrix for a sketch recognized as a landmark and figure 3.30 shows a polygon recognized as a landmark satisfying the values in the matrix.

Table 3-12. Reasoning Matrix for Landmark

	..... ST_Disjoint		
addresses			
bikeways			
boundary			
communities			
hardsurfaces		TRUE	
hydrology		TRUE	
majorroads		TRUE	
naturalareas			
pathways			
roads			
schools			

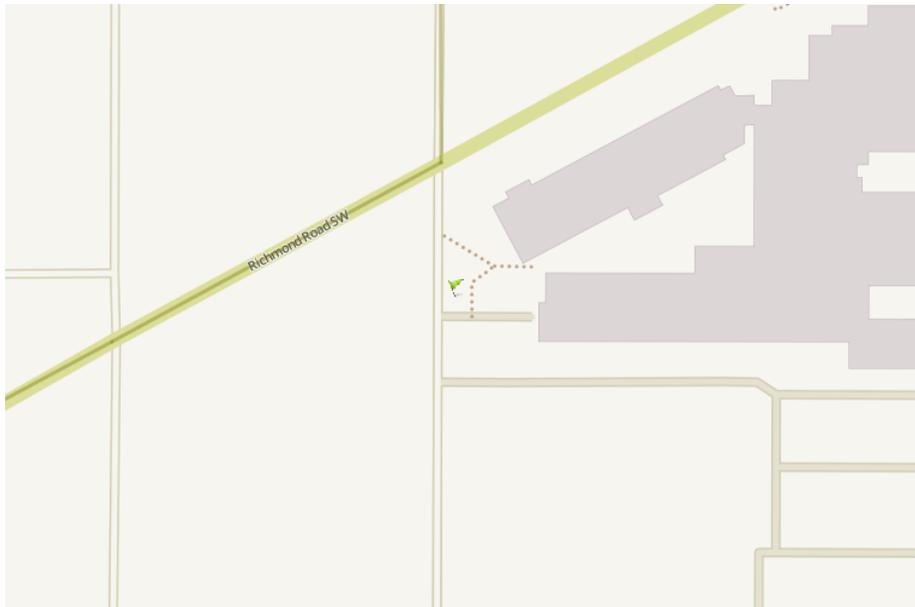


Figure 3.30. A Sketch that is recognized as Landmark

3.8.PYPsketch: A Web-based Sketch Recognition System

User Interface Design is mainly concerned with effective (i.e. accurate) and efficient (e.g. time efficient or storage efficient) design of the interfaces between humans and computers. An appropriate interface should be intuitive (easy to understand) and expressive (able to perform the desired task) to make it effective and efficient. Simpler interfaces are easier to understand and more intuitive, so designing a simple form of interface was considered for this research following the major rules of user interface design; such as: consistency, simplicity, obvious tools, and providing instant feedback to the user.

In designing a user interface, three different components should be considered: human, interface, and computer. The interface should provide a compatibility between human cognition and computer processing. Humans and computers send and receive information in a variety of modes. These modes are usually compatible with human senses (e.g. visual, auditory, haptic, olfactory, and gustatory senses). From this perspective the interface of PYPsketch platform is more visual, relying on visual components of an interface (e.g. symbols, colors, visual contents) for human to receive information from a computer and haptic (e.g. using computer mouse) for human to send information to a computer.

Of different interfacing tools available, WIMP offers a collection of interfacing tools including: Windows, Icons, Menus, and Pointers. Pointers are highly intuitive and facilitate a more natural type of interaction with a computer system. On the other hand, cartographic maps represent spatial content more intuitively, by employing a great array of symbolization and cartography rules. Maps can be classified as: static or dynamic/interactive, 2D or 3D, silent or talkative, fixed or animated, softcopy/digital or hardcopy/analog, and online or offline. These classifications can provide advantages or disadvantages for maps of different applications. Dynamic and interactive maps have changeable content and cartographic representation of the content. They are suitable for illustrating the results of analysis, or giving feedback to users. The online web-based PYPsketch platform designed in this research considers simplicity and

efficiency as major criteria for the user interface. Users interact with the client side of this platform on a personal computer (although the platform is considering tablet users for the future, the design and testing was implemented on personal computers). The client side is a web browser with a URL leading to a website as the major gateway between the user and the platform. The interface contains an interactive online map and one sketching tool. Figure 3.31 shows the initial interface. The canvas contains an online map of the desired area with some more layers added to highlight the important features. There are two major buttons designed for interaction: one for sketching and one for panning. The rest of the interface provides feedback to the user based on their interaction. For example, upon the sketching process, all the properties of sketch (including: length, number of points in the sketch, area it occupies and distance between the first and last point on the sketch, as well as zoom level or scale of the map and so on) is returned to the user.

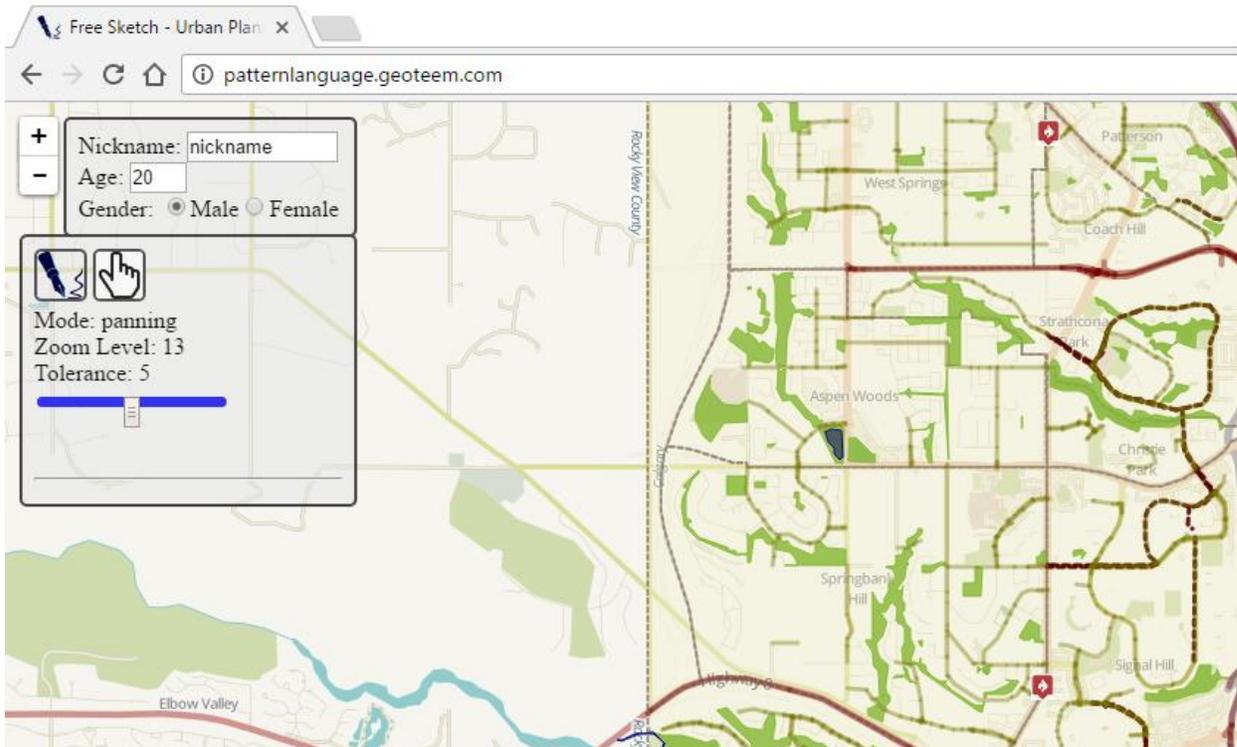


Figure 3.31. Interface of the PYPsketch platform

Although sketches use different building blocks in 2D space (point, line, and polygon), for varying features in the urban domain (e.g. roads, schools, bridges, and so on) in this research just one tool is provided for the user. This prevents users from the confusion caused by the complexity of choosing the appropriate tool to sketch the intended urban feature. These tasks are instead given to the program running behind the interface. The interface owes its simplicity to the complexity of the programs behind it. From a technical perspective, the client side of

PYPsketch platform utilizes web tools and libraries, including: HTML, CSS, JavaScript, jQuery, and Ajax, Leaflet Web Mapping Library, and GeoJSON format for handling Geospatial data.

Since designing tools to recognize and interpret the sketches of users is the major goal of this research, a detailed investigation of different features and their inter-relationships in an ontology framework is required.

The recognition of sketches is composed of two main parts. First, recognition of the geometry of the sketch as one of the primary types of point, polyline, or polygon. Second, recognition of the type of the sketch as an urban entity (e.g. road, house or park).

For geometry recognition, different criteria and thresholds are considered, which are geometrical in nature. Users create sketches with three events: holding the button of computer mouse down (Mouse-Down Event), moving (Mouse Move Event) the pointer on the screen (map), which creates the drawing, and releasing the button of the mouse (Mouse-Up Event).

During the drawing, the trace of the pointer is illustrated on the map and recorded and the points on which the mouse has moved are collected to shape the main sketch. The number and density of points in the drawing, the total geometrical length of the sketch, the distance between the first point and the last point, the scale of the map on which the sketch is produced, and the area of the concave hull containing the sketch which reveal the type of geometry are calculated and shown

to the user. Investigation of these parameters helps us design a more precise geometry recognition algorithm and a more intuitive sketching tool.

3.9. Test Design

The process of testing the PYPsketch platform starts with selecting the volunteers. After completing the ethics for this research, an invitation was sent to more than 60 people from different walks of life including students, engineers, and housewives and other community residents from City of Calgary. Out of these invitations 12 responses were received. Of these 12 people 9 had no specific GIS education, but used Internet daily, and 3 were bachelor students of Geomatics Engineering with some basic knowledge on GIS. Also 8 were male and 4 were female. Personal information of volunteers containing private information were not collected. The test was focused on two major tasks: geometry recognition and feature recognition.

For geometry recognition volunteers were asked to sketch different geometries (e.g. point, polyline, and polygon) at different zoom levels, with different tolerance values. Based on zoom level, tolerance value, and properties of the sketch the geometry types have been recognized either correctly or incorrectly comparing to volunteer's intention. Volunteers had to provide feedback on correctness of the geometry by clicking either Yes or No button on the interface (figure 3.32).

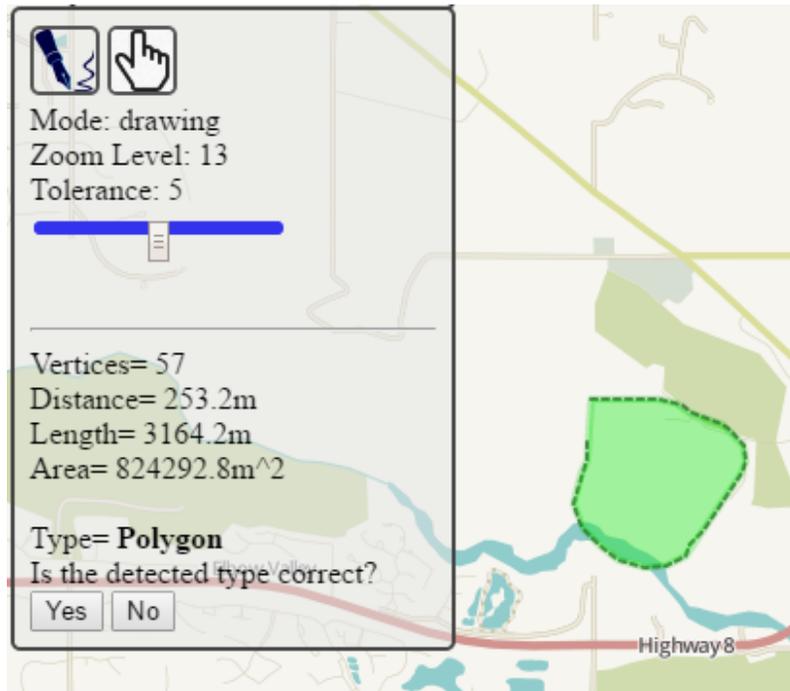


Figure 3.32. Geometry recognition test

For feature recognition, volunteers were asked to draw six different features; including: bridge, road, house, park, footpath, and landmark. The ontology of these features includes their geometry, topological relationships with base-layer features. The base-layers were downloaded from the City of Calgary open data gateway and include the following layers: "addresses", "bikeways", "boundary", "communities", "hard surfaces", "hydrology", "major roads", "natural areas", "pathways", "roads" and "schools". Volunteers were asked to feedback on the type of feature recognized by the PYPsketch platform, by clicking either Yes or No, based on their

initial intention of sketching. Their feedback was collected in the database for further analysis.

Figure 3.33 shows an example of feature recognition test. Feature recognition is dependent on the correct geometry of the sketch, the completeness of ontology and deductive spatial reasoning.

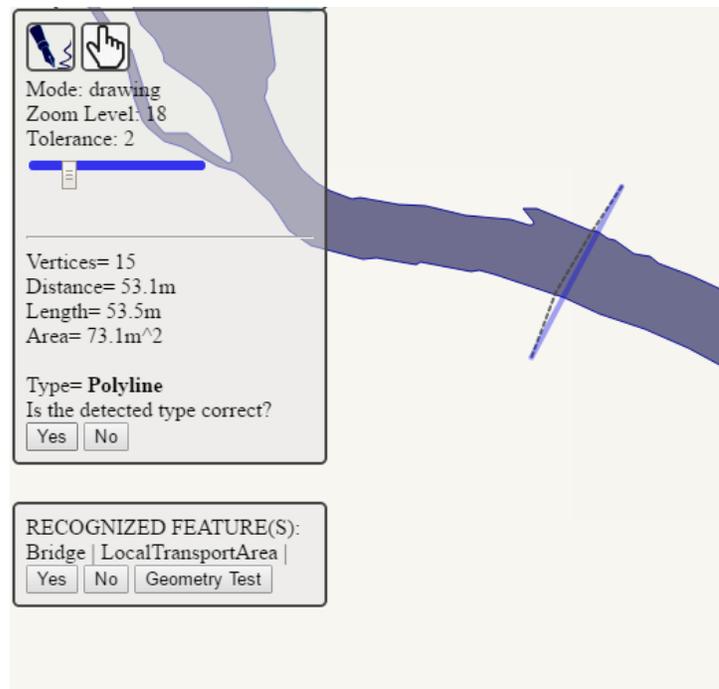


Figure 3.33. Feature recognition test

The west section of City of Calgary was selected for study area, as shown in figure 3.34. The spatial database contains the base-layers used as feature repository so sketches can be examined as entities having a semantic relationship with features in these base-layers.

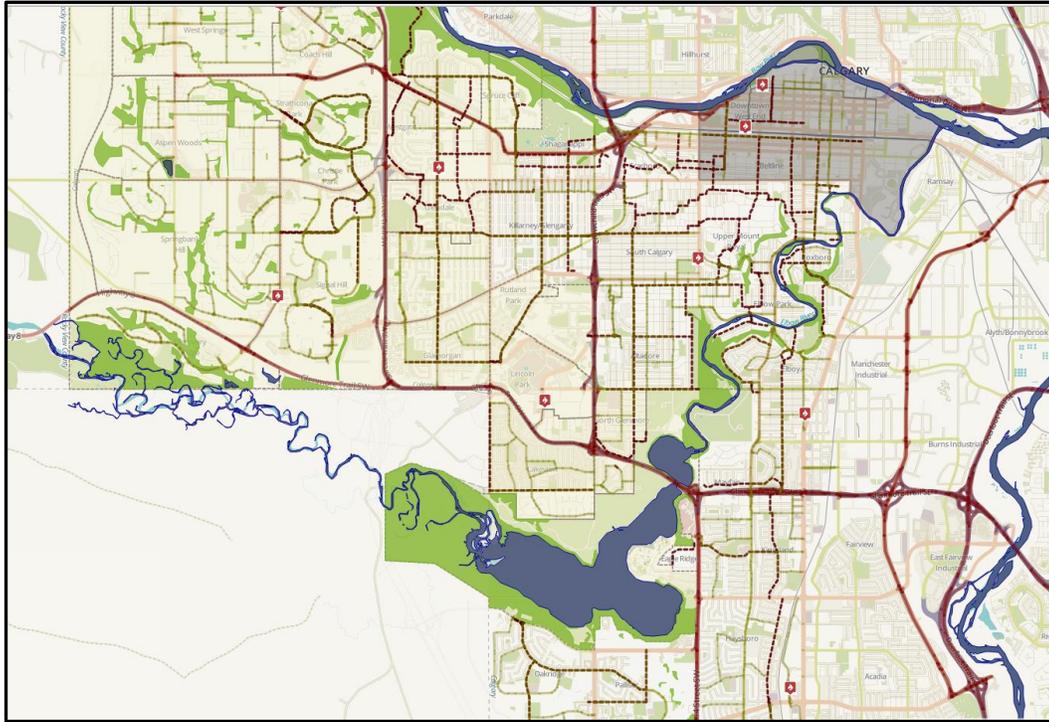


Figure 3.34. Study area

All the sketches, results and feedbacks from participants were stored in the platform's database for further tests. A Period of 6 months were assigned for collecting participants' data and overall 551 records were collected for both geometry recognition and feature recognition test. Next chapter analyzes these results for achieving better insights on the algorithms designed in this research and how these algorithms can be tuned to produce better results.

The purpose of this chapter is to assess the data gathered from volunteers who participated in testing the PYPsketch platform. Once the data was collected, a series of statistical and mathematical analysis have been used to help us understand the sketch patterns for geometry type recognition. Also the result of feature type recognition algorithms will be discussed here.

4.1.Geometry Recognition Results

When volunteers start sketching on the map, they are provided with the details of their sketch and the type of geometry recognized by the PYPsketch platform. Participants can return feedback to the system and approve (confirm) or disapprove (reject) the results of recognition.

Based on the variables and criteria, and following the algorithm discussed in the previous chapter, PYPsketch platform recognizes sketches as points, polylines, or polygons. In order to test the algorithms, we asked participants to confirm or reject the results. A participant has the control over tolerance (0 to 10) and zoom level (12 to 19). Through 551 different tests the following results were achieved: 192 sketches were rejected by participants and 359 were confirmed. Figures 4.1 and 4.2 show the scatter plot matrixes of geometrical variables (e.g. zoom level, tolerance, vertices, length, distance, and area) in a sketch for both confirmed results (green) and rejected results (red). In the next few paragraphs we will scrutinize these graphs.

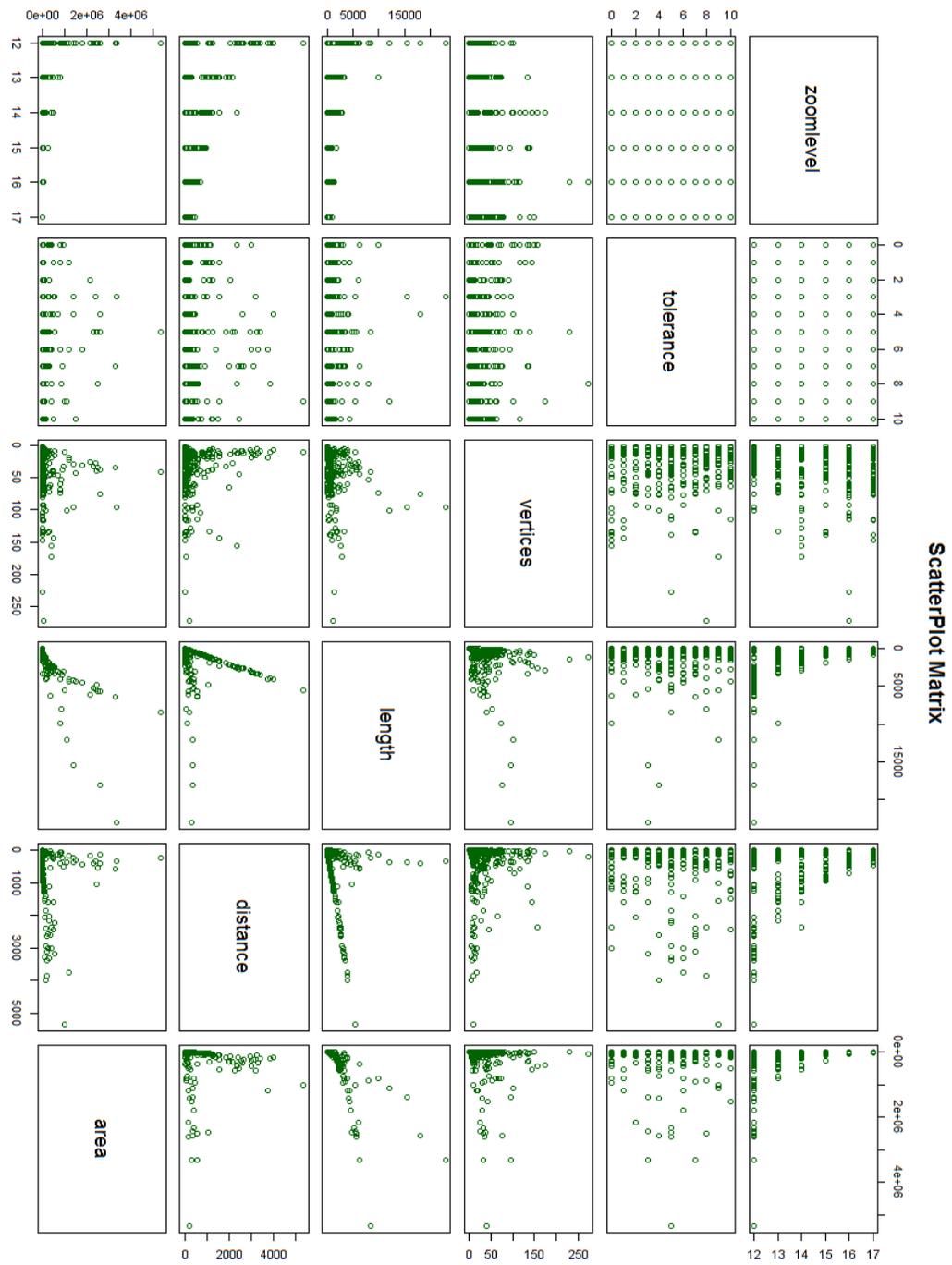


Figure 4.1. Scatter plot matrix of independent variables for confirmed geometry recognition

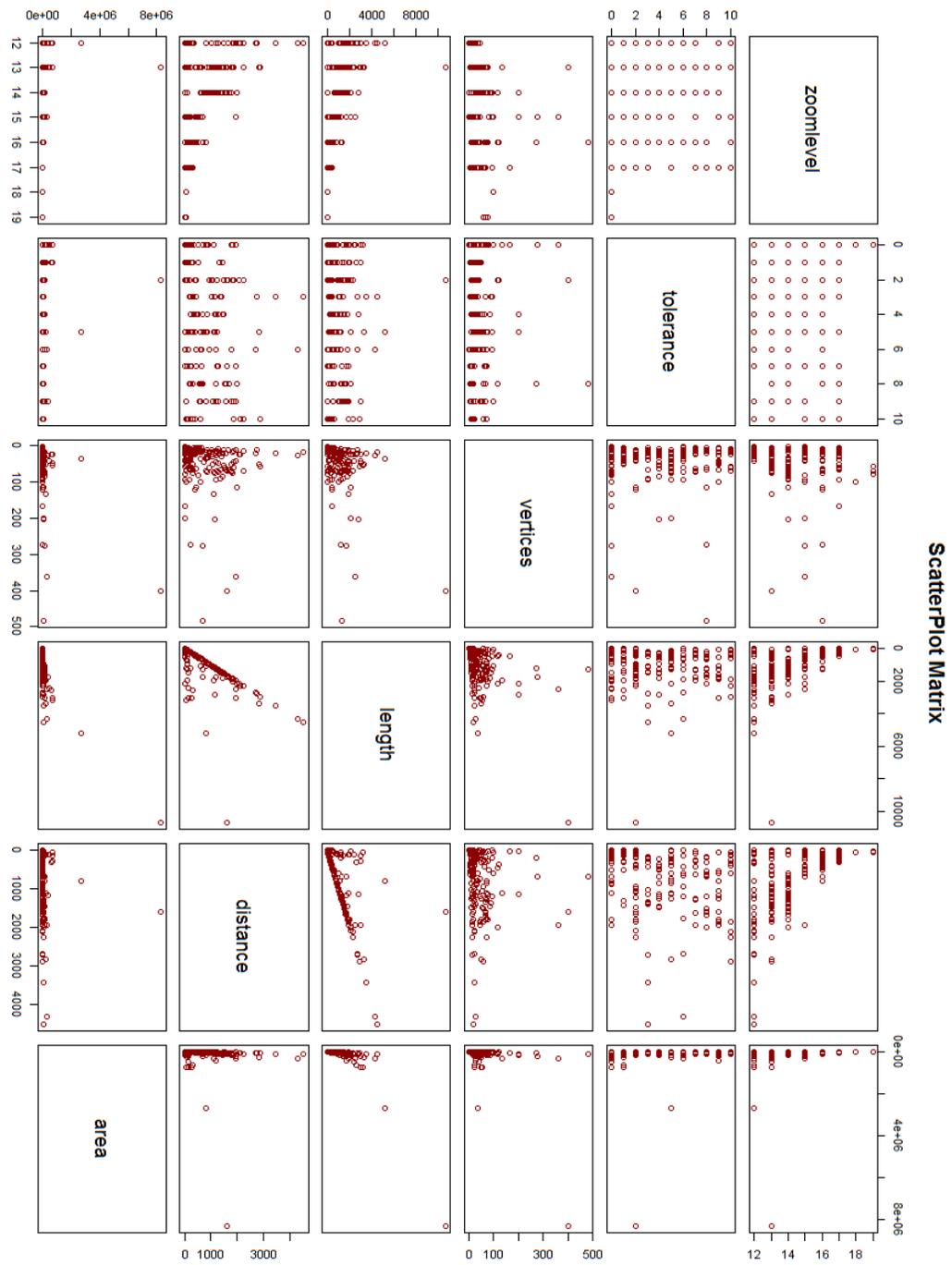


Figure 4.2. Scatter plot matrix of independent variables for rejected geometry recognition

The first and most important parameter that should be investigated is “distance tolerance” that helps to distinguish between polylines and polygons. If the sketch distance is less than this tolerance the sketch will be recognized as a polygon and if it is more than this tolerance it is recognized as a polyline. We need to see which distances were approved or rejected by participants during recognition process. Figures 4.3 and 4.4 show the histograms of the distribution of distances for confirmed and rejected sketches.

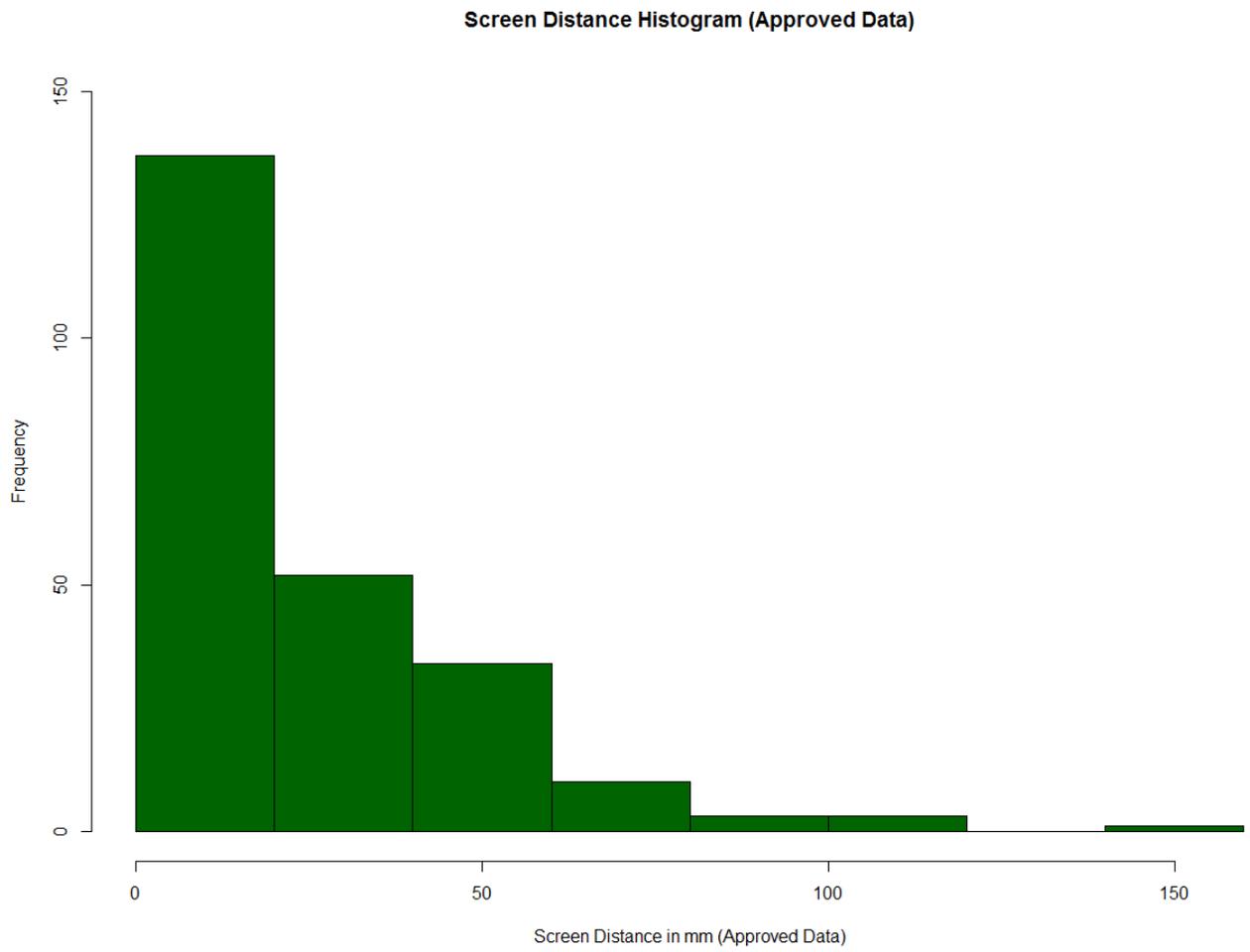


Figure 4.3. Histogram of screen distance for confirmed data

Screen Distance Histogram (Rejected Data)

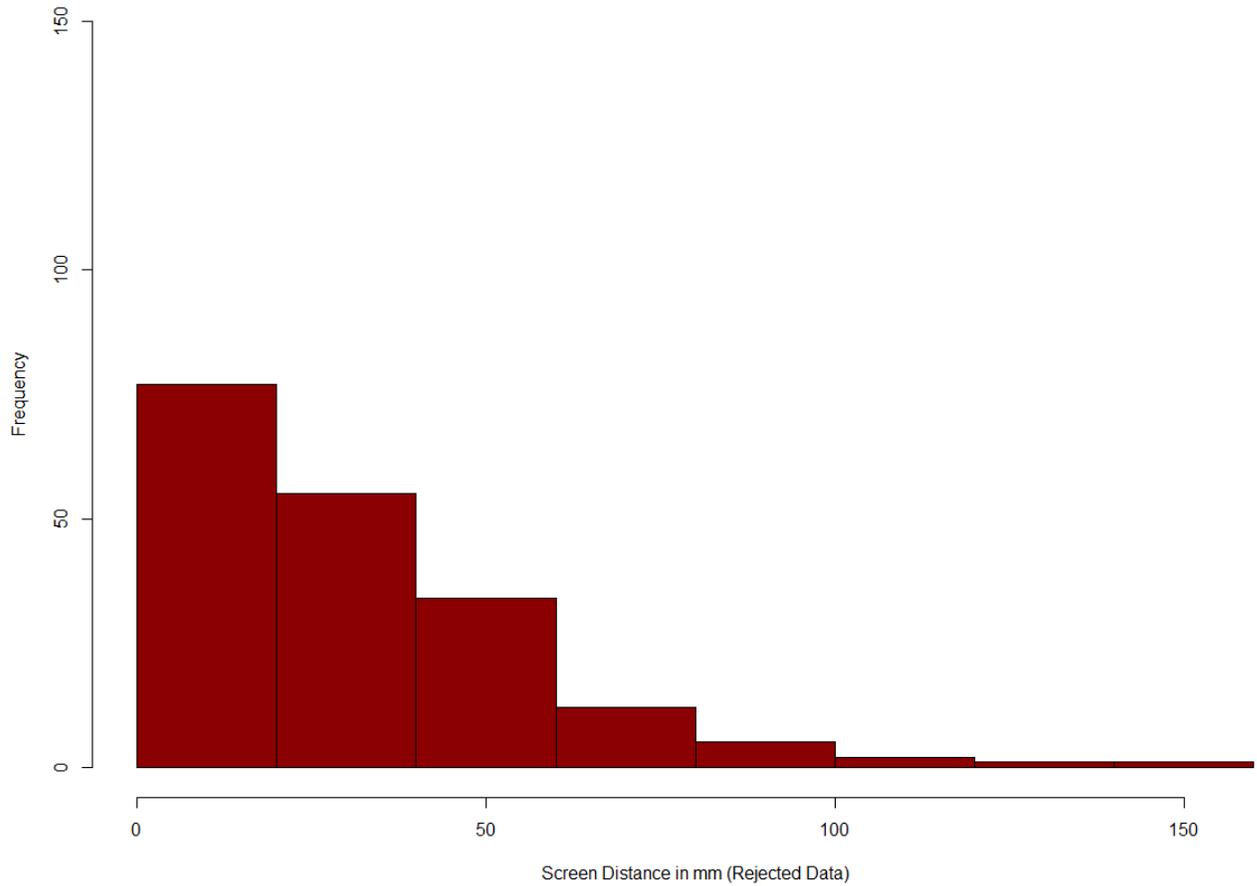


Figure 4.4. Histogram of screen distance for rejected data

The statistical summary of each of the datasets (e.g. both approved and rejected data) are:

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.3582	3.1190	8.5640	22.2100	35.6200	152.2000

for approved data, and

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
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0.000 7.962 27.430 30.050 46.380 158.100

for rejected data.

For approved data the mean value of 22 mm is the threshold where people approve the sketch geometry and for rejected data the mean value of 30 mm is the threshold that people reject the sketch geometry. Although the distributions of both data are not quite normal t-student test shows that the difference between means are significant (i.e. two datasets have significantly different mean values). The result of the t-student test from R package is as follow:

$t = -3.076$, $df = 389.288$, $p\text{-value} = 0.002246$

This result can be interpreted as if the distance between two end points of a sketch on the computer screen is less than 22 mm there is a high probability that sketch was intended to be a closed polygon and if it is more than 30 mm there is a high probability that the sketch was intended to be a polyline.

Similar investigations are valid for “area tolerance” parameter. This parameter is used to distinguish between a point and a polygon. In order to draw a point, if someone draws a small area rather than using a click to mention a point this criteria can be used. Also similar analysis have been applied on area on screen parameter. The results are shown in Figures 4.5 and 4.6.

Screen Area Histogram (Approved Data)

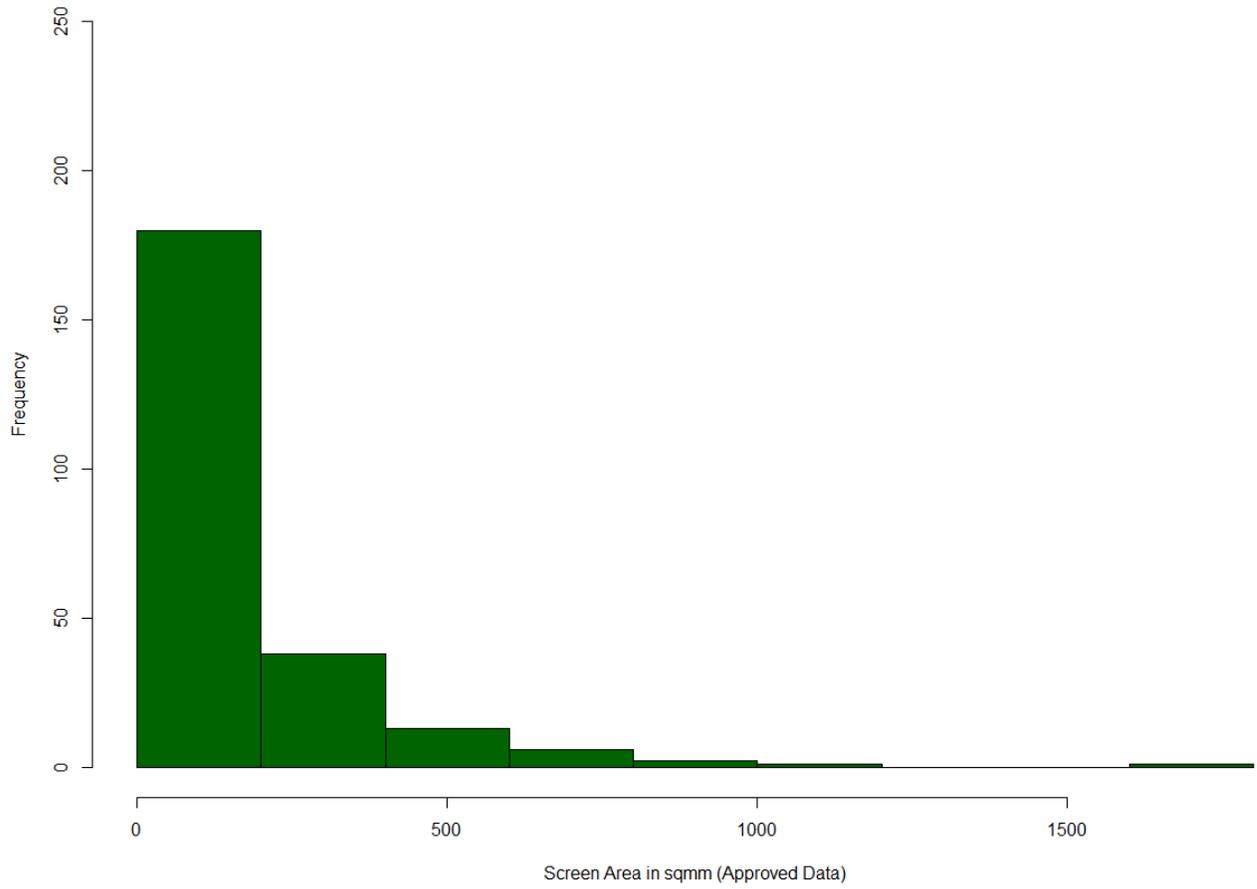


Figure 4.5. Histogram of screen area for approved data

The statistical details of screen area for approved data are:

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.000	0.000	6.474	127.800	202.000	1664.000

Screen Area Histogram (Rejected Data)

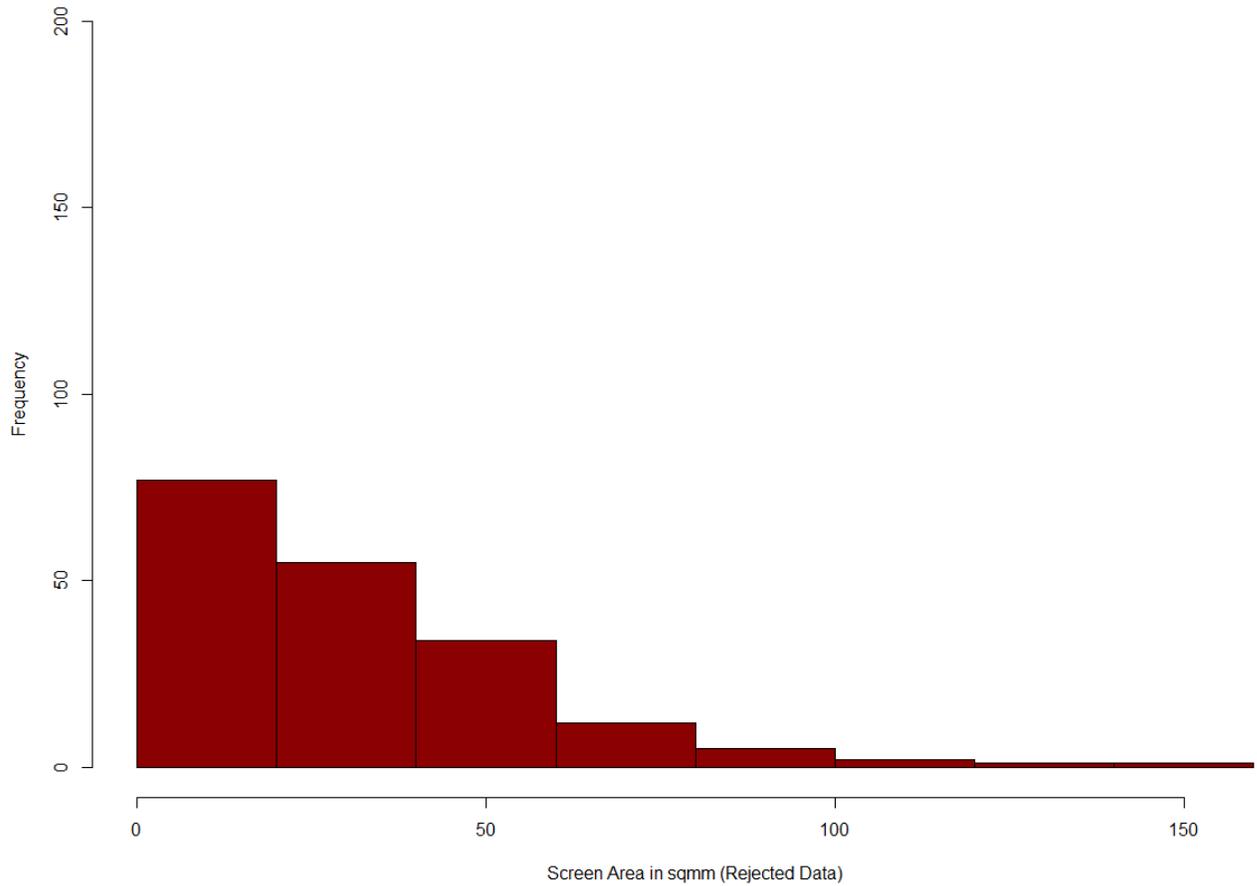


Figure 4.6. Histogram of screen area for rejected data

The statistical details of screen area for rejected data are:

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.000	1.387	10.250	96.600	31.790	3700.000

T-student test was run to see if the mean values of two data sets are different. The results are as follow:

$$t = 0.967, df = 251.187, p\text{-value} = 0.3345$$

Although the result of t-student test is not as good as for “distance”, we can somehow explain it as if the area of a sketch on the screen of the computer is more than 127.8 sq-mm on it is more likely a polygon than a point and if it is less than 96.6 sq-mm it is more likely a point.

Flashing back to scatter plot matrix, another noticeable output merges comparing the zoom level and tolerance. In higher zoom levels where mouse movements on screen mean shorter distances on the ground there are no disapproved results (except when tolerance value is set to zero). Figures 4.7 and 4.8 demonstrate this fact. So all the sketches on higher zoom values are recognized accurately. This means higher zoom levels at which more details can be seen are more appropriate for free sketching.

ScatterPlot Matrix: Zoom Level ~ Tolerance (Confirmed Results)

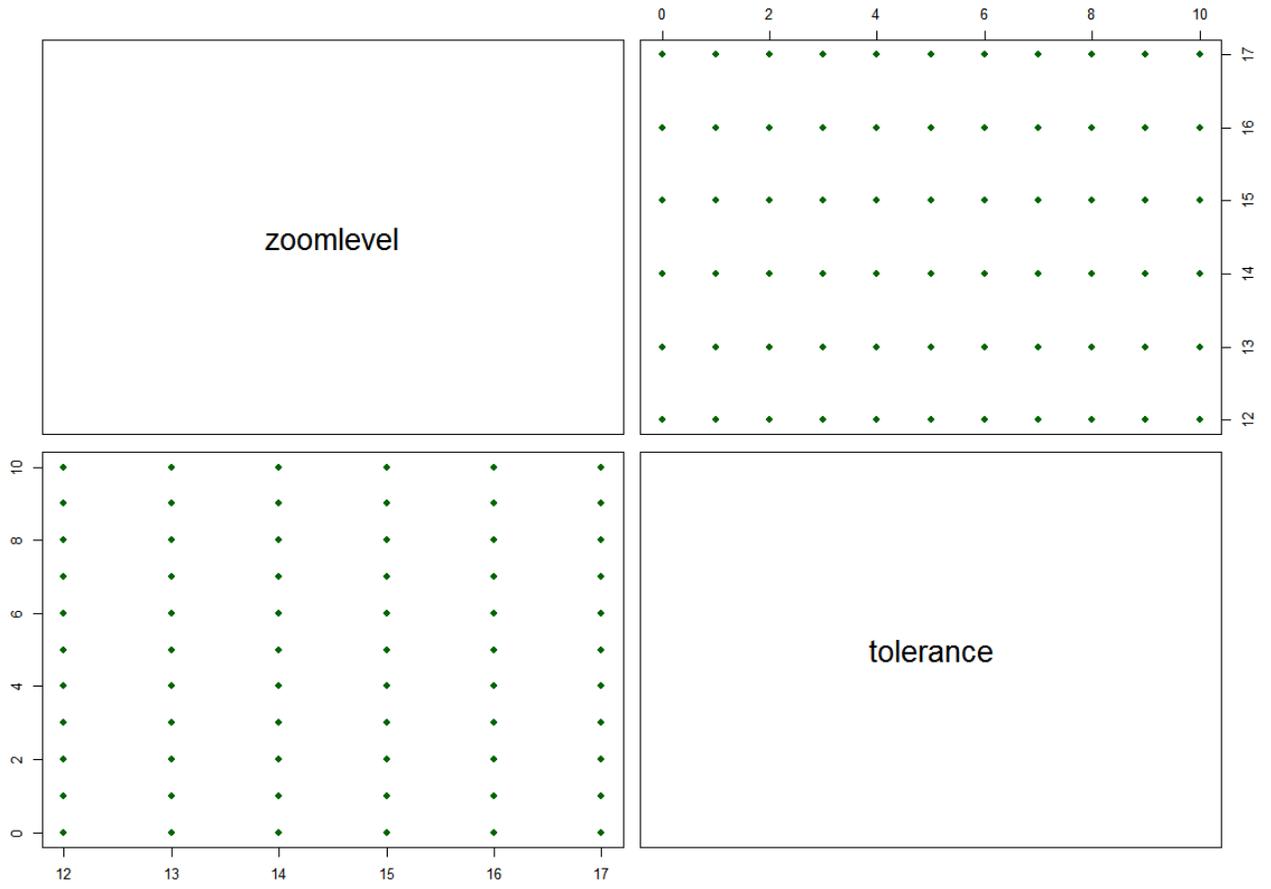


Figure 4.7. Zoom Level ~ Tolerance (Confirmed Results)

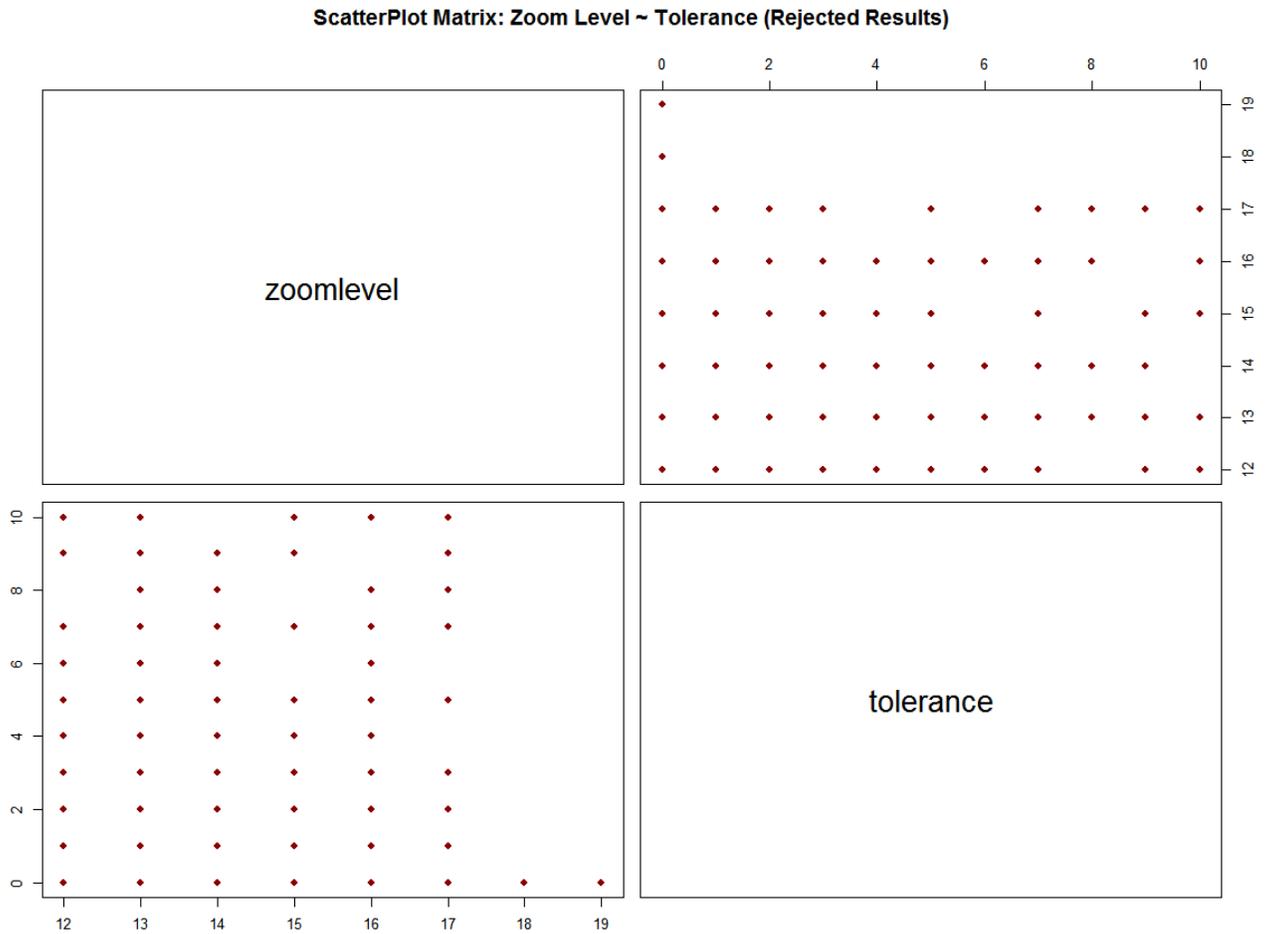


Figure 4.8. Zoom Level ~ Tolerance (Rejected Results)

The other noticeable pattern is the relation between the number of vertices and the length.

When the ratio between the number of vertices and length increases, the geometry recognition algorithm produces better results. Higher numbers of vertices come with complex objects and slow sketching. Figures 4.9 and 4.10 provide the scatter plot of vertices versus length for two

types of results. Based on this fact, sketches that are drawn slowly and more accurately are also recognized correctly.

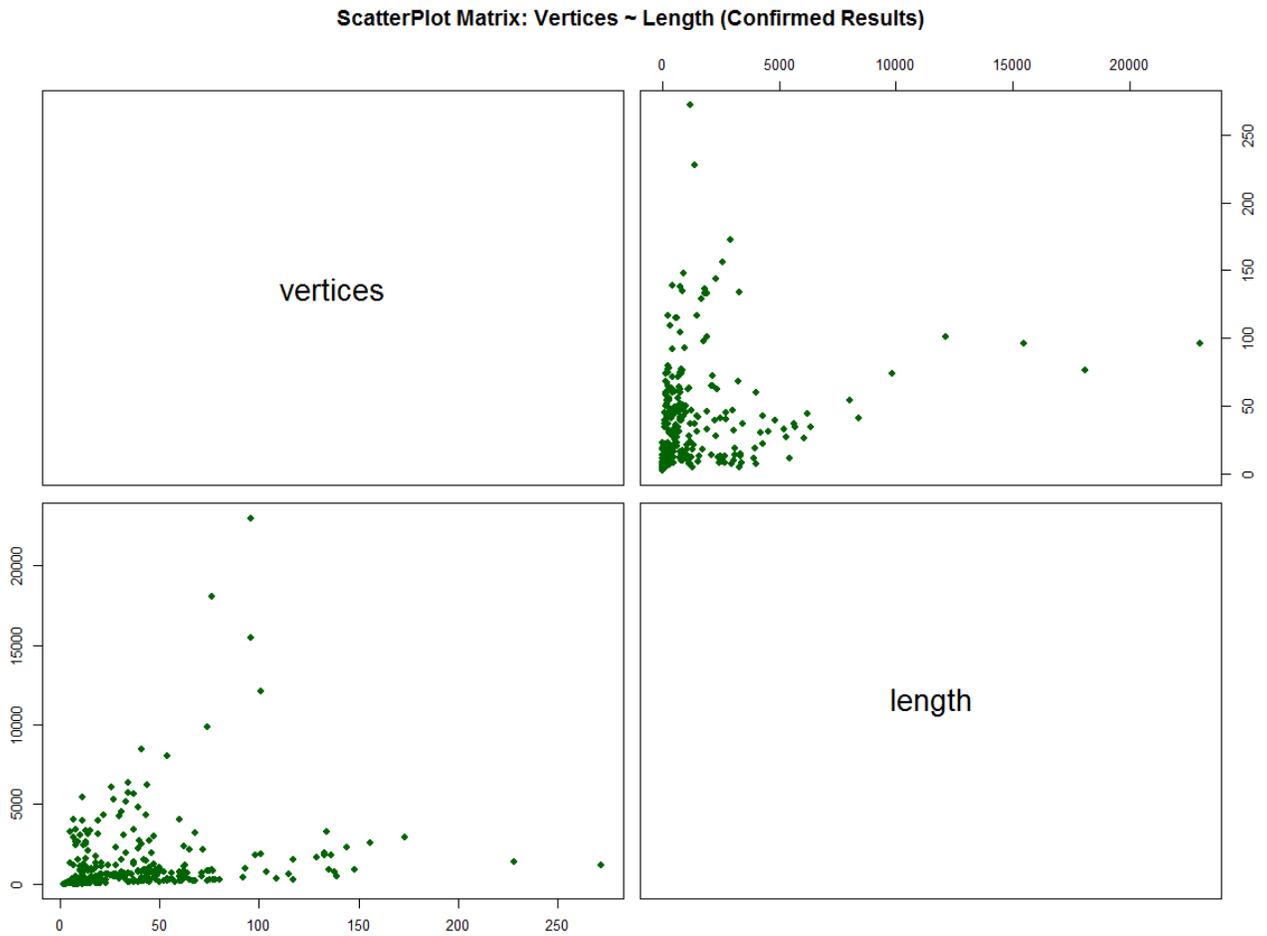


Figure 4.9. Vertices ~ Length (Confirmed Results)

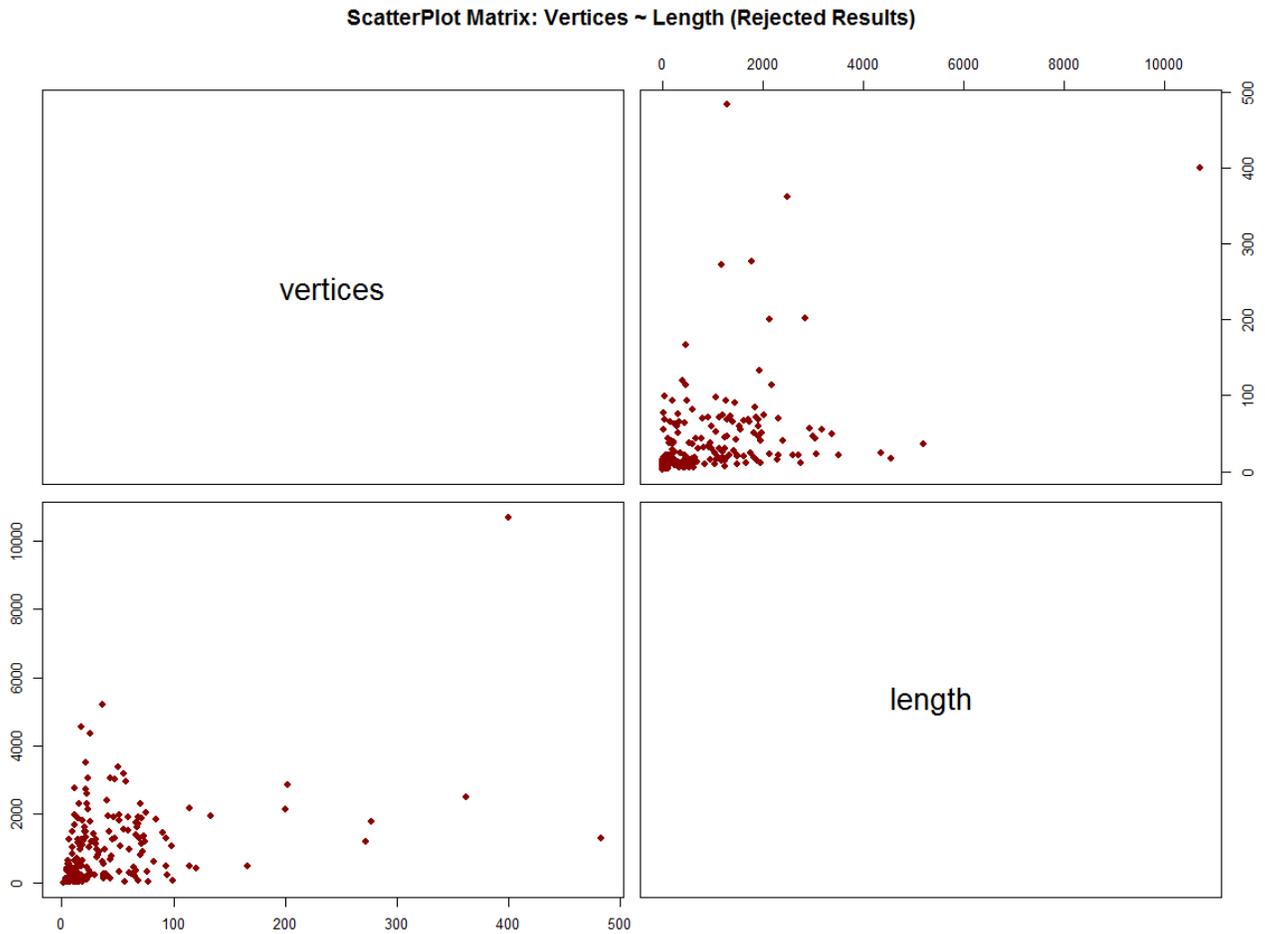


Figure 4.10. Vertices ~ Length (Rejected Results)

The other interesting pattern that was revealed between two datasets is the small deviated slope of the line that passes through the majority of data when length versus distance is illustrated. Both confirmed and rejected data show almost the same pattern with very little difference, as shown in figures 4.11 and 4.12 This small difference is not significant enough to be relied upon.

ScatterPlot Matrix: Distance ~ Length (Confirmed Results)

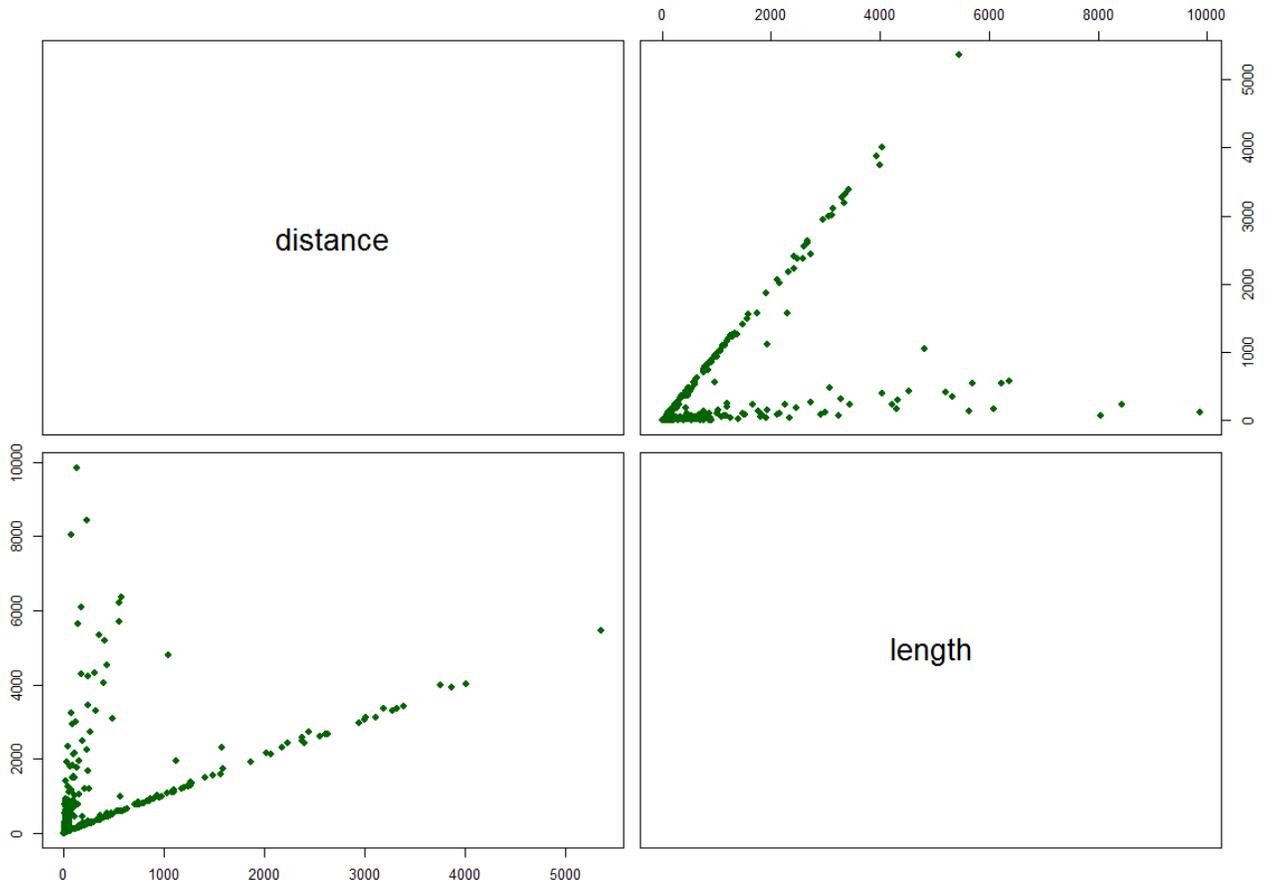


Figure 4.11. Distance ~ Length (Confirmed Results)

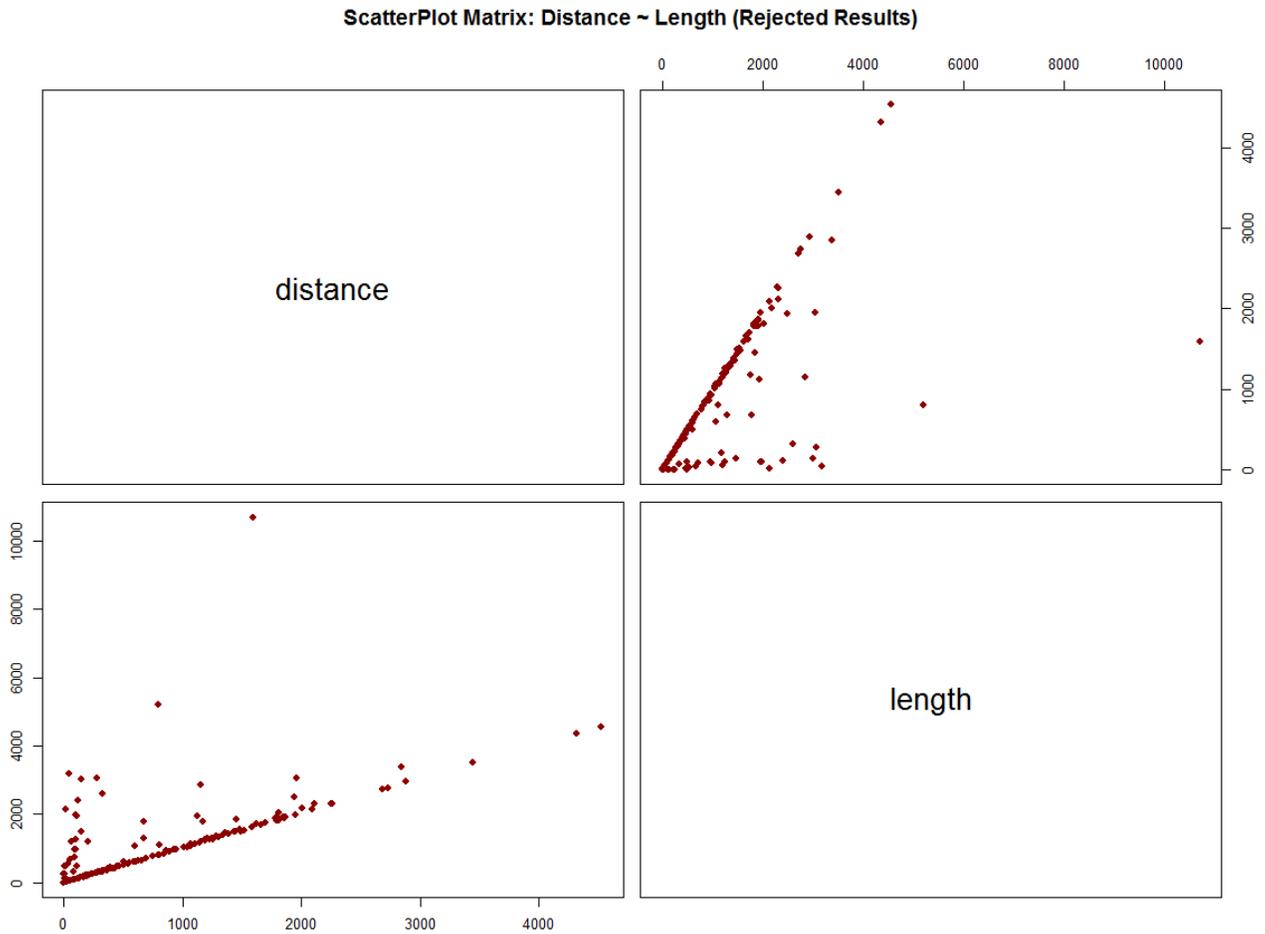


Figure 4.12. Distance ~ Length (Rejected Results)

The relationship between the area and the distance for two datasets also provides interesting patterns. It can be seen that distance to area ratio for rejected results is higher than the same ratio for confirmed results. Figures 4.13 and 4.14 show the scatter plots of distance versus area for

both types of results. This output can be interpreted as if the sketch covers a big area but the distance between two end points is small the sketch is recognized more accurately.

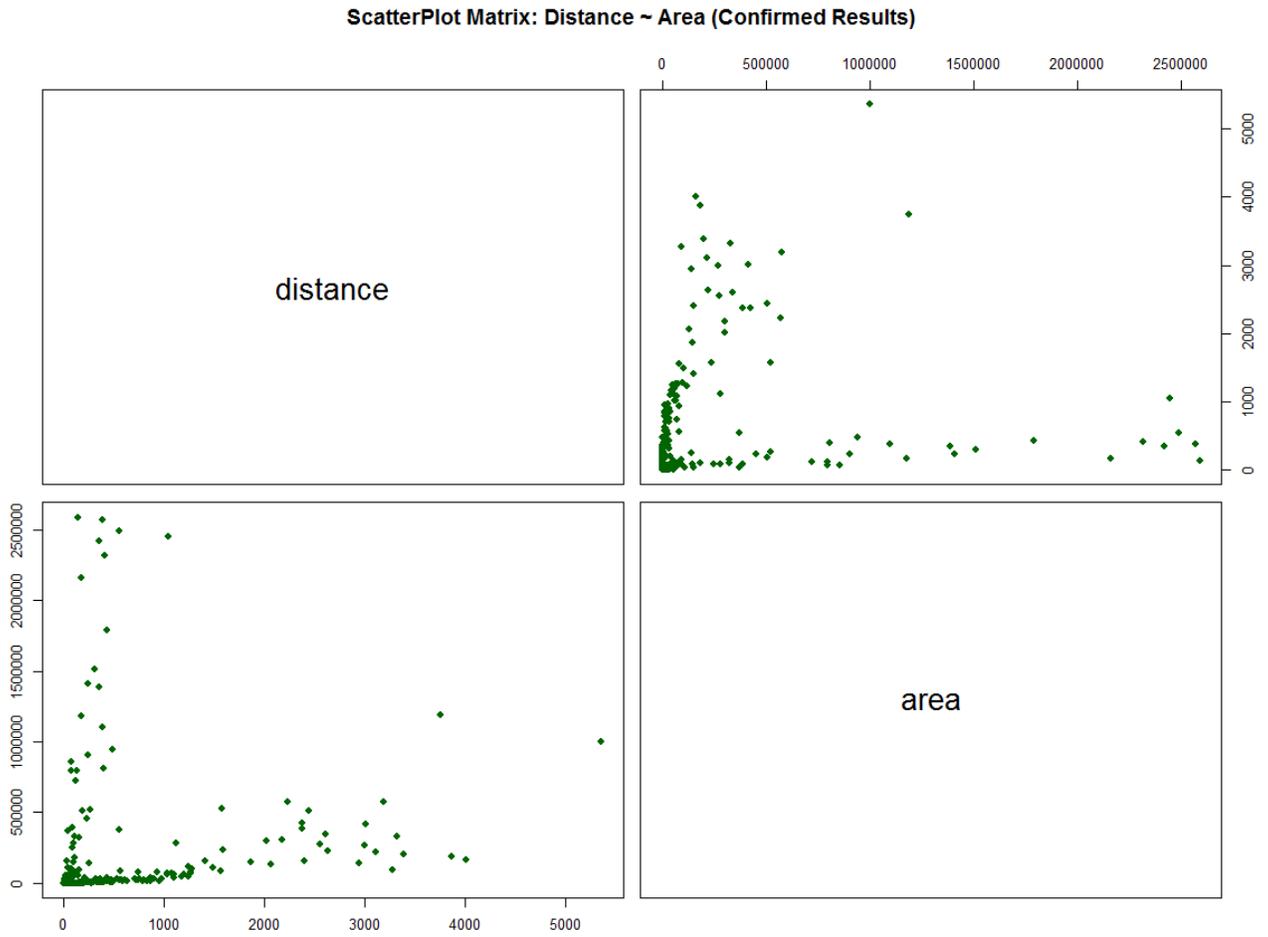


Figure 4.13. Distance ~ Area (Confirmed Results)

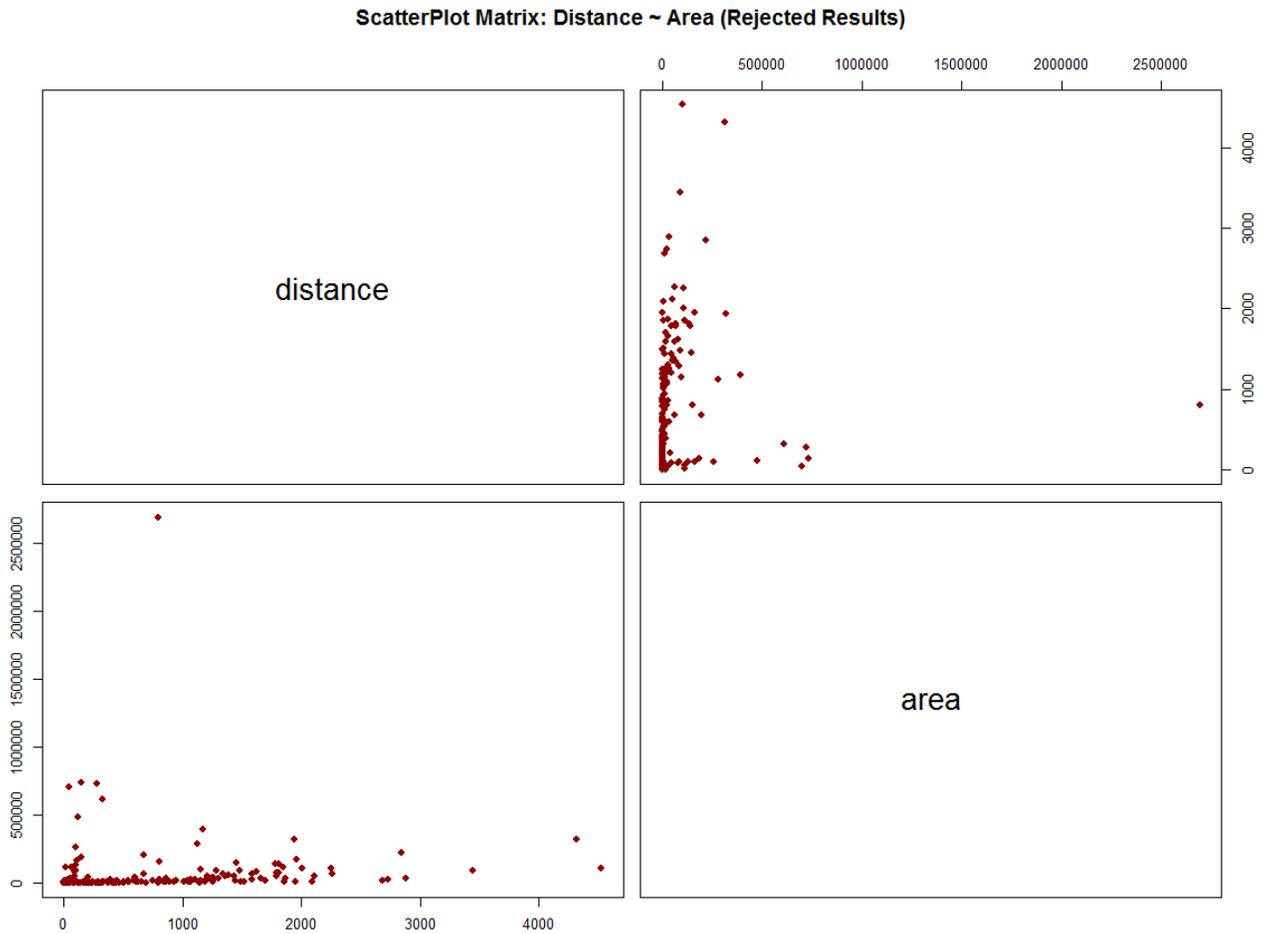


Figure 4.14. Distance ~ Area (Rejected Results)

The relationship between the length and the area reveals a completely different pattern from one dataset to another. Figures 4.15 and 4.16 show more details of length versus area relationships. The results can be interpreted as if in a sketch the length is significantly high and the area covered by the sketch is low, then the sketch is more subject to misinterpretation. This

pattern can be seen in narrow drawings and may reveal the necessity of introducing a new criteria which tests the narrowness of a sketch.

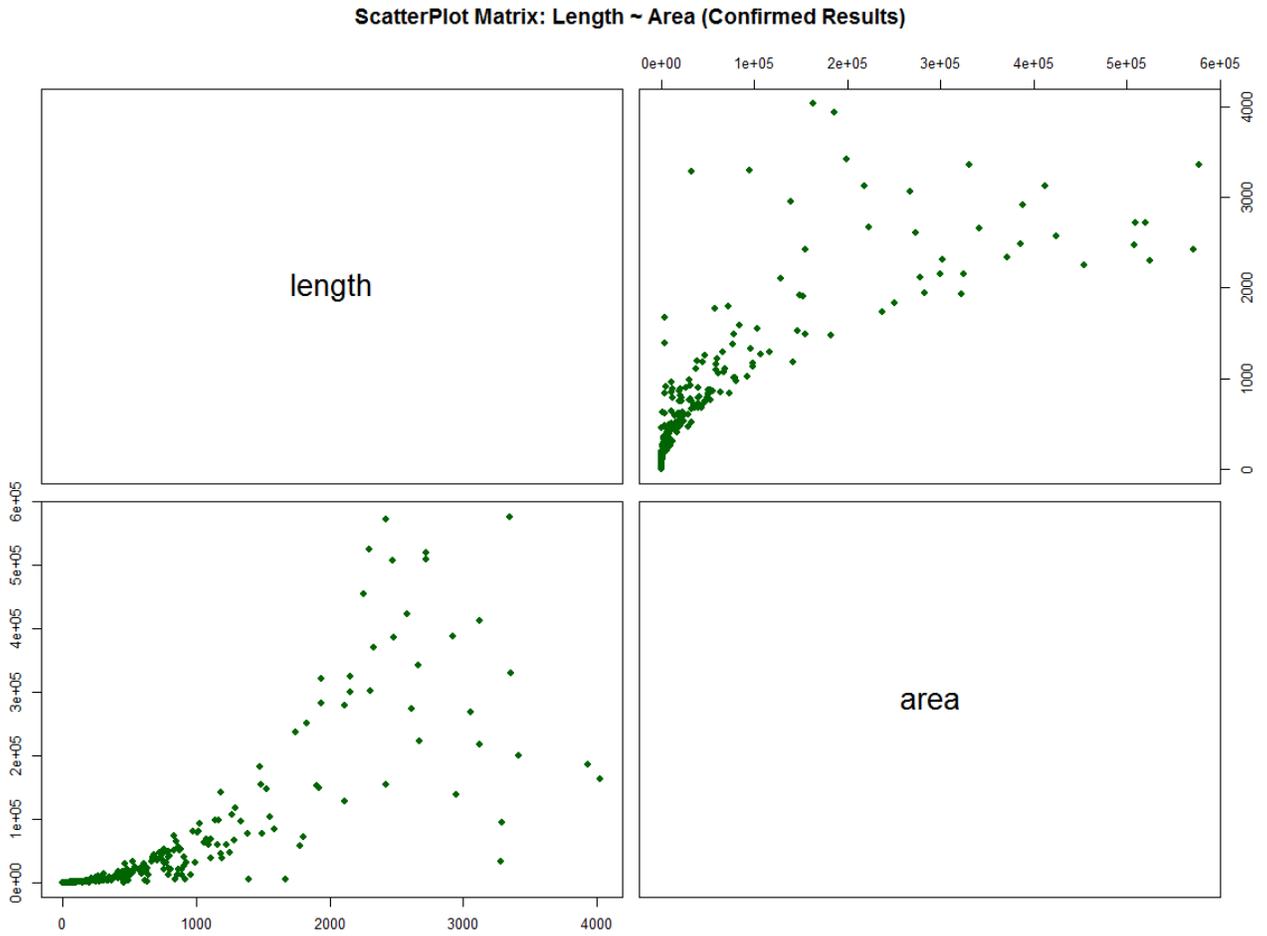


Figure 4.15. Length ~ Area (Confirmed Results)

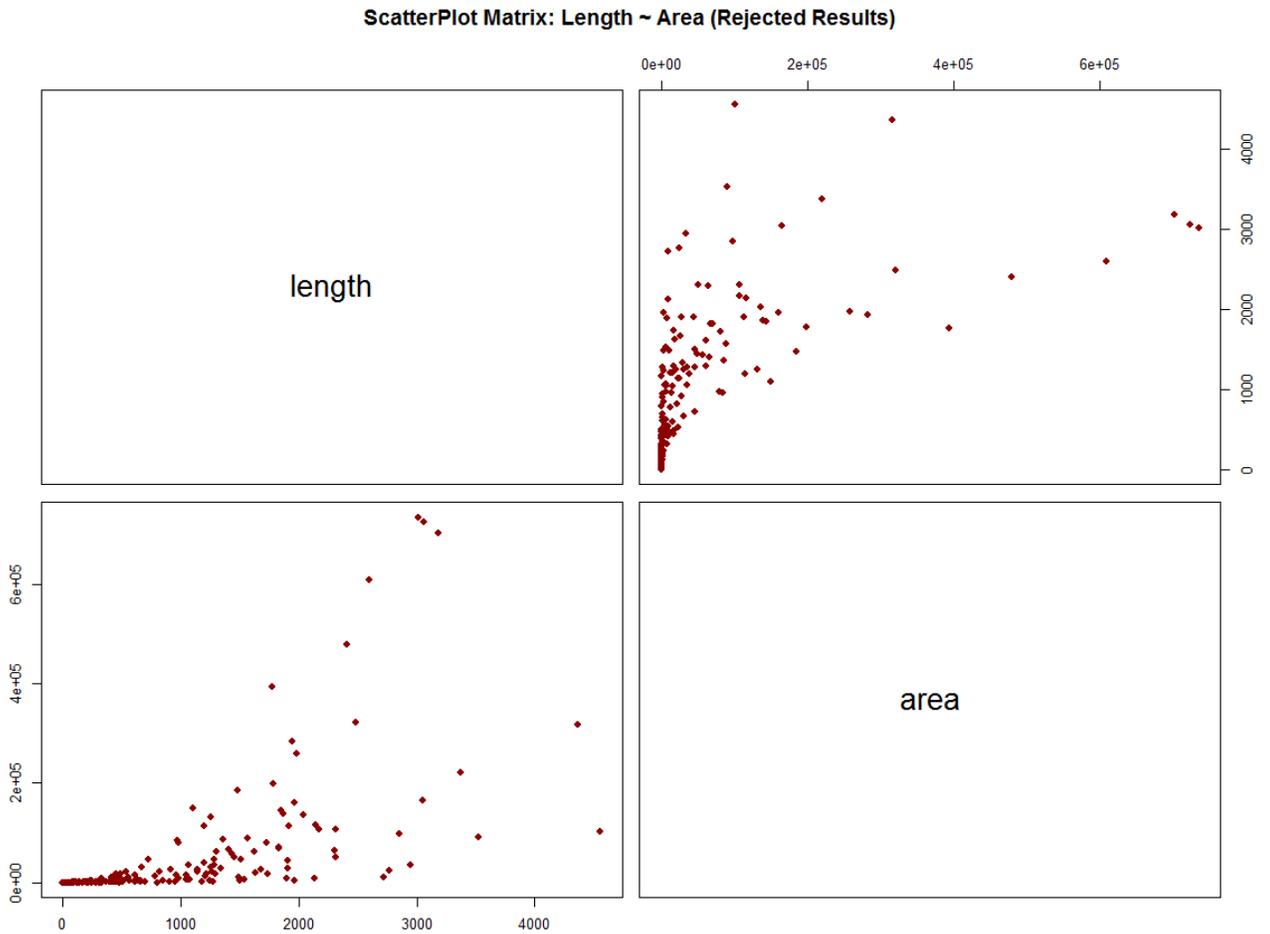


Figure 4.16. Length ~ Area (Rejected Results)

The overall results from both datasets reveal that in higher zoom levels geometry recognition is more reliable with the algorithm used in this research. However, as the tolerance increases, the sensibility of the detection algorithm also increases.

4.2.Feature Recognition Results

The results of feature recognition depends on many factors; including: 1- The result of geometry recognition. If the geometry is not recognized correctly at the first stage, the results of feature recognition will be completely wrong. 2- The completeness of underlying ontology. Ontology provides the premises for reasoning. If the premises are not complete the conclusion may be uncertain or incorrect. 3- The quality, completeness and accuracy of the base-layers is critical for feature recognition. Base-layers provide the facts for the reasoning process. If the quality and accuracy of the base-layers is low or the data is incomplete we cannot expect reliable results in the reasoning process which leads to feature recognition.

However in our tests for few features on urban domain we achieved reliable results. The main reasons lie in the following facts:

1. A complete definition of tested features and their relationships (including geometric, topologic, and semantic relationships) with other features were modeled precisely.
2. The features were tested if and only if their geometry were recognized correctly and confirmed by the volunteer participants. So the algorithm deals just with the correct geometry type and the rest is just the matter of reasoning which follows the rules that are modeled in ontology.

3. For each feature in the test, there is one unique property that distinguishes it from the rest of similar objects. This property can play a major role in correct recognition. However, if the feature does not have a distinguishing property it will be among the results of candidate features.

This last chapter provides a summary of contributions with respect to the objectives and questions of this research. This work started with the idea that free sketching is the best modality in the interaction between human and computer in graphical applications, but comes with limitations in the field of spatial information and participatory activities. Facilitating the participation by utilizing interfaces that recognize the type of interaction may help to shorten the gap between average people's understanding of the spatial field and the de facto standard used by specialists in this field.

The basic assumption behind this research has been that good interface design leads to efficiency and effectiveness, but requires higher levels of intelligence on the computer side. However, maintaining and adding the intelligence to computers is more like a road to travel than a destination to arrive and can be improved by time and with more tests.

The results of this work provide a new insight on how interactions between humans and computers in the context of participatory GIS can be modeled and how spatial reasoning opens opportunities in sketch recognition, and even data validation, in the field of spatial information in a framework called PYPsketch. With the aid of free sketching tools, interactions between users and computers become more efficient, and using spatial reasoning enables us to recognize the sketched features or to validate the sketch. However this research shows that sketch recognition

in the web-mapping applications can be different from other applications in two different aspects: 1- Geometry recognition of a sketch on an interactive map depends on a collection of parameters including: zoom level which defines the scale at which the sketch is drawn; distance between the first and last point of the sketch; the overall length of the sketch; number of points in the sketch; and overall area that a sketch occupies. However, these parameters introduce some other tolerance values that are useful in the process of geometry recognition including: distance tolerance, area tolerance and line-polygon criteria. 2- Feature recognition which is a combination of geometry recognition, ontology of the domain, and spatial reasoning. The ontology consists of geometrical, topological and semantic relationship between an urban entity and other entities. The completeness of the ontology is the key to correct feature recognition.

This research has contributed to science in different ways by trying to bridge the gap between human cognition and digital maps that are used for decision making. These contributions include: 1- Developing a framework based on participants' requirements for a comprehensive and rich experience in a PGIS activity in which difficulties of interaction with a computer is minimized; 2- Developing an ontology to identify urban entities and model the semantic, topological and geometric relationships between them; 3- Investigating and applying spatial reasoning tools based on logical and semantic relations between urban entities; and 4-

Developing and testing a PGIS platform (named as PYPsketch) for sketch recognition in the domain of urban planning.

This research focused on facilitating user participation by developing a framework that focuses on average people's requirement. From this perspective, the objective to develop a framework that can assist participants in providing their local spatial knowledge, or their plans in the form of spatial sketches, has been achieved. We have shown that based on a thorough ontology for urban features, the PYPsketch platform developed in this research can recognize the sketches successfully. The more complete the ontology, the more accurate results achieved.

Many contextual factors affect the way that people sketch things on a map. Previous experiences, current trend of online applications and general knowledge of people in computer interaction are among these factors. However, free sketching gives people the flexibility to draw what they perceive and is efficient compared to drawing based on straight segment lines which requires a great number of clicks or taps on computer screen.

Utilizing the vast spatial functions, we have been able to create lots of reasoning patterns for different features in an urban context. These patterns mostly rely on DE-9IM calculus, however the review chapter of this thesis covers most of the developed reasoning algorithms. Utilizing these algorithms can enhance the functionality of spatial reasoning for further applications.

Lack of a standard ontology for spatial features in urban context was one of the major deficits in this research. Developing a customized urban ontology for the purpose of this research showed us the necessity and usefulness of such a standard. Having such a standard for both urban and non-urban contexts provides a huge convenience in validating the spatial data collected from different sources.

This research showed that sketch recognition in the field of urban planning is a combination of at least three major fields: geometry recognition, ontology (containing geometric, topologic, and semantic relationships), and spatial reasoning.

Another achievement in this research was the investigation of spatial reasoning and the role of ontology in modeling the urban patterns. Ontology and spatial reasoning are promising tools for data quality checking in urban planning, and for crowdsourcing applications (e.g. OpenStreetMap) where data comes from different sources. Inconsistent data may lead to lots of problems, while spatial reasoning can help detect ambiguities and inconsistencies in data.

5.1.Recommendations

The most important recommendation that can be made to enhance the quality of data gathered from participants, (given the tools developed in this research) is the requirement to detect the

pattern of screen focus of users when dealing with a computer application. This will reveal how people want to see maps and where they pay more attention while interacting with the map.

The other recommendation is the need to collect both paper drawings and computer drawings and compare them based on both geometrical and conceptual properties. Also, collecting further contextual data (e.g. gender, age, background, experience, nationality, environmental situation while participating such as during a natural disaster, and so on) can enhance our understanding of the social aspects of participation in mapping applications.

Considering general drawing on an empty canvas, other analysis such as principal component analysis and classification analysis can be used to extract the pattern of interaction between human and digital screens.

5.2.Future Works

Looking back at the first stages of this thesis and what we had planned; and comparing to the path travelled for this thesis, I have to admit that lots of changes have been made and the final output is not exactly as original plan. However, for those who are interested to continue the goals of this research I can propose some primary but major fields of research:

- The first field is human-computer interaction, in combination with other fields of research such as psychology and anthropology. Considering the

principles of Gestalt (Wertheimer, 1923) in pattern recognition (e.g. proximity, similarity, closure, symmetry, common fate, continuity, and past experience), to reveal the way that urban patterns are understood by lay people is an interesting field of research.

- The next field concerns the features to be sketched on the map. In this research only simple features were considered. By simple features, we mean simple points, simple lines and simple polygons. But real features are not always simple but vastly complex. Multi-points, self-intersecting lines, multi-polygons, polygons with islands, and complex features composed of other features, are a few examples that can be considered for future research.

- Considering fuzzy ontology for sketch recognition in the shade of vagueness and uncertainty is another field of research for future work.

- Developing a standard ontology for applications with spatial components is the next field of research. Urban features exist together based on written and unwritten laws. Collecting these laws and creating a knowledge base that describes the features and their ontological relationships can be both demanding and useful.

- For geeks, gurus, and hackers who are interested in developing new applications, I recommend developing similar tools for smart phones, tablets, smart boards, and any new devices brought about by new advances in hardware technology. Combining both interaction concepts and spatial reasoning concepts with fields of research such as Internet of Things (IoT), Smart Cities and autonomous cars is also recommended for fans of the technology world. On-the-fly validation of data collected by volunteers based on reasoning methods is also another field of research that combines new mapping technologies with deep spatial concepts.

- Connecting people's cognitive maps to spatial reasoning models requires a comprehensive understating of the way people perceive their environment and how they describe the relationships between features using simple everyday words. In order to convert these words to spatial functions we need to map everyday jargons and terminologies (such as: is away from, is surrounded by or surrounds, is divided into or divides into, is along with, is around, is part of, is separated by or separates, is distributed evenly and so on) to spatial concepts and functions. Some of these jargons convey simple spatial relationships between

urban features and some contain more complicated relationships. Another recommendation is to work on the mapping between everyday use of spatial terms and concepts, and how they can be modeled using spatial functionalities, and extend the boundary of spatial reasoning to cover these terms and concepts.

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APPENDIX A.

List of primary meetings and workshops shaping the foundation of this research

Title	Content
<i>Workshop, Jun. 8, 2011</i>	<i>Transportation scenarios, Land use scenarios, Required data, Population and demographic information</i>
<i>Research Team Meeting, Jul. 28, 2011</i>	<i>Research Groups: Geomatics, Transportation, Urban Planning</i>
<i>PYP API and Tools Meeting, Aug. 8, 2011;</i>	<i>Social Networking Platform; Authentication Service; User Education Tools: Photoshop imagery, web-map design, community feedback tools</i>
<i>Research Team Meeting, Sept. 16, 2011</i>	<i>PYP: a geospatial cyber infrastructure for sustainable community planning</i>
<i>Developer Meeting, Oct. 27, 2011</i>	<i>Tools: Like/Dislike a location, Add comment to a location/pushpin, Browse other preferences, Agree/Disagree option</i>
<i>Developer Meeting, Oct. 31, 2011</i>	<i>Social Network Web Design; Web Platform; PYP data schema;</i>
<i>Research Team Meeting, Nov. 3, 2011, and Workshop Nov. 4, 2011</i>	<i>Urban Renewal Tools; Review of educational and design tools that can be implemented in the PYP platform with the aim to have a group discussion to rank and prioritize the tools, and identify any missed tools;</i>

<p><i>Community Engagement</i> <i>Workshop, Jun. 15, 2012</i></p>	<p><i>General discussion of different aspects of participation for the community</i></p>
<p><i>Community Engagement</i> <i>Workshop, Jun. 20, 2012</i></p>	<p><i>Future development of the community</i></p>
<p><i>Community Engagement</i> <i>Workshop, Jul. 1, 2012</i></p>	<p><i>Plan Making</i></p>
<p><i>Community Engagement</i> <i>Workshop, Jul. 25, 2012</i></p>	<p><i>Wrap up</i></p>