The Legibility of Montreal's Urban Landscapes Through Google Street View

by

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ABSTRACT

Legibility is the perceptual quality of remarkable and distinctive urban landscapes. A city made up of highly legible environments is more clearly imagined in the minds of those that live within it. In this project, I develop a survey tool for studying the legibility of urban environments by implementing existing image recognition survey approaches in a web-based environment. I present an online, gamified survey platform, titled Geo-MTL, to assess the spatial patterns of legibility across Montreal's urban landscapes. I also investigate the factors that contribute to differences in legibility throughout the city. I find that legibility arises from a mix of individual and environmental factors in Montreal. I conclude that Geo-MTL is an appropriate way to survey populations of citizens about their perceptions and understandings of urban landscapes.

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CHAPTER 1. INTRODUCTION

A city is a multifaceted entity. To the architect or the engineer, a city may be an object with an ordered set of built features existing in a space that can predictably be manipulated and arranged. The taxi driver may know a city as a rationally organized grid of road networks. A young child may know a city as a park across the street and a back lane for bike riding. Individuals understand cities through their experiences living in them, leading to nuanced and idiosyncratic ideas about reality. It is unlikely that the cognitive structure of a city in the mind of a resident will conform to the way that such a city is objectively presented on a map. Citizens' knowledge of their surrounding environments is defined by how they perceive the environments around them and cognitively structure their complex nature.

This project is fundamentally an interrogation into the ways that we perceive and understand the urban landscapes around us. To improve urban life and create livable cities, researchers must work to better understand how residents' environmental perceptions and cognitions impact the ways that cities are understood (Appleyard, 1970; Gollege and Spektor, 1978; Nasar, 1990; Ittelson, 1978). I focus specifically on the concept of legibility, which is a perceptual quality of distinct and identifiable urban environments. Highly legible environments allow for the complex collection of diverse elements that make up a city to be cognitively organized in a coherent pattern (Lynch, 1960). Such a cognitive organization allows for the creation of an internal city image, which then defines the way that individuals will interact with the urban environment around them (Rappoport, 1977). Legibility is thus acknowledged to be a desirable characteristic of cities that contributes to enhanced livability and greater feelings of comfort in citizens (Lynch, 1960).

It is challenging to effectively survey citizens about their perceptions of the legibility of various environments, as legibility is an inherently internal and intangible form of spatial knowledge. Past research efforts have often assigned individuals tasks to perform, such as sketch mapping (e.g., Appleyard, 1969) or wayfinding exercises (e.g., O'Neill, 1991), to learn about how they imagine and navigate through external environments. More legible environments might then be those which feature prominently on an individual's sketch map or those which are considered easy to navigate. Past research efforts have also used image recognition tests whereby citizens are asked to locate photos from various urban landscapes throughout the city (Milgram, 1976; Quercia et al., 2013; Yeung and Savage, 1996). More legible environments are those that are more easily identified. As such methodological approaches have commonly been conducted manually, requiring great amounts of time on the part of both the researcher and the participants, population samples and study areas are often limited in size.

In this research project, I aim to expand the toolkit for research methods in the field of urban perception and cognition by developing and evaluating an online, gamified image recognition survey to capture the variations in legibility within an entire city. The approach presented in this project follows other research efforts that have used web-based tools to collect data on urban perceptual features (Quercia et al., 2013; Salesses et al., 2013). It is hoped that such an approach will facilitate the implementation of existing manual survey to be capable of easily collecting data from a large and geographically dispersed sample population. The approach that I develop is also distinct as it presents a means to quantify the legibility of a given landscape, allowing for statistical analysis and visualization of the overall study area's perceptual characteristics. I test and apply this method to the island of Montreal in Quebec, Canada to learn about the legibility of urban landscapes throughout this metropolitan area. I also use this method to explore the factors that contribute to enhanced legibility. In this research project, I explore the following specific research questions:

I. Is an online, gamified implementation of the image recognition survey tool an appropriate approach to collecting data on the legibility of various urban landscapes?

II. What do the spatial patterns of Montreal's legibility reveal about citizens' city image?

III. Which individual and environmental factors contribute to enhanced legibility of Montreal's urban landscapes?

By "appropriate", I am referring to the extent to which an image recognition test can be developed in an online environment in a manner that is engaging and easily usable to a survey participant. I am also referring to the extent to which this tool can facilitate the implementation of existing manual survey strategies, thus expanding the size and geographic scope of survey participant population samples.

To address these questions, my thesis is structured as follows. I begin by providing a review of relevant literature in the field of urban perceptions and cognitions. I address theories on the nature of the urban human-environment interaction, introduce the work of Kevin Lynch in "Image of the City" (1960), and discuss the ways that legibility has been operationalized as a concept in subsequent academic research. I then outline my methodological approach to developing the survey tool, called "Geo-MTL". I also detail my process of analysing the data collected from Geo-MTL. In my discussion of the results, I directly address the research questions presented above. I first discuss how the varied legibility of Montreal's urban landscapes reveals characteristics of citizen's city image. I discuss the factors contributing to the variability of legibility in Montreal. I then evaluate the appropriateness of Geo-MTL as a platform for collecting data on the legibility of Montreal and highlight contributions that this platform makes to existing research methods in the field. I conclude by proposing recommended directions for future research

CHAPTER 2. LITERATURE REVIEW

This chapter provides an in-depth review of literature pertaining to the ways that citizens understand their surrounding urban environments and how research has been conducted in this field. I begin by addressing theories of urban human-environment interactions, with a particular focus on the concepts of environmental perception, environmental cognition, and city image. These theories highlight the subjective nature of space in cities and address the complex ways that individuals are thought to develop spatial knowledge of their surroundings.

I then focus particularly on the concept of legibility, which is defined as the perceptual quality of distinct and identifiable urban environments that makes them clearly understood in the minds of citizens. In the field of urban perception and cognition, this concept was popularized by the work of Kevin Lynch in "Image of the City" (Lynch, 1960). Lynch's investigation into the legibility of various urban environments has inspired a wealth of subsequent research on this topic. I first discuss the concept of legibility as it was originally presented by Lynch, and then examine the various ways that subsequent research has both directly and indirectly operationalized this concept. I finish by highlighting gaps in existing research and suggesting directions for future research on the topic of legibility.

2.1 The Urban Human-Environment Interaction

In an investigation of how citizens understand their surrounding urban environments, it is first necessary to consider the ways that individuals and their surrounding environments coexist. The urban environment can fundamentally be viewed as both a social subject and a spatial object (Hillier and Hanson, 1989). The surrounding urban environment, in the object sense, exists independently to anyone's experience of it and holds consistent properties. The view of the city as object is likely not how we think about cities as we inhabit them (Ittelson, 1978). The ways that people live in and experience cities are defined by how people perceive the space around them and cognitively structure these environments (Ittelson, 1978; Golledge and Spector, 1978; Rappoport, 1977). Ittelson (1978) argues that it is not possible for an individual to ever know an environment in its entirety so one is continually seeking out new information and exploring to live more effectively and comfortably in space. Those living within an city and interacting with its spatial features may understand the environment in a separate way from how it exists in an absolute sense (Milgram, 1976). These authors argue that our human understandings of the environments around us will never converge on a single objective reality. The urban environments surrounding us should thus be considered as social subjects, rather than as spatial objects.

If one recognises that urban environments can exist in variable and idiosyncratic ways, it is important to think about how these variable understandings can come to be. The spatial knowledge that an individual possesses is first informed by processes of environmental perception. Environmental perception arises from the experience of an observer in viewing their surroundings (Ittelson, 1978). Perception is a direct visual experience, responding to incoming stimuli and specific contextual conditions (Rappoport, 1977). Perception also can be considered both in terms of process and product. Environmental perception is a continuous interaction between the individual and his or her environment, through which the characteristics of both entities have an impact on the resulting perceptual product (ibid.). Imagine, for example, an environment that contains a church. The way that an individual perceives this church may depend on the building's structural and design properties, the characteristics of its surrounding landscape, and the cultural or symbolic value that the individual attaches to its existence.

The nature of this process means that the city, as a social subject, does not exist as a single environment with invariant properties (ibid.).

Perceptions are transformed into knowledge through processes of cognition. Spatial cognition is concerned with the ways that people understand, learn about, and mentally structure their environment (Rappoport, 1977). While perception is concerned with an individual's immediate visual surroundings, cognition is concerned with an individual's knowledge of a greater whole. Cognition thus requires the development of schema that incorporate multiple layers of information (ibid.). As urban environments become increasingly complex, our cognitive understandings of space allow us to imagine relationships and understand configurations that are beyond our current visual field. Whereas perception is an instantaneous process of interpreting often-visual characteristics; cognition of space in cities pertains to the relational dynamics of urban elements and is an ongoing and iterative process (Rappoport, 1977). Urban environmental perception and cognition may have subtle differences but should be considered as extensions of each other.

Through processes of spatial perception and cognition, urban human-environment interactions ultimately lead to the creation of an internal city image. The metaphorical concept of city image refers to an internalized representation of the way that an individual understands an external reality (Rappoport, 1977). An individual's knowledge of the urban environments around them is organized and encoded in this internal city image. Depending on the nature of an individual's spatial knowledge, their city image may be relatively clear and well-formed in some parts of a city and fuzzy or ill-formed in others. As will be outlined further in the next section, legibility is a significant factor in determining the clarity of a city image. The characteristics of an individual's city image will impact that individual's spatial behaviour and urban experience (ibid). The concept of city image may also be referred to as a "cognitive map" (Downs and Stea, 1973), a "mental map" (Milgram,1976), or a "mental image" (Koseoglu and Onder, 2011).

Whereas city images may vary according to the nature of the individual; they also show regularities and interrelationships across groups of people (Rappoport, 1977). These regularities allow for the perceptions and cognitions of individuals to be aggregated, leading to the creation of a collective city image.

These theories on the nature of urban human-environment interactions provide a foundational conceptual framework for this thesis. The broad aim of this thesis is to advance research on how citizens understand and perceive their surrounding urban environments. Thus, it is important to first address the theories that acknowledge the subjective nature of the urban experience and describe processes and products of spatial knowledge attainment. The foundational concepts presented in this section of environmental perception, environmental cognition, and city image will be applied throughout this thesis to discuss the nature of legibility in Montreal.

2.2 Kevin Lynch and "Image of The City"

"Image of the City" (Lynch, 1960) is a foundational reference for literature in the field of urban perception and cognition. Fundamentally, Lynch is concerned with how a given city's visual character is translated to the cognitive understandings of its citizens. In pursuit of this aim, Lynch defines the term "legibility" and applies it to the previously outlined concept of city image. This work has informed many subsequent studies that have attempted to further operationalize the concept of legibility and investigate the ways that people understand their surrounding urban environments. Before addressing the various ways that legibility has been operationalized in other research efforts, it is first important to understand how the concept is originally used by Lynch.

Legibility is a perceptual quality of urban environments and refers to the “ease with which the parts of a city can be recognized and can be organized in a coherent pattern” (Lynch, 1960, p. 3). Legibility results from an urban environment that is perceived to be “visibly organized and sharply defined” (Lynch, 1960, p. 92). A city made up of legible environments can thus be easily visually understood and cognitively organized. Legibility is a necessary characteristic of urban environments that offers security and engages people with their surroundings (Lynch, 1960).

Note that Lynch’s work also introduces the term “imageability”, which he defines as “the quality in a physical object which gives it a high probability of evoking a strong image in any given observer” (Lynch, 1960, p. 9). The concepts of imageability and legibility have considerable overlap. In describing the concept of imageability, Lynch even suggests that it is equivalent to legibility. As the distinction between these two concepts is ill-defined (both from the perspective of Lynch and in subsequent literature), I will consider them to be synonymous and continue to solely use the term “legibility.”

A legible environment directly facilitates the creation of a clear city image. The visual form and structure of some cities may enhance legibility and facilitate the creation of a clear mental image, while another city’s form and structure may inhibit this cognitive clarity. Lynch compares Boston and Jersey City, for example, and finds that Boston’s distinctive neighbourhoods (e.g., Back Bay, Common, Beacon Hill) allow residents to clearly structure their city; whereas Jersey City’s apparent lack of distinctive character leaves residents with fragmented city images (Lynch, 1960). Lynch asserts that a clear city image is a necessary characteristic of a successful city and as it allows individuals to make decisions, feel connected, and learn new things about their surrounding environment. Lynch uses the concept of city image in a similar manner as is described in the previous section. Lynch's investigation into this concept leads him to suggest that the city images that people hold are made up of five city elements: pathways, nodes, landmarks, districts, and edges.

"Image of the City" is a preliminary exploration into the interactions between humans and their surrounding urban environments. As such, this work is highly conceptual and exploratory. Lynch does not offer any specific recommendations for how to create legible environments, nor does he offer approaches for measuring or quantifying the legibility of different environments. Moreover, Lynch identifies legibility as a perceptual characteristic, but does little to acknowledge the significance of the characteristics of the observer in contributing to legibility. Lynch's work is also lacking in empirical evidence as his findings are only based on a handful of survey respondents from each city and inferences made by researchers in the field. Lynch's work provides a useful theoretical basis, but further research is necessary to inform successful urban design and policy strategies to create legible urban environments.

2.3 Theories and Research Methods Pertaining to Legibility

Further exploration and investigation has been made into the concept of legibility in cities (Koseoglu and Onder, 2011; Jonge, 1962; Appleyard, 1969; O'Neill 1991; Yeung and Savage, 1996). Existing scholarship has operationalized the concept of legibility in a wide variety of ways. Some bodies of work offer insight into the conceptual foundations of this perceptual quality (Rappoport and Hawkes, 1970; Salingaros, 2000), while others have developed ways to apply this concept and investigate the way that it manifests in specific urban contexts (Appleyard, 1969; Ewing and Clemente, 2013; Weisman, 1981; Yeung and Savage, 1996). Both research focuses offer important insight into the ways that legibility shapes how citizens understand urban environments.

Conceptually, legibility is often linked to spontaneity and complexity in urban environments. Traditionally, urban design has aimed to create simple and clear environments (Rappoport and Hawkes, 1970). Paradoxically, it is organically flourishing complexity, which is a key dimension of urban coherence and is lacking in many contemporary cities (Salingaros, 2000). Analogous to legibility, urban coherence is said to be an essential characteristic for a "psychologically nourishing" city (Salingaros, 2000, p. 292). Salingaros' (2000) work in complex systems theory finds that connectivity across many levels of spatial granularity leads to greater coherence/legibility. A coherent urban environment, resulting in a vibrant city, fundamentally requires a diversity of naturally interconnected elements (ibid.). It is older cities such as Florence, Italy that are cited as examples of highly legible cities (Lynch, 1960). The comparatively organic and unplanned process of growth in a city such as this has resulted in visually irregular, but highly differentiated and characterizable urban forms.

This connection between legibility and complexity is echoed by Appleyard's (1969) work analyzing the legibility of buildings within a city. This research finds that, while simple building shapes allow for faster perception, buildings with a high degree of structural complexity are attention-grabbing. The distinctiveness enhances the presence of a given building in a citizen's city image. These findings connecting complexity to legibility point to the need for urban environments to be internally distinguishable. Intuitively, one may conclude that regularity allows for easier orientation and understanding of cities. Visual complexity, however, enhances our ability to identify features and differentiate between the many objects in our surroundings.

Our ability to assign a distinct identity to objects and features is connected to the strength of our image of a city (Lynch, 1960; Jonge, 1962).

This call for visual complexity in contributing to legibility echoes urban planning literature that discusses the principles of "good city form" and advocates for the creation of vibrant and lively urban spaces (Montgomery, 1998, p. 93). With the aim of creating livable urban spaces at the human scale, many urbanists advocate for urban form to be compact and diverse (eg., Gehl, 2013; Jacobs, 1961). While there may be an apparent sub-disciplinary divide between the "physical determinists" and the "subjective mental mappers" (Montgomery, 1998, p. 96), both perspectives offer a way to understand the human dimensions of cities.

To conduct research on the legibility of urban environments in specific urban contexts, it is necessary to learn about the perceptions and spatial knowledge that residents have about such environments. Capturing the spatial knowledge and environmental perceptions that urban residents have about their surroundings is acknowledged to be a challenging task because it requires externalizing an inherently internal form of information (Blades, 1990; Milgram, 1976). Individuals are likely not aware of the specifics of the spatial knowledge that they posses and so cannot directly communicate this information to a researcher. To address this challenge, past research efforts have often assigned tasks to people in the hopes that performance on these tasks will reveal information about the nature of how these people understand and perceive the environments around them. Commonly utilized approaches include sketch mapping, wayfinding exercises, and image recognition tasks. All of these approaches have been implemented specifically in the context of legibility.

Sketch mapping is an exercise whereby an individual draws a map of the study area of interest, thereby externalizing internal spatial knowledge. Legible parts of a city are then identified as those that feature more prominently on an individual's sketch map. Research on these sketch maps relies on the theory that one's internal understandings of the physical world adhere to a form of spatial structure (Cadwallader, 1979). This approach imposes the mapping metaphor on an individual's environmental knowledge (Blades, 1990; Golledge and Spektor, 1978).

Other studies have attempted to evaluate legibility by means of individual wayfinding performance (O'Neill, 1991; Weisman, 1981). Wayfinding within an urban environment is aided by the city image that an individual possesses (Lynch, 1960). As was previously outlined, greater legibility contributes to greater clarity of city image. With this approach, an environment that is more easily navigable would thus be considered to be more legible.

A further tool used by researchers to measure legibility is image recognition (Long and Baran, 2012; Milgram, 1976; Yeung, 1996). Such efforts assume that places and buildings that are more easily recognized are more prominent in a citizen's mental image of the city and thus more legible (Milgram, 1976). The notion of recognizability is also strongly linked to the concepts underlying legibility. As legibility is a product of environments that are well-formed and distinct, it is likely that environments that have these characteristics will be more easily recognized. Recognition tests acknowledge that people may encode the visual aspects of urban environments to facilitate their cognitive structuring of the city (Milgram, 1976).

Note that the survey methods outlined above have commonly been conducted manually and are thus labour and time intensive. This restriction limits the population sample size and geographic scope of research efforts.

As with many other forms of spatial knowledge, research has found that legibility results from a mix of subjective and objective factors. (Koseoglu and Onder, 2011). The literature does not hold a consensus on the specific factors that contribute to legibility, but it is relatively agreed upon that both characteristics of space (such as environmental design features), and characteristics of the observer (e.g., lived experiences) are noteworthy when considering legibility. Previous studies have attempted to isolate these factors in hopes of replicating successful urban spaces. To examine the legibility of Orchard Road in the eyes of Singaporeans, Yeung and Savage (1996) broke down legibility into personal and landscape factors. Personal factors included experience with a landscape, spatial proximity (based on an individual's place of residence), and mode of transport. Landscape factors included visual landscape cues (e.g., landmarks), internal structure, and functionality (ibid.). Research that focuses on the legibility of buildings has considered distinctiveness of physical form, visibility within the landscape, role as a setting for personal activities, and cultural significance to be predictors of whether an individual is able to recall a building or place (Appleyard, 1969). This tangle of contributing factors may vary from person to person and place to place, making it difficult to understand exactly why a feature, building, or city is legible or not.

2.4 Computational and Web-Based Research Approaches

In addition to the traditional research approaches previously outlined, theories and concepts regarding the urban human-environment interaction have been operationalized in new ways to take advantage of recent technological developments and newly available sources of data. Drawing from the expanding field of computational urbanism, recent research has focused on programmatic methods to extract a city image, often using newly available quantitative data sources. By mapping geo-tagged photos from Flickr, for example, researchers have attempted to create a representation of a collective city image, here called a "C-Image", of cities that point to the locations of Lynch's five city elements (Liu et al., 2014). This technique attempts to capture collective cognitive understandings of cities by making use of open, readily-available data. Lynch's framework for urban analysis has been further operationalized using the concept of an isovist, which is the field of view from a given vantage point (Benedikt, 1979). Three-dimensional isovists may be used to reimagine ways to characterize the legibility of urban form (Morello and Ratti, 2009).

The emergent concept of web-based crowdsourcing, or volunteered geographic information (VGI), offers the potential to collect unprecedented volumes of data on the ways that citizens understand and interact with their urban environments. The rise in crowdsourcing to solve spatial problems has been made possible by modern ICT technologies such as the "Web 2.0", GPS technologies, and broadband communication (Goodchild, 2007). Many traditional social science techniques to understanding urban perceptions and cognitions are taxing, both in terms of time and cost to implement. Many of the techniques presented previously to capture urban factors such as legibility can thus only be applied to small samples of urban populations. Online crowdsourcing offers a means to solve these problems (Quercia, 2016). The MIT Place Pulse project, for example, uses online imagery from Google Street View to map urban perception according to factors such as inequality, liveliness, and safety. The data from this project is collected with voluntary crowdsourcing on an online platform (Salesses et al., 2013). At the time of writing, this platform has collected nearly 1.5 million data points. Quercia et al.'s (2013) work on mapping legibility throughout the city of London also employs crowdsourcing methods to collect large volumes of data from residents on the recognizability of various Google Street View panoramas throughout the city. Participation on this platform is encouraged by structuring the survey as a game, with participants each receiving a score after completing the required tasks. With the relative ease of access of digital platforms, surveys distributed online and presented as “fun” activities can reach large populations across a wide geographic area with minimal effort from the researcher (ibid.).

When collecting data from citizens using digital tools, however, it is important to think about the bias that will be present in the resulting sample. The use of digital tools may result in several types of barriers to access. Individuals lacking basic digital experience, possession of computers or network connectivity, digital skills, or opportunities for usage (Van Dijk and Hacker, 2003) may be unable to participate in digital crowdsourcing platforms.

2.5 Conclusion

The examples presented in this chapter of recent efforts to operationalize the concepts of legibility and city image highlight the many ways that space in cities can be understood through the lens of their inhabitants. This literature review also demonstrates ways that these longstanding concepts are being adapted to our current information age full of new geospatial data sources and methods of engaging with citizens.

While there has been much research on how people interact with and understand their surrounding cities, we still have much further to go in learning how to apply the concept of legibility to create better urban environments. I argue that we need to be able to translate information about city image into a set of tools that designers and planners can use. To do this, we must consider legibility as a factor of urban environments that can be measured and quantified. We must more deeply explore the characteristics of the urban environment that contribute to enhanced legibility. Likely due to the time and resources required for survey implementation, little research has been conducted on legibility at the scale of an entire city with data from a geographically dispersed population sample. Many studies that attempt to capture the collective perspectives of citizens have analyzed big data sources such as geo-tagged photos and social media data (e.g., Liu et al., 2014). Despite the wealth of work that has applied computational approaches to analyzing the concepts of legibility and city image, little work has been done to adapt the traditional survey approaches (such as sketch mapping, or image recognition) to take advantage of newly available online tools and concepts such as crowdsourcing and gamification.

CHAPTER 3. METHODOLOGY

This chapter provides a detailed review of the methods used in this study. These methods are applied to gather and analyze data on the spatial knowledge that self-identified residents of Montreal have about their city. The design and development of the survey tool is a major outcome of this thesis. The survey tool is applied to specifically examine spatial patterns of legibility throughout Montreal and explore the potential factors that contribute to enhanced legibility. In this chapter, I first discuss the survey design, implementation, and pretesting. I also describe the methods used to recruit survey participants. I then outline the analytical techniques that are applied to the data collected from the survey. I finally outline several methodological limitations of this study.

3.1 Creation of the Survey Instrument

I designed a survey to collect data on the legibility of various urban landscapes throughout Montreal. As my aim is to learn about a perceptual characteristic on Montreal, a survey is an appropriate approach that allows me to collect data from individuals on their perceptions. The survey tool that I developed, titled “Geo-MTL”, is an extension of existing image recognition surveys that have been used to test people on the legibility of various landscapes (Milgram, 1976; Yeung and Savage, 1996). With this approach, the ability of an individual to recognize or identify a given landscape is considered to be a metric with which to evaluate the legibility of that landscape.

Using Geo-MTL, I collect several different types of information from survey participants. I firstly use this survey platform to test participants on their ability to recognize a set of five landscapes from throughout Montreal. I collect quantitative data on participants’ performance in this task. I also ask for data on the home location, work location, and years lived in Montreal of each survey participant. This data is collected to aid with future investigations into the factors that contribute to legibility in Montreal. I collected these selected personal variables as existing literature has shown that an individual's familiarity with a given landscape is likely to impact the legibility of that landscape (Appleyard, 1969; Koseoglu and Onder, 2011; Rappoport, 1977; Yeung and Savage 1996). I also chose to collect data on these variables as they are factors that can be quantified. This was done so that the data could be aggregated and analyzed using statistical techniques. Lastly, I used Geo-MTL to collect data on the qualitative perceptual features that survey participants can identify in each of the urban landscapes that they are shown. I collected this information as it allows me to investigate the features of the built environment that contribute to legibility.

3.1.1 Technical Implementation

Geo-MTL is implemented as an HTML webpage that uses the Google Maps JavaScript API to display Google Street View panoramas. These Street View panoramas function as the urban landscapes that Geo-MTL participants are asked to recognize. Google Street View primarily uses cars mounted with cameras to capture images as the car moves through a city. Panoramas are generated by stitching these images together. Individual users can also contribute to Street View by adding photos from social media platforms like Flickr, Panoramio, and Picasa (Anguelov, Dragomir, et al., 2010). As our experiences within a city are most often on or adjacent to streets, Google Street View data is an effective way to display various landscapes within a city. This approach also mirrors past research that has used Google Street View to collect data on the perceptual features of urban landscapes (Quercia et al., 2014; Quercia et al., 2014; Salesses et al., 2013). The API was also used to remove absolute identifiers, such as street name labels, that are ordinarily present in the panoramas.

The five Street View panoramas that a Geo-MTL participant is shown is determined by an algorithm that randomly selects five x,y coordinates from a dataset of 2,600 coordinates that are all within the island of Montreal. Based on the assumption of a total sample size of approximately 200 participants, the size of this dataset was chosen to ensure that it would be unlikely for two participants to be shown the same panorama twice. The closest Street View panorama within 500 meters of each randomly selected coordinate is shown to a participant. The size of this buffer was found to be large enough that each of the coordinates could be associated with a Street View panorama.

The dataset of 2,600 random coordinates was generated in a manner that created a distribution corresponding to the population density per borough on the island of Montreal. This bias towards where people live was presumed to render the game more engaging for participants. It is assumed that landscapes in higher population density boroughs are generally in more recognizable parts of Montreal. Boroughs with higher population density are also assumed to be more internally heterogeneous, resulting in a need for greater sampling. The probability that a participant will be placed at a Street View location within a borough with a higher population density is greater than the probability that a participant will be place at a Street View location within a borough with a lower population density. A breakdown of the number of Street View points per borough can be found in Table 3.1.

Table 3.1: Montreal boroughs with associated 2016 population density (Statistics Canada) and number of Street View points

Borough Name	Population Density (people/km^2)	Number of Street View points
Plateau Mont Royal	127921	256
Rosemont-La Petite Patrie	88069	176
Villeray-St. Michel-Park Extension	87237	174
Côte des Neiges-Notre Dame de Grâce	77668	156
Montreal North	76230	152
Verdun	71260	142
Outremont	62218	124
St. Leonard	58047	116
Ahuntsic-Cartierville	55565	112
Mercier-Hochelaga-Maisonneuve	53532	108
Ville Marie	53977	108
Westmount	50553	102
Sud-Ouest	49841	100
Côte St. Luc	46755	94
LaSalle	47236	94
Hampstead	39043	78
Montreal West	35969	72
Dollard des Ormeaux	32234	64
Anjou	31284	62
Mont Royal	26522	54
Pierrefonds-Roxboro	25609	52
Pointe aux Trembles-Rivière des Prairies	25247	50
Lachine	25107	50
St. Laurent	23107	46
Kirkland	20938	42
Beaconsfield	17599	36
Pointe Claire	16656	34
Dorval	9103	18
Île Bizard-St. Geneviève	7802	16
Baie d'Urfé	6358	12
St. Anne de Bellevue	4700	10
Montreal East	3090	6
Senneville	1233	2

The Google Maps JavaScript API was also used to display maps that enabled Geo-MTL participants to identify each of the Street View panoramas. By placing a marker on a map, participants were asked to estimate the corresponding location for each Street View panorama. The API was used to style the maps so that only roads, highways, parks, and bodies of water are present. Road labels are visible when the user zooms in to the map. More detailed labels such as notable businesses and institutions are not present on the maps. This simplified cartographic representation of Montreal was chosen to reduce the amount of visual clutter present on the map. The removal of business and institutional labels was also done to better test participants' spatial knowledge. For example, if a participant is shown a Street View panorama that contains the Montreal Biodome, he or she should be tested by being asked to locate the Biodome and not be aided by a label on the map that already indicates its location.

3.1.2 User Interface Design

Geo-MTL functions as an online app that participants can engage with one their own without researcher guidance. It was necessary to create a clear user interface to ensure that participants would interact with the survey in the way that was intended. The user interface was designed to communicate a clear flow of desired interactions and control for potential errors in participant interaction. The intended progression of participant engagement with the platform is indicated by "next" and "previous" buttons linking multiple webpages and by a linear progression of instructions that appear as participants scroll through each single webpage. Popups will also appear if the participant fails to fill in the required information.

In designing the user interface, I focused on adhering to seven principles: use of colours to promote visual clarity and draw attention to significant places of interaction; consistency of graphics and colours across multiple webpages; clear logo to facilitate recognition of the app; organized and clearly structured layout, text, colour, and placement on the page to prompt users on where to click next; and finally minimal use of text. Many of these design principles follow those outlined in the literature on human-interface and user-interface design (Norman, 2002; Oppermann, 2002; Reynolds, 2006; Shneiderman, 2004). Good interface design can be used to create a sense of professionalism, which can improve the quality and number of survey responses (Reynolds, 2006). By adhering to the above principles, the usability of the online survey can also be enhanced (Oppermann, 2002).

3.1.3 User Experience

After navigating to the Geo-MTL webpage (accessed via a URL), participants are first presented with a page that presents the requirements for participation (being a resident of Montreal) and describes the task that they will be asked to perform (see Figure 3.1). The image recognition tasks are framed as a test of how well participants know the city around them. This was done to make the game appealing to participants and induce competition between participants. I decided not to directly refer to the concept of legibility on the Geo-MTL's user interface (aside from on the consent form) as I feared that a more academic framing of the survey's aim would intimidate potential survey participants.

Participants are then prompted to navigate to another page where they are presented with a consent form, as per Research Ethics Board requirements. The participant then navigates to the next page, which contains the series of image recognition tests. On this page, participants are first asked to click on a map to indicate their home and work locations, and type in the number of years that they have lived in Montreal (see Figure 3.2). Participants then scroll down the page and are presented with a series of five map/Street View panorama pairs (see Figure 3.3).

For each of the five Street View panoramas, Geo-MTL participants have the opportunity to explore the panorama as much as they wish. Exploration of the panorama may entail zooming in to get a closer look at certain features, travelling further down a street, or panning around a complete 360-degree view. This level of interaction was chosen to allow participants to obtain a greater amount of information about the landscape than would be communicated through a static photograph. Written instructions encourage participants to avoid looking at street signs as locational indicators. Participants will then place a pin on a map of Montreal to indicate their guessed location of the Street View panorama. Participants must click on a button to confirm their guess. After the guess is confirmed, a marker displays the true location of the Street View panorama and indicates the error distance (in meters) of the participant's guess.

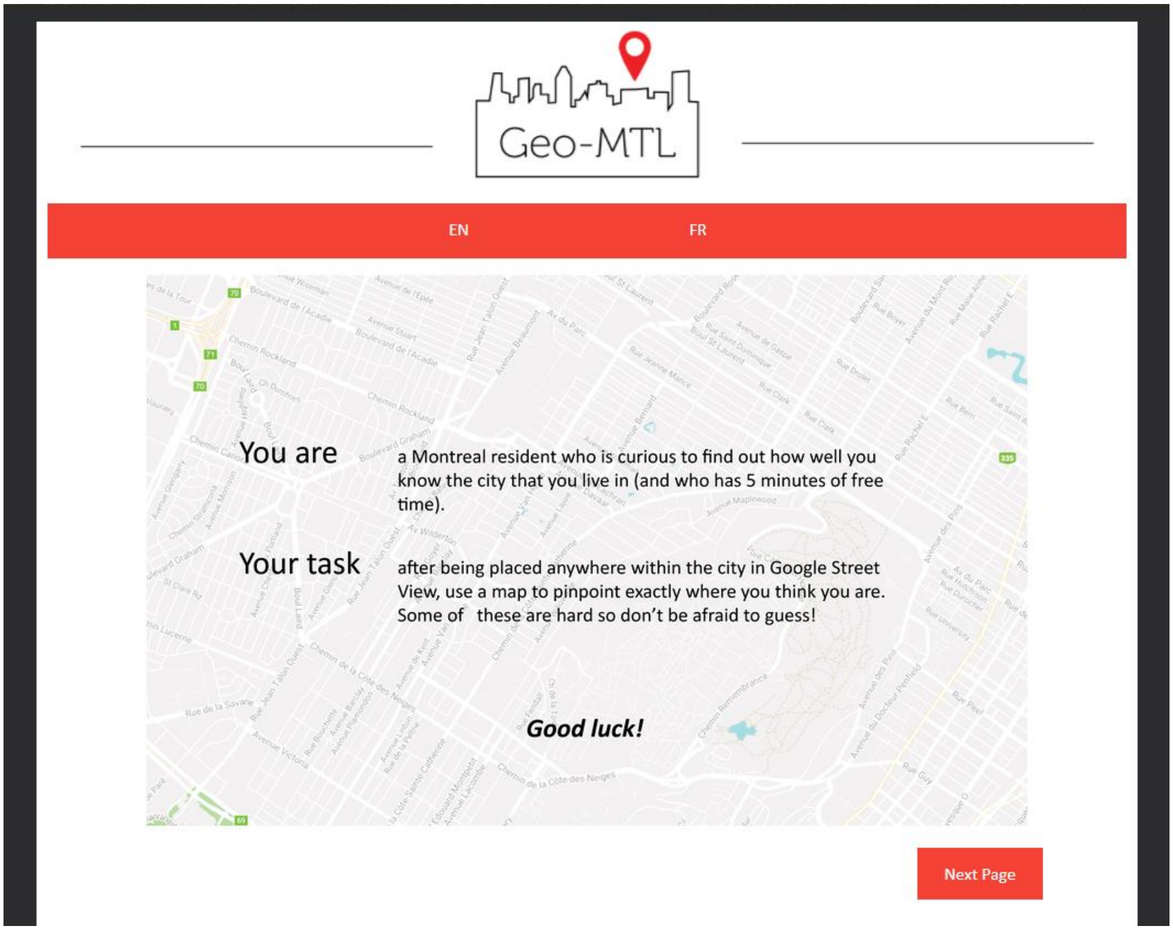


Figure 3.1. Introduction page for Geo-MTL

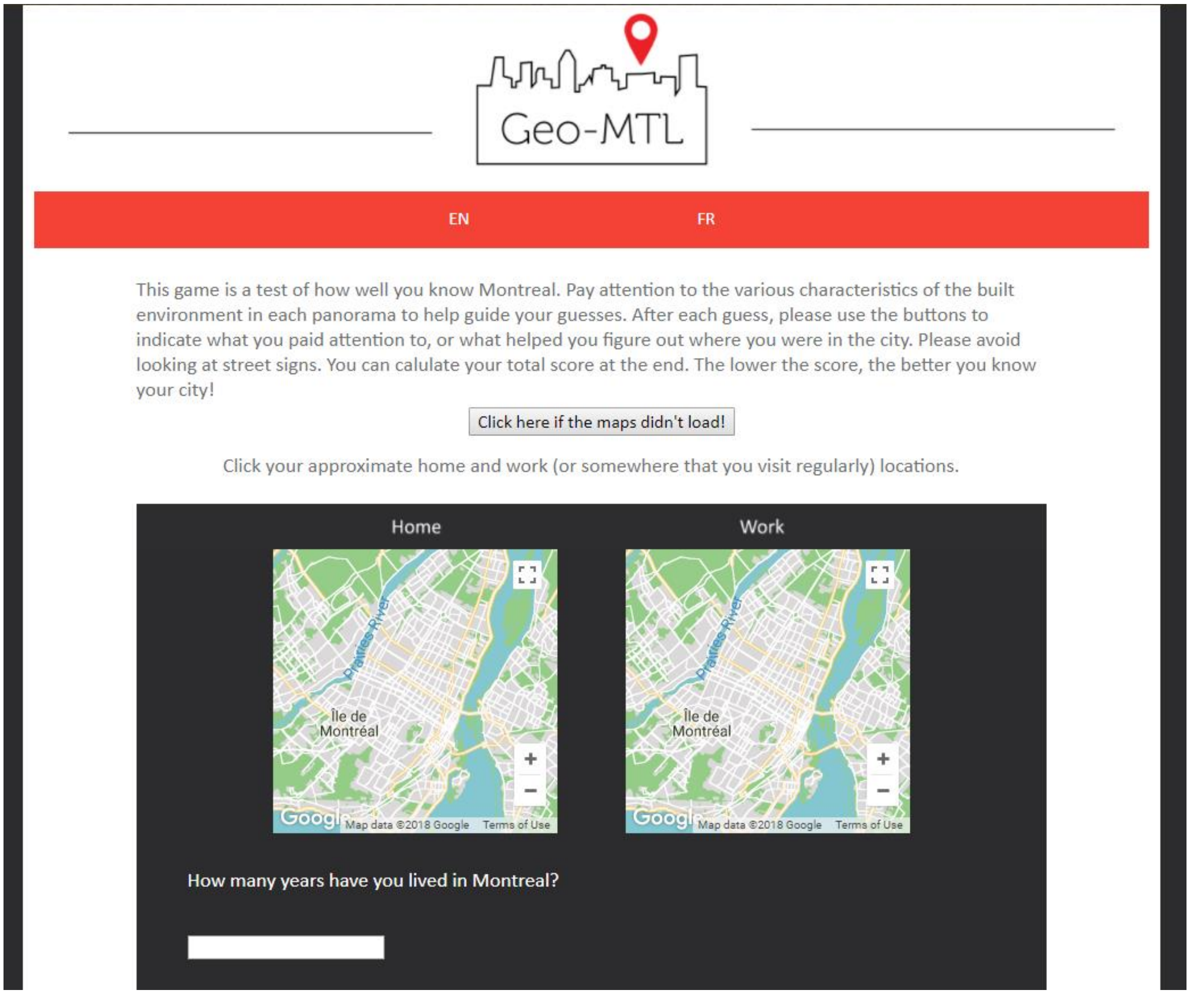


Figure 3.2. Geo-MTL personal information input

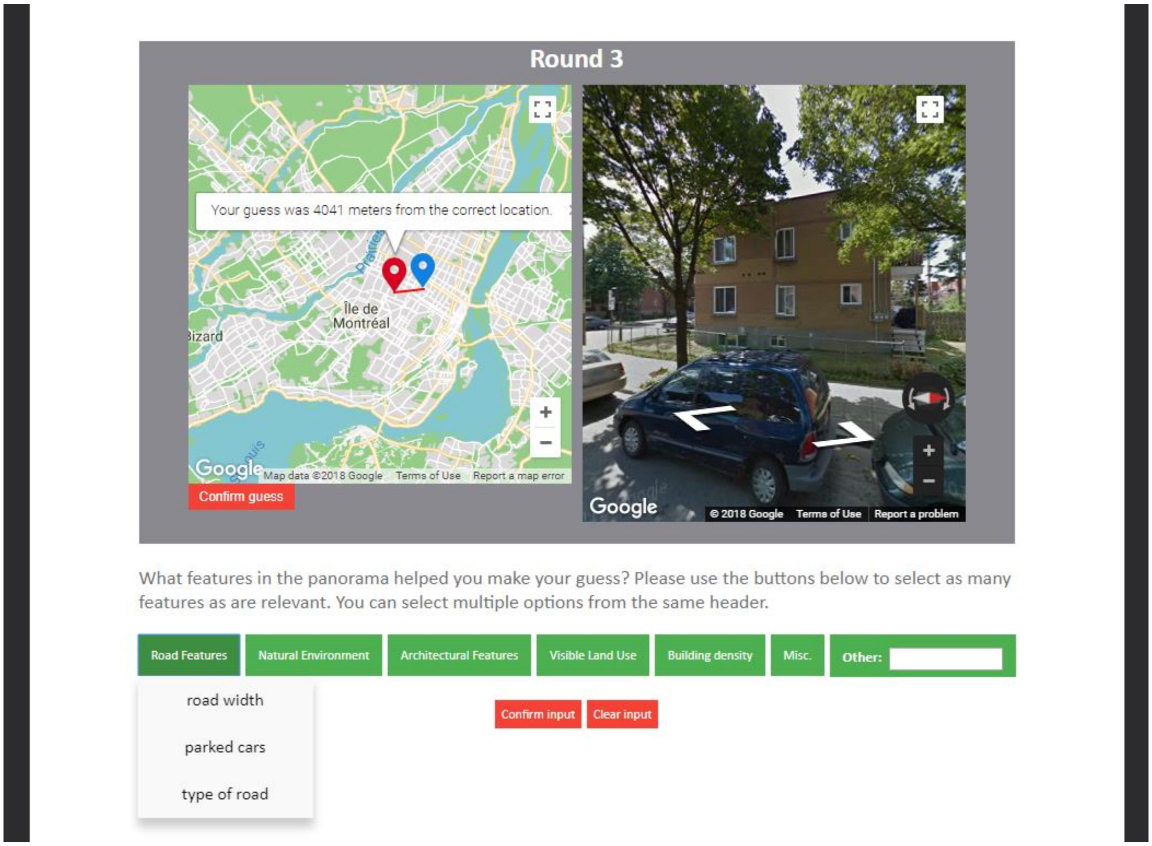


Figure 3.3. Geo-MTL Street View recognition task

Participants are then prompted to select from a series of pre-determined tags to indicate the visual features that they perceived in the panorama. Geo-MTL allows participants to pick any number of a set of tags, which are associated with urban features relating to road features, the natural environment, architectural features, visible land use, building density, landscape elevation, visible signage, and visible landmarks. A comprehensive list of the tags available can be found in Table 3.2. Participants also have the option to create their own tag if desired (a text box with an “Other” prompt). These tags were chosen based on a focus group discussion and a review of the urban design qualities highlighted by Ewing and Clemente (2013). Participants are required to select at least one tag for each panorama. There is no limit to the number of tags that can be assigned to each panorama. Interaction with this page is completed when the participant completes all five of the panorama recognition tasks and clicks on a "Submit" button.

Table 3.2. Panorama tags in the Geo-MTL survey.

Road Features	Natural Environment	Architectural Features	Visible Land Use	Building Density	Misc.
Road width	Amount of vegetation	Building façade characteristics	Residential	High density	Landscape elevation
Presence of parked cars	Landscape design	Building material	Commercial	Medium density	Visible signage
Type of road	Type of vegetation	Distinctive neighbourhood style	Industrial	Low density	Visible landmark
			Open space/recreational land		

The Geo-MTL user experience is also gamified in the hopes of encouraging greater participation. Online survey platforms also commonly use gamification as a means to increase the level of survey participation. Defined as the inclusion of game elements in non-game settings (Deterding et al., 2011), gamification is an increasingly popular survey strategy because it can redirect the motivations of participants from traditional gain-seeking extrinsic motivations, to those that are self-driven and intrinsic. With techniques such as points systems and leaderboards, gamification has been shown to increase engagement, reduce cheating and increase the output quality of information collected (Morschheuser er al., 2016).

After completing the five panorama recognition tasks, participants are given a score, which can be input onto a public leaderboard. This score is a reflection on the recognition performance of the participant. The leaderboard enables each participant to compare his or her performance with that of his or her peers. Overall, the survey is intended to be completed in under ten minutes. By only demanding a minimal amount of participants' time, it is hoped that more people will be encouraged to participate in the survey.

3.2 Focus Group Testing

After a beta version of the Geo-MTL platform was built, I conducted a focus group to test the user interface design and gain a better understanding of how the platform would be used by participants. A focus group can be defined as a small group of people convening under the supervision of a facilitator to discuss a pre-defined topic (Cameron, 2016). Focus groups are a valuable discussion platform for the interaction that is enabled between participants. Focus group discussions are often characterized by energy and dynamism as participants are able to actively share ideas and agree or disagree with each other (ibid.).

Participants of the focus group were required to be Montreal residents who had not previously been exposed to Geo-MTL. Due to ease of access, I recruited McGill students to be focus group participants. Fourteen participants (four men and ten women) were recruited online through Facebook posts in "Groups" affiliated with McGill University.

The focus group began with participants being given a brief introduction to the aims of this research project. Participants were then asked to play a round of the Geo-MTL without any additional instruction from myself. Participants were encouraged not to communicate with each other while playing the game. By playing the game, this focus group also functioned as a pilot test to detect any technical problems with the implementation of Geo-MTL. After completing the game, participants filled out a brief online survey, the contents of which can be found in Appendix A. The group then collectively discussed their experiences with Geo-MTL. Acting as the focus group facilitator, I led the group's discussions and kept participants focused on topics relating specifically to the usability of the online platform, the methods of navigating within the street view panorama, the use of a text box to input image tags, and the factors of the urban environment that participants focused on while navigating through the panoramas. The focus group lasted for approximately one hour.

I took detailed notes during the focus group discussion to inform further analysis. After the focus group concluded, the comments made by each focus group participant were categorized according to the topics that they pertained to. Categories included overall usability and interface design, panorama navigation, text box use, and panorama factors. The information obtained from this focus group was used to modify and improve the Geo-MTL app in terms of its user interface and underlying structure. The results of the focus group will be reported in the next chapter.

3.3 Participant Recruitment

Any individual who identifies as a current resident on the Island of Montreal qualifies as a potential participant in this research project. This sole requirement was selected as my focus is on understanding how Montreal is perceived and understood from the perspective of its inhabitants, rather than from the perspective of transient visitors such as tourists. The differing interpretations of "resident", in terms of the length of time lived in Montreal, is factored into the data analysis. As there are no limitations of the number of people that can play Geo-MTL, the recruitment strategies used for this project aimed to reach a large and geographically widespread sample of the Montreal population.

The web-based nature of Geo-MTL allows for a virtual recruitment process. One dimension of the recruitment strategy involved advertising the app on social media. Many participants were recruited through online social media platforms including Facebook, Twitter, and Reddit. I personally posted on these social media sites by both advertising the platform as a "status update", and by posting on group pages that I had access to and that I knew contained a high percentage of Montreal residents. Participants also were recruited through "snowball sampling" techniques (Baltar and Brunet, 2012; Browne, 2005) as initial participants were asked to pass on information about the app to those in their personal social networks. I personally reached out to targeted individuals who I knew to be part of communities that I would not be able to reach online (such as residents from the West Island). Participant recruitment via social media sites such as Facebook has been shown to enhance the geographic scope of the study, save time and cost, and improve access to "hard to reach" populations (Baltar and Brunet, 2012; Sadler et al., 2010). Participants' confidence in participating in Geo-MTL may also have been enhanced as my personal information (via a social media profile) was publicly available (Baltar and Brunet, 2012).

Additionally, participants were recruited through advertisements at McGill's Geographic Information Centre, where a link to the game was published on the screen savers of the public computers. Finally, Geo-MTL was made part of an extra credit assignment for an introductory course at McGill.

Research Ethics Board (REB) approval was required to permit data collection from human subjects. Proof of REB approval can be found in Appendix B.

3.4 Data Analysis

The data collected from each participant of Geo-MTL includes the variables indicated in Table 3.3. This data was analyzed to understand patterns of legibility across Montreal's urban landscapes and investigate the factors that contribute to variations in legibility between different landscapes. For each data point, variable E is representative of the corresponding urban landscape in question.

Table 3.3. Overview of variables collected from Geo-MTL

Variable label	Variable description	Variable Type
A	Home location	Latitude/Longitude coordinates
B	Work location	Latitude/Longitude coordinates
C	Number of years lived in Montreal	Integer
D	Guessed panorama location (X5)	Latitude/Longitude coordinates
E	Actual panorama location (X5)	Latitude/Longitude coordinates
F	Panorama tags (X5)	Pre-determined text input

Before applying further analytical techniques, it was first necessary to preprocess the data by removing all incomplete responses. Any data entry with one or more of variables A through F missing qualifies as an incomplete response. Basic descriptive statistics were then calculated variables A, B, and C to characterize the population sample. The home and work locations (variables A and B) of all users were visualized, and the mean center for each variable was calculated. The total number of participants with home and work locations in each borough was also determined. The mean and standard deviation was also calculated for variable C.

The first goal of the analysis was to determine the spatial distribution of legibility throughout the island of Montreal. Greater legibility of a given landscape is determined by greater recognizability. For each data point, the Euclidean distance between variables D and E was calculated. This distance value reflects the recognition error associated with each Street

View panorama. An urban landscape is considered to be more legible if the recognition error value corresponding to the associated Street View panorama is low. Spatial patterns of legibility can then be visualized by displaying the recognition error values for each Street View panorama in the dataset.

The recognition error values were paired with their corresponding Street View panorama locations (variable E) and interpolated using the inverse distance weighting (IDW) technique. The interpolated results were smoothed using a mean focal statistics function to provide a clearer visualization. These results were then presented as an estimation of the continuous patterns of legibility throughout Montreal. The IDW interpolation technique was chosen as it generates missing values based on the presumption of spatial autocorrelation in the data. A Moran's I was conducted to confirm this assumption regarding the spatial nature of the recognition error values. IDW is also conceptually and computationally simple relative to other interpolation techniques. As the results of the interpolation are only used for visualization purposes, IDW's simplicity gives it an advantage over other techniques.

The recognition error values for each Street View location were also were aggregated by borough. The mean recognition error for each borough was calculated and visualized as a choropleth map. This approach enables the quantitative comparison of Montreal's boroughs in terms of legibility.

Lastly, a buffer analysis was conducted to produce a radial pattern of legibility throughout the island. The center point of Montreal's "Golden Square Mile" district, which is acknowledged to be the location of Montreal's downtown core (Shillier, n.d.), was identified and concentric buffers were created from this point at 1km intervals to encompass the entire island.

The mean recognition error values for each of the data points were then calculated for each buffer.

Each of these visualization approaches (interpolation, aggregation by borough, and buffer analysis) allows for the visual examination of the spatial nature of legibility in Montreal, highlighting regions of comparatively higher and lower legibility. The results of this analysis were used to make inferences about the ways that Montreal residents cognitively imagine the island. Note that the recognition error values are simply intended to capture various relative degrees of legibility, rather than serve as an absolute measurement. The scores are significant only when compared with each other. The recognition error values have little significance when considered independently from each other.

To explore the variations in recognition error values throughout the island of Montreal, an OLS (ordinary least squares) multiple linear regression model was first created. This model was created to investigate the significance that the personal variables (variables A, B, and C) have in explaining the recognition error values. The dependent variable in this model was the set of recognition error values. The Euclidean distances between variables A and E, and variables B and E were both calculated. These distance values were calculated to capture the proximity of each participant's home and work locations to the Street View panorama that they were shown. These two distance variables and the number of years that a participant has lived in Montreal (variable C) were selected as potential independent, explanatory variables. To capture the spatial dependency of the dependent variable, 32 dummy variables, corresponding to the borough location of the data point's Street View panorama, were created to serve as further potential independent, explanatory variables. To avoid the perfect collinearity, one of the borough dummy variables was excluded from the model. The regression model was then specified through a process of backwards elimination. All potential explanatory variables were initially included in the model. Explanatory variables that were found to have no statistical significance (based on a t-test with $P<0.05$) were removed from the model. Regression model specification also was guided by the principles of parsimony, goodness of fit (with the adjusted R^2 values as high as possible), and theoretical consistency (Allen, 1997).

An analysis of the tags that Geo-MTL users associated with each of the Street View panoramas was conducted to reveal some of the perceptual features that contribute to the variability in recognition error values. This was done in the following manner. To first describe the nature of the results, the mean and standard deviation for the number of tags selected for each panorama was first calculated. The total number of tags used from each of the categories indicated in Table 3.2 was then counted. Next, the entire collection of data points was ranked according to the recognition error values. The data points were then divided into quartiles with the following score categories: low, low-medium, high-medium, and high scores. For the top and bottom quartiles (reflecting the data points with highest and lowest recognition error values), the frequency of occurrence of each panorama tag was calculated. This was done by identifying the total number of occurrences for each panorama tag within a given subset of the data points and dividing that value by the total number of data points in the subset. This tag frequency calculation also was performed on the entire set of data points. The results were then visualized on a single histogram to enable a descriptive comparison of the frequency values associated with each tag between all the data points.

This quantitative analysis of qualitative data was made possible by the fact that users almost always chose tags from amongst the pre-set options. A descriptive analysis was conducted for the tags in the “other” category that were contributed by the users.

3.5 Methodological Limitations

3.5.1 Survey design

As with other strategies to capture spatial knowledge, this methodological approach is embedded with a set of assumptions that have not been empirically tested. Firstly, the theory behind this app assumes that participants' knowledge of Montreal's visual features has geospatial associations. This approach also assumes that the differences in recognizability between landscapes can be determined by a linear distance value. The scoring of recognizability based on recognition error distance reflects one of many ways that recognizability could be quantitatively measured. Recognizability also could have been scored based on distance thresholds or according to a non-linear equation. Rather than scoring recognizability as a Euclidean distance value, distances along a path (such as a road network) could also have been calculated and compared. Conceptual difficulties also arise with quantitative approaches to understanding inherently subjective phenomena, such as urban perceptual features. Whereas the quantification of legibility across different landscapes enables effective comparison and statistical analysis; the recognizability scores used to determine legibility of environments are not objective characteristics of these landscapes.

As an online platform, Geo-MTL may also have problems with equitable access. Geo-MTL requires that participants have some familiarity and comfort level with Google Maps, both in its planimetric and Street View form. Geo-MTL also requires that participants have access to a computer and have a certain degree of technological literacy and confidence.

This approach also limited in its consideration for the individual characteristics of participants. In an effort to retain participant privacy and reduce the amount of time required to complete the survey, minimal individual factors are collected from participants. To aid with future analysis I also focused on personal factors that could be quantified. Perception and cognition are likely impacted by a complex series of factors that are not considered by this survey. Nuanced factors such as the symbolic meaning and cultural values that individuals attach to different landscapes likely impact how those landscapes are perceived. Difficult to quantify factors such as race and language may also have an impact. An analysis of factors such as these is beyond the scope of this research project but could be interesting for future research.

Furthermore, the perceptual tags that survey participants assign to the Street View panoramas may not be consistently interpreted across all participants. While the tags are intended to be easily interpretable and unambiguous, it is nevertheless possible that some users assign tags to images according to different personal interpretations of the meaning behind the tag content. Such a source of error could perhaps have been mitigated by a detailed set of instructions and definitions for each tag. This would likely have significantly increased the time that users were required to spend playing Geo-MTL, thus decreasing the number of participants.

3.5.2 Survey Recruitment

Due to the online nature of this game and the fact that users participate remotely, it is not possible for me (as the researcher) to verify that participants are truthful in reporting the required personal information. Whereas the instructions on Geo-MTL indicate that it should only be played by Montreal residents; there are no functional blocks on who is able to participate. This drawback owing to the web-based nature of this survey is offset by the benefits of ease of dissemination and participation.

The self-selected nature of participation in a web-based survey also makes if difficult to ensure that the population sample is unbiased and representative. The access that I have to online communities (via platforms such as Facebook) is skewed towards populations of undergraduate, English-speaking, University students who have very similar activity-spaces in the city.

CHAPTER 4. RESULTS

In this chapter I present the results of the research. First, I report on the outcomes of the focus group pertaining to Geo-MTL's usability. In presenting the focus group results, I address the reported ease of navigability of the platform, enjoyment of user experience, and reported behaviour patterns when navigating through the Street View panoramas. I highlight specific suggestions that participants made for ways that the app could be improved. I then report on how the focus group informed further development of the app.

In the second part of my findings, I describe the results of the data collected from Geo-MTL over the span of two months. I describe the characteristics of the survey population sample and illustrate the spatial patterns of recognizability throughout Montreal. I then report on the results of the regression analysis that attempts to explain the variability in recognition error values. I finally present the data on the tags associated with each Street View panorama.

4.1 Geo-MTL Usability

The results of the focus group revealed the usability of Geo-MTL as an online survey platform and informed further refinement of its user interface. Overall, focus group participants found the beta version of Geo-MTL to be simple to use and clear in its prompts and instructions. Over half of participants indicated that the app was very easy to navigate. The interface design also was well-received. Participants commented on the interface's "user friendly" nature, "clean-looking" design, and straightforwardness. Recommendations for changes included having a button to confirm a guess, using bigger maps and panoramas, and including more street labels on the map where guesses would be placed. All of these recommendations were incorporated into the final version of Geo-MTL.

Participants reported that the game was generally enjoyable to play as it enabled them to determine how well they knew Montreal. One participant indicated that, after playing, she felt the desire to "get out and explore more places in Montreal." Several participants, however, reported feeling frustrated after not being able to recognize any of the Street View panoramas. Many focus group participants indicated that they would feel more incentivized to play Geo-MTL if they were able to compare their scores with other users. This led to the creation of the leaderboard on the Geo-MTL platform.

Focus group participants also responded to questions about their interactions with the Street View panoramas and the features that they noticed within the panoramas. The majority of participants reported that they spent 15 seconds to 1-minute navigating through each panorama. Participants did "travel" beyond the origin point, moving the cursor to examine adjacent Street Views. Participants typically reported travelling no more than two blocks from the origin point. In response to an open-ended question about the visual factors that drew attention in the panoramas, participants indicated that they noticed architectural features (e.g., "housing style" "types of roads/buildings", and "building façade aesthetic"), street signs, and known landmarks ("proximity to large buildings, the mountain, and the river"). These consistent categories of responses informed some of the image tags that I created. Participants also took an average of 7.5 minutes to complete the survey, which is within the 10-minute goal.

Despite the positive feedback from participants, this focus group testing of Geo-MTL also revealed several issues with the survey platform. Many of the responses collected by Geo-MTL were incomplete, indicating that the users did not clearly understand the tasks that were required of them. Most commonly, users failed to select tags for each of the panoramas that they were shown. Some users also failed to click "submit" after completing the survey, resulting in the data not actually being stored in the database. To address these issues, I added alert boxes to the survey, which are designed to pop up if a user attempts to submit an incomplete survey. The message in the alert box indicates the specific portion of the survey that the user has neglected to fill out. However, users are still able to submit incomplete responses if they choose to ignore the alert messages. I also added and emphasized instructional text on the page, which requests that users click "submit" when they have completed the survey. The focus group also revealed problems with web browser interoperability. Geo-MTL functioned well on Chrome, Microsoft Edge, and Firefox. Some of the HTML elements (such as the buttons allowing users to select panorama tags) did not function properly on Safari and Internet Explorer. The functionality of these elements was adjusted to suit all of the browsers mentioned above.

4.2 Image Recognition Reported by Geo-MTL Participants

4.2.1 Characteristics of Geo-MTL Participants

Over the span of three months, 209 responses were collected from the Geo-MTL app. As the platform is unable to uniquely identify each participant, it is unknown whether these 209 responses are from 209 distinct users or whether some people participated more than once. As each user played five rounds of the game, there was an initial total of 1045 data points. After removing incomplete responses (most often a response without any image tags), 976 data points remained. The 209 users of the Geo-MTL platform can be characterized by the number of years that they have lived in Montreal, and their home and work locations. Table 4.1 shows that users have lived in Montreal for an average of 5.29 years, with a standard deviation of 6.27.

Table 4.1. Univariate statistics of participants in Geo-MTL

Variable	Mean			Standard deviation
Number of years lived in Montreal	5.29 years			6.27
Home location	Longitude	Latitude	Borough	*See Figure 4.1 for standard deviation ellipse*
	-73.59	45.51	Outremont	
Work location	Longitude	Latitude	Borough	*See Figure 4.1 for standard deviation ellipse*
	-73.58	45.5	Ville Marie	

As illustrated in Figure 4.1 and Table 4.1, most users live and work towards the center of Montreal. More specifically, Figure 4.1 shows that a high number of users work at or in the area surrounding McGill University. As is shown by Figure 4.1, the distribution of user home and work locations roughly corresponds to the population density of Montreal, as more residents live downtown and fewer live in the outer areas of the island. Note that some users have also indicated home locations that are off of the island. Figure 4.1 also indicates the mean center of both users' home and work locations. The mean home location is in the southern end of Outremont, and the mean work location is in the northwestern end of Ville Marie. The standard deviation ellipses indicate that work locations are less variable than home locations.

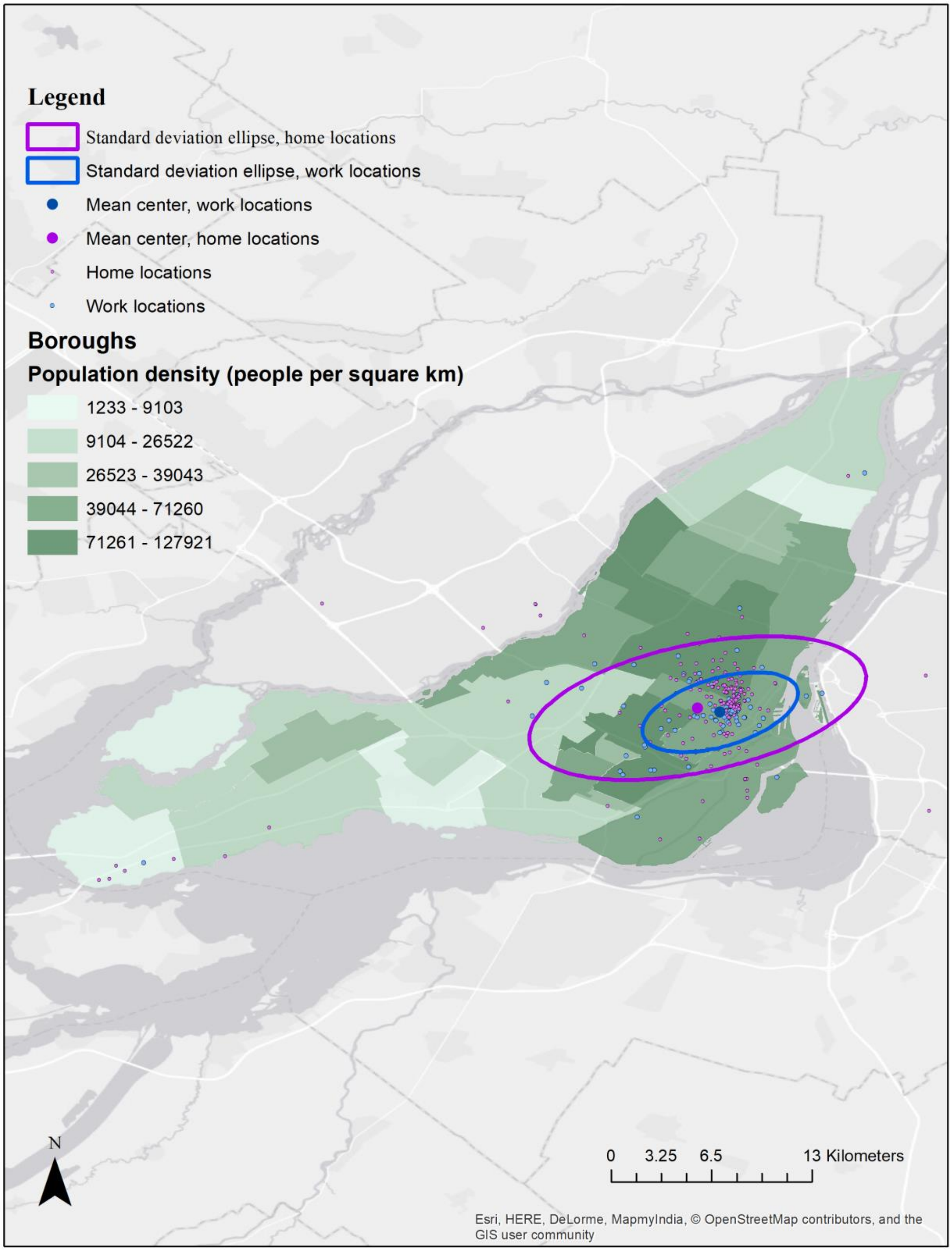


Figure 4.1. Home and Work Locations of Geo-MTL Participants, Overlaying Montreal's Population Density by Borough

4.2.2 Examining Spatial Patterns of Recognizability Throughout the Island of Montreal

The spatial distribution of the recognition error values indicates how the legibility of Montreal's landscape varies throughout the island. Figures 4.2 through 4.4 illustrate this spatial distribution of recognition error values in different ways to show the patterns of how legibility of Montreal's landscapes is clustered and dispersed through space.

A visual examination of the maps in these three figures suggests that the users were generally better able to recognize Street View panoramas located near the center of the island. Peripheral locations such as the western and northern tips were comparatively less recognizable to users. Note that the panorama point locations were not evenly sampled throughout the spatial extent of the island. As such, the mean recognizability values for boroughs (Figure 4.3) and for buffers (Figure 4.4) were not derived from the same number of points in each case.

Figure 4.2 shows the greatest spatial variability in recognizability. Some concentrations of low recognizability are visible in the island's outer boroughs. Whereas the center of the island appears to be consistently recognizable, the map of interpolated values (using inverse distance weighting) shows how recognizability becomes more variable towards the periphery. Figure 4.3 shows how the island's central boroughs (e.g., Plateau Mont Royal, Ville Marie, and Westmount) are well recognized and the outer boroughs (eg., Pointe Claire and Senneville) are much less so.

Emanating from Montreal's downtown core, the series of concentric buffers in Figure 4.4 clearly show how recognizability decays as one moves further from the city center towards the periphery. This trend is further demonstrated in Figure 4.5, which indicates how the mean recognizability error increases in a linear manner, proportional to the distance from the city center. Increase in recognition error is relatively consistent up to fifteen kilometers from the city

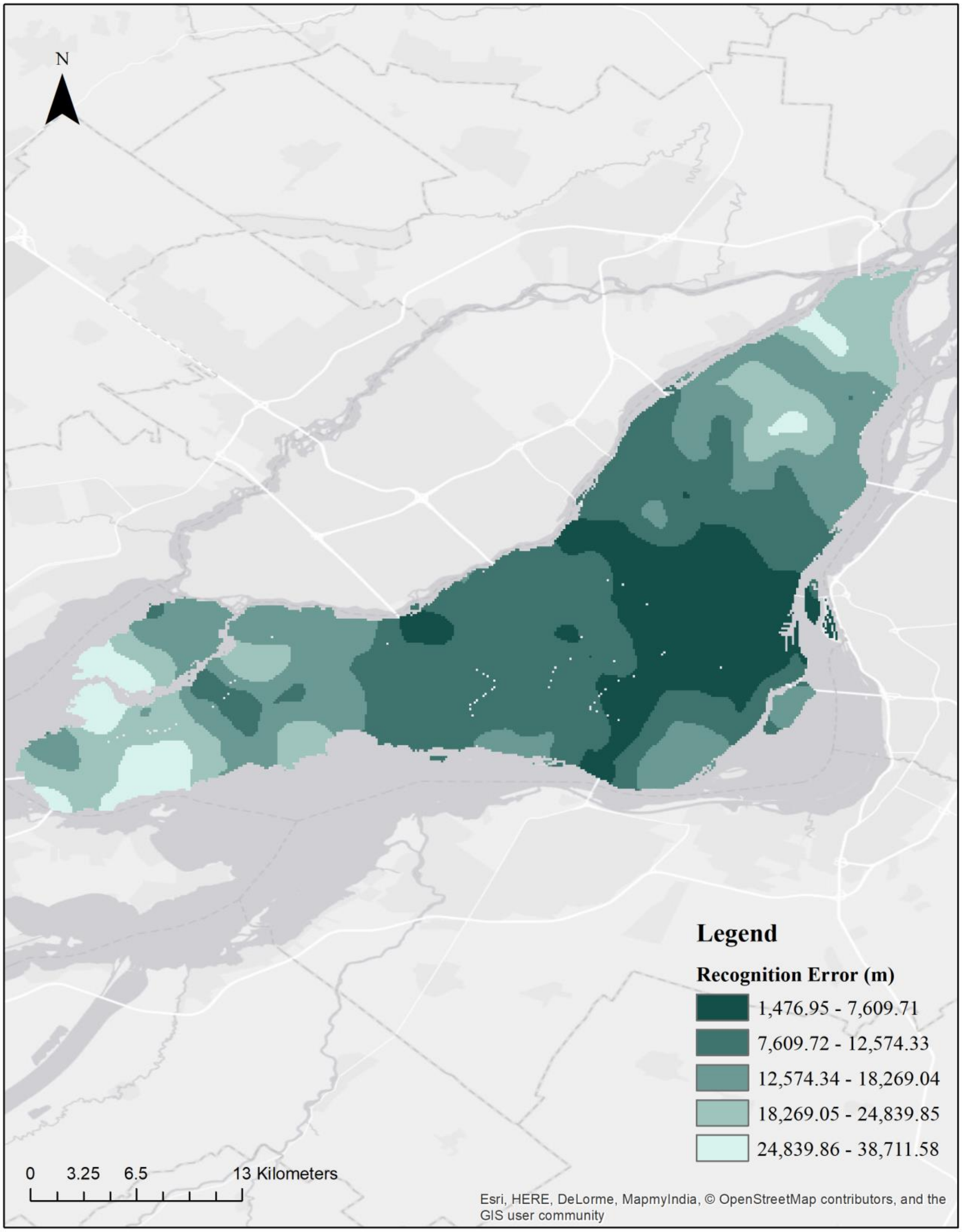


Figure 4.2. Interpolated Recognition Error Values

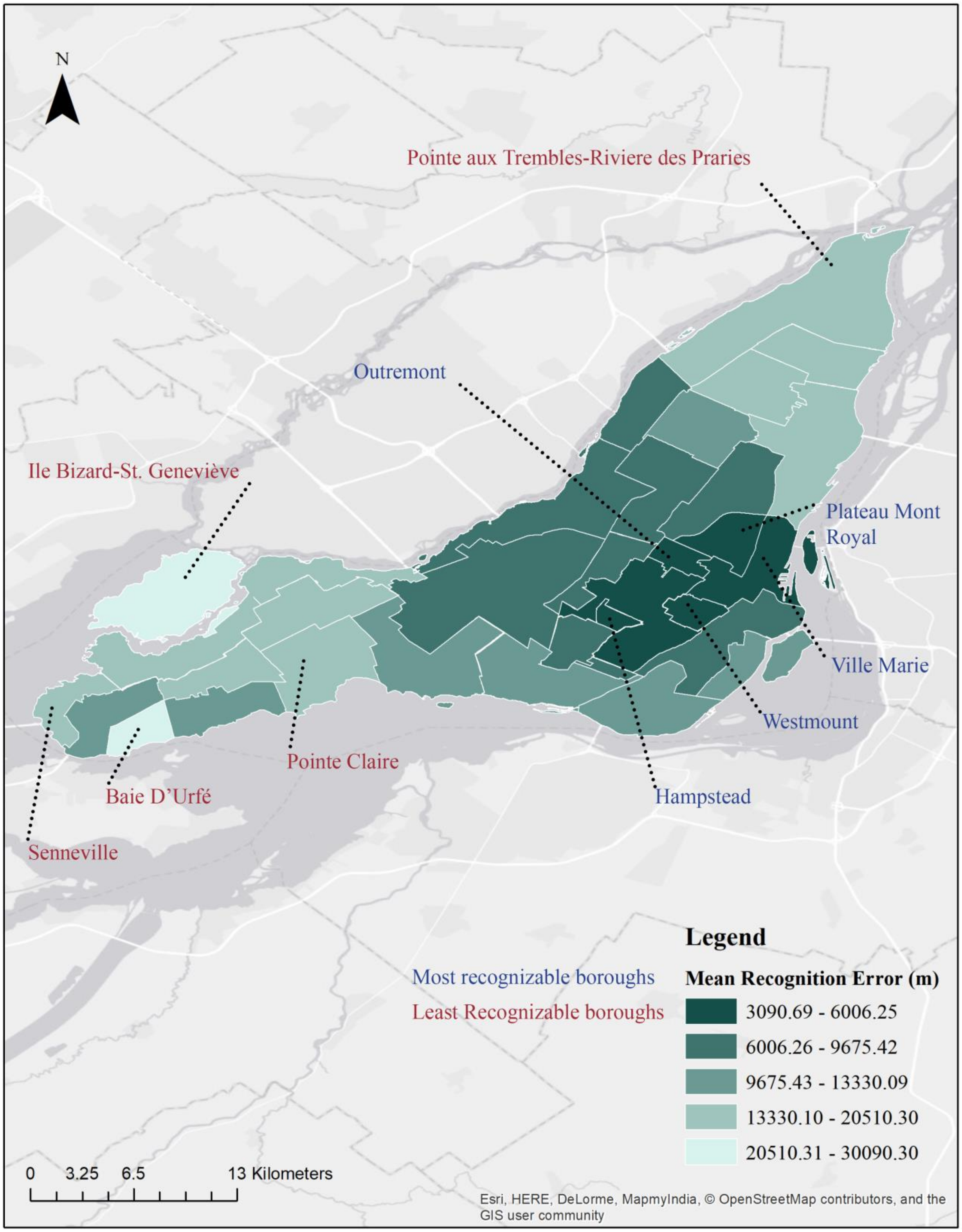


Figure 4.3. Mean Recognition error by borough, highlighting the most and least recognizable boroughs

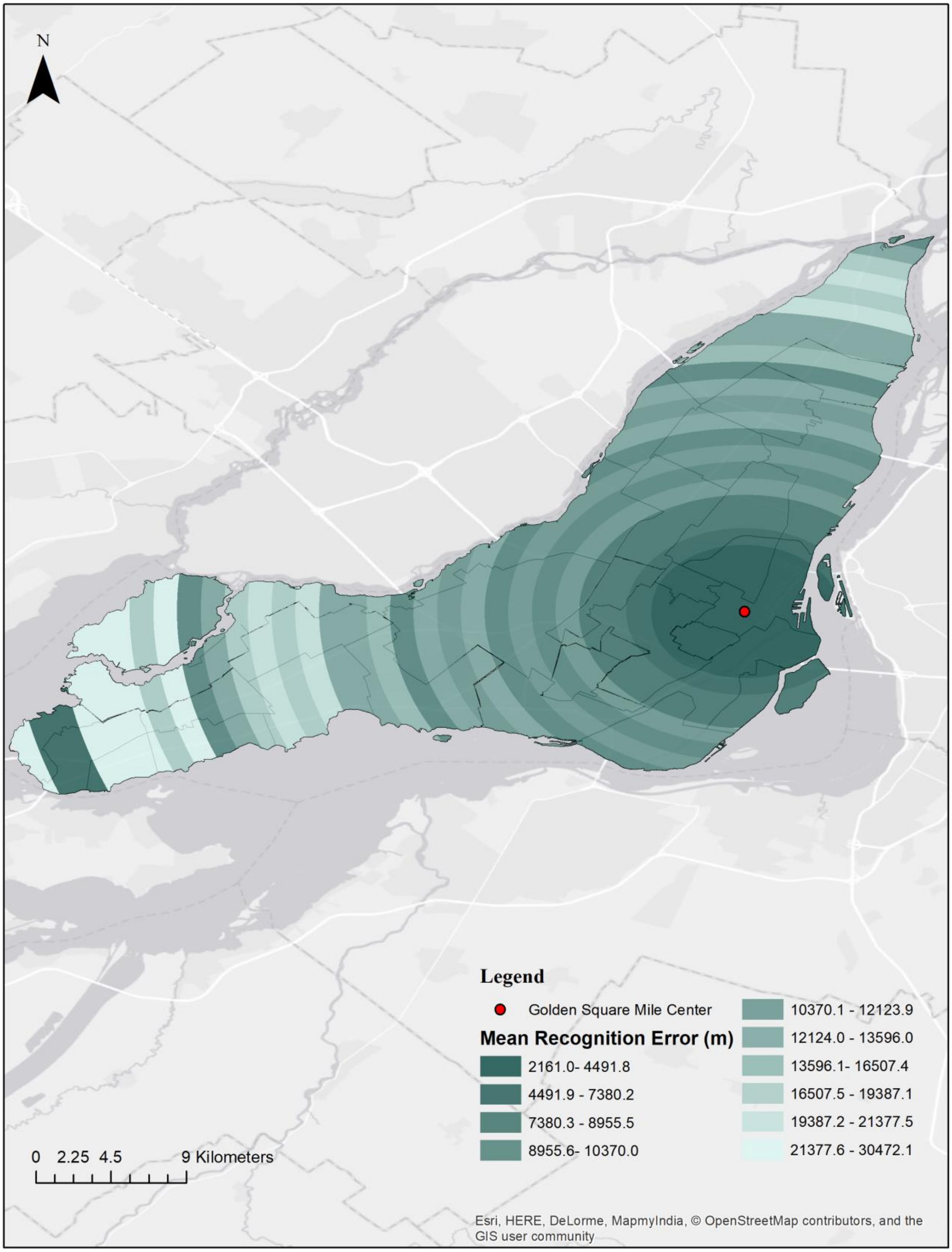
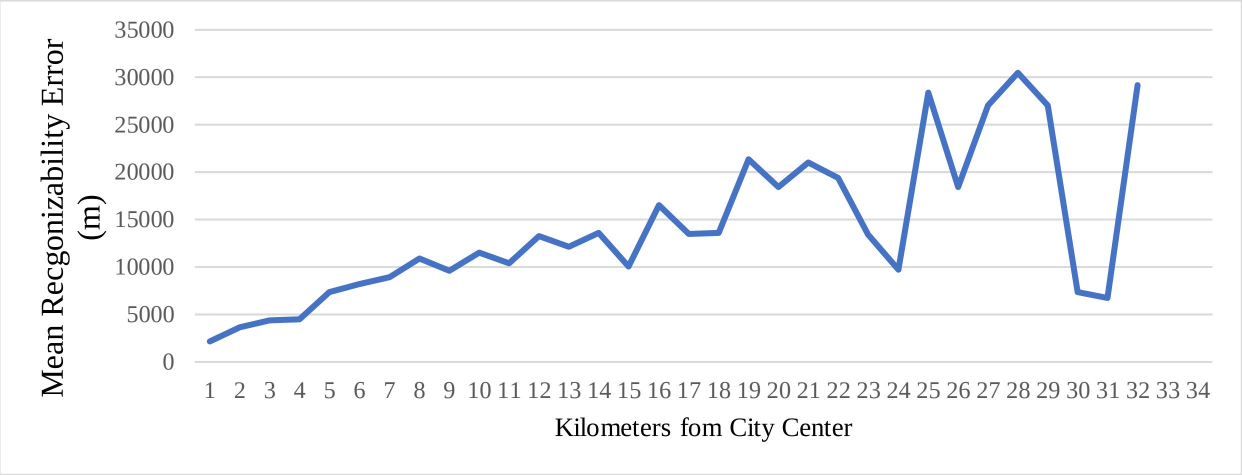


Figure 4.4. Mean recognizability error buffer analysis

center. At further distances from the city center, however, the recognition error values become much more variable. This is likely due to the greater number of points sampled closer to the city center than in the periphery.

Figure 4.5. Graph of mean recognizability error by distance from city center



A Moran's I of the mean recognition error values by borough points to statistically significant spatial autocorrelation in recognition error throughout the island of Montreal. The Moran's I value of 0.458 indicates that like recognition error values are clustered together in space. The GeoDa output can be found in Appendix C.

4.2.3 Statistical Analysis of the Factors that Contribute to Recognizability

An OLS multiple linear regression model was developed that accounts for 25.8 percent (adjusted R-squared) of the variability in recognizability throughout Montreal. An F-test indicates that this regression model is statistically significant at the $p<0.05$ threshold level. The independent variables included in this model were the distance between the Street view location and the participant's home location, and the collection of dummy variables indicating the borough of the Street View location. As the Plateau Mont Royal dummy variable contained the largest number of data points, it was excluded from the model to serve as the reference variable for all of the other dummy variables. Whereas the distance between the Street view location and the participant's work location was also found to be a significant contributing factor to the variability in recognizability throughout Montreal; its inclusion into the regression model introduced problems with multicollinearity (as it was highly correlated with the distance between the Street view location and the participant's home location). Table 4.2 shows the regression coefficients and the beta weights for the independent variables that were found to have a statistically significant effect on the recognizability error values (considered at a $p<0.05$ threshold) in the regression model. The beta weight values indicate the relative impact that each of the independent variables have on the dependent variable. Note that not all of the borough dummy variables were statistically significant. The complete results from the regression model can be found in Appendix C.

Table 4.2. Summary of results from regression analysis

Independent Variable	Regression Coefficient	Beta Weight
Panorama to home distance	0.22	0.22
Anjou	0.08	0.14
Lachine	0.05	0.10
LaSalle	0.07	0.17
Le Sud Ouest	0.03	0.08
L'Ile-Bizard-Sainte-Genevieve	0.16	0.14
Hochelaga	0.09	0.22
Montreal North	0.04	0.13
Pierrefonds-Roxboro	0.07	0.13
Riviere-des-Praries-Pointe-aux-Trembles	0.13	0.24
Rosemont	0.03	0.11
St. Leonard	0.07	0.17
Verdun	0.07	0.19
Villeray	0.04	0.13
Pointe Claire	0.09	0.12
Dollard des Ormeaux	0.09	0.14
Côte St. Luc	0.05	0.10
Baie d'Urfé	0.19	0.16
Kirkland	0.07	0.11
Montreal West	0.04	0.06

The positive regression coefficient for the variable representing the distance between the Street View panorama location and the user's home location indicates that for every meter increase in this distance, the recognition error will increase by 0.22 meters. The positive regression coefficients for all of the significant borough dummy variables indicate that each of these boroughs will have higher recognition error values than the Plateau Mont Royal (the reference dummy variable).

This multiple regression model was evaluated with various post-estimation diagnostics to ensure that it did not violate the assumptions required for multiple regression. Examination of variance inflation factors (VIF) showed no signs of multicollinearity between the variables as all values were approximately 1. The Breusch-Pagan/Cook-Weisberg test (Breusch and Pagan, 1979; Cook and Weisberg, 1983) and the White test (White, 1980) for heteroscedasticity also both confirmed the null hypothesis of constant variance in the regression error terms. Between these two tests, both linear and non-linear heteroskedasticity are checked.

4.2.4 Features of a Recognizable Environment

An analysis of the tags associated with each Street View panorama point towards some of the environmental and landscape features that contribute to the stronger recognizability of a given landscape or environment. Table 4.3 indicates the total number of panorama tags used for each tag category (previously detailed in Chapter 3 – see Table 3.2 for an overview of the specific tags in each category). Geo-MTL participants selected an average of 3 tags to accompany each Street View panorama, with a standard deviation of 2.

Table 4.3. Count of panorama tags by category

Tag Category	Number of Tags Used
Road features	386
Natural environment	304
Architectural features	445
Visible land use	425
Building density	417
Misc. (signage, landmarks, and landscape topography)	105

Figure 4.6 displays the frequency of occurrence of each pre-selected panorama tag among different subsets of Street View panoramas. The tag frequency, measured as the percentage of panoramas that were assigned a given tag, is provided for three categories: all of the data points, the top quartile of all data points (data points with the lowest recognition error), and the bottom quartile of all data points (data points with the highest recognition error). When considering the results for all 969 data points, one can see that panoramas most commonly fell in areas of what users perceived to be residential land use. This is indicated by the frequency of tags. These results also indicate that users commonly tagged panoramas as containing notable building facades and for reflecting distinctive neighbourhood architectural styles. Panoramas also were tagged relatively often for the amount of vegetation visible. When looking at the frequency of usage of different density tags (high density, medium density, low density), one can see that panoramas were most commonly perceived to be in low density areas. Few users paid attention

to the types of vegetation, landscape elevation, building materials, and visible landmarks in panoramas.

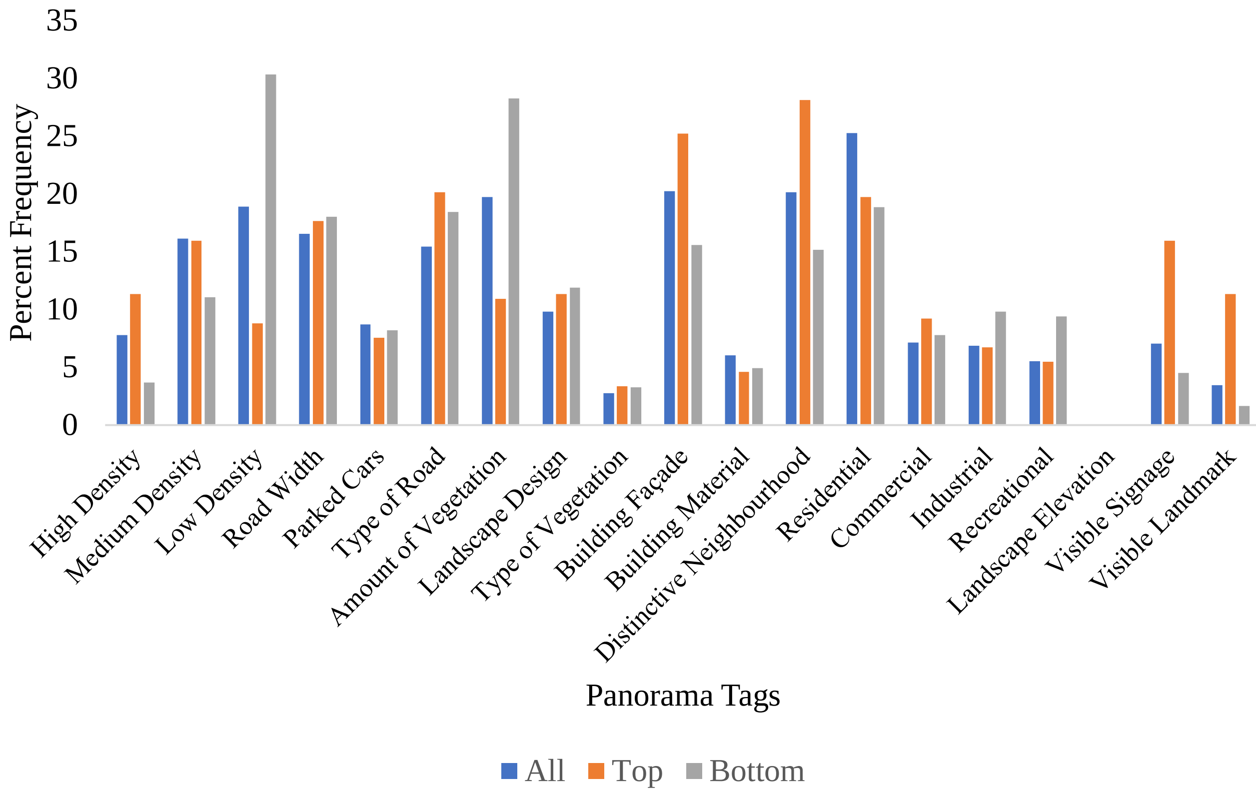


Figure 4.6. Frequency of occurrence of Street View panorama tags

In the top quartile of data points (lowest error), more than 25 percent of the panoramas were tagged as being in landscapes of a distinctive neighbourhood style. Many panoramas were tagged for their notable building facades. Relative to the results from all the data points, panoramas that were more recognizable were much less frequently tagged as being low density and for the amount of vegetation visible. These panoramas were tagged much more frequently for having visible signage and visible landmarks. It is likely that panoramas with low recognition error scores tagged as having visible signage are likely to have been located based on street signs, rather than for actual recognition of the landscape.

The bottom quartile of data points contains panoramas that were the least recognizable, having the highest recognition error values. The panoramas from these data points were most commonly tagged as being low density (over 30%) with high amounts of vegetation. Land use was still most commonly perceived to be residential. However, these panoramas were perceived to be in industrial areas more frequently than other panoramas. Relative to the frequencies for the top quartile of data points, panoramas were also much less frequently perceived to be in high density areas.

The Geo-MTL platform also allowed users to create their own tags for panoramas to reflect perceptions that were not included in the pre-set options. For the data points with lower recognition error values (those in the top quartile), many users pointed to identifiable landmarks. These included the canal, Jarry Park, Lower Canada College school, or Atwater Market; as landmarks allowed users to recognize a particular landscape. Some users also pointed to their past experiences with a landscape (e.g., “I drive past this area to get to work” or “been there before”), allowing them to better recognize its characteristics. For the data points with higher recognition error values (those in the bottom quartile), users reported much less specific perceptions, such as “single family homes”, “water”, and “housing”.

CHAPTER 5. DISCUSSION

This chapter addresses the implications of the results presented in the previous chapter. I begin by establishing a connection between spatial patterns of recognizability and patterns of legibility throughout Montreal. I outline how the patterns of legibility reveal characteristics of the city image that Geo-MTL participants have of Montreal. I then discuss the potential factors that contribute to the different levels of legibility of Montreal's urban landscapes, addressing both factors that relate to the individual and factors that relate to the surrounding environment. Finally, I reflect on the methodological approach of this research project and the contributions that it makes to existing survey approaches that have been applied to examine legibility.

5.1 Impacts of Recognizability on City Image

The results indicating the relative recognizability of Montreal's landscapes reveal some of the characteristics of participants' city image of Montreal. As recognizability is considered to be a metric for legibility and legibility contributes to the clarity of an individual's city image, regions in Montreal that are more recognizable are likely to be featured more prominently in an individual's image of the city.

The spatial patterns of Montreal's recognizability point to the varying degrees of legibility in Montreal's landscapes in the minds of the 209 survey respondents. These variations in legibility provide insight into the way that Montreal is imagined in the minds of residents. When comparing variations in legibility across constituent parts of the entire study area (boroughs, in this case), we can learn about how residents of Montreal understand the city as a whole.

As boroughs such as Plateau Mont Royal, Ville Marie, and Outremont were more easily recognized, they are more legible to the survey respondents. These regions are thus more prominent in the respondents' city image of Montreal. Accordingly, boroughs that were much more difficult to recognize, such as Baie D'Urfe and Pointe Claire, contribute relatively little (if at all) to the respondents' city image of Montreal. Figure 5.1 represents the impacts of recognizability on participants' city image of Montreal through a cartogram, distorting the area of each borough by its legibility. This figure, when compared to Figure 5.2, illustrates how legibility may be the strongest in the city centre and decrease in a manner proportional to the distance from this point. This visual representation suggests that Montreal's downtown core (and the surrounding areas) is more prominent in the survey participants' city image than the periphery of the urban area.

Figure 5.2. Cartogram of Montreal, boroughs scaled by legibility

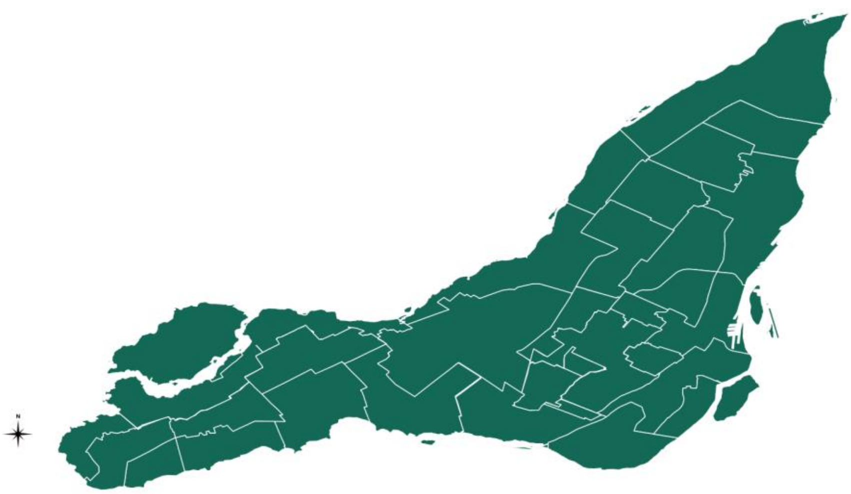


Figure 5.1. Map of Montreal boroughs

5.2 Factors Contributing to Legibility in Montreal

5.2.1 Individual Factors

Variations in legibility throughout Montreal arise from a complex interaction of factors. As indicated by the results of the regression analysis, Geo-MTL participants were more likely to recognize landscapes that were closer to their home locations. While eventually excluded from the regression model due to problems with multicollinearity, statistical analysis also showed that participants were more likely to recognize landscapes closer to their places of work. The prominence of Montreal's downtown core in participants' city image may in part be explained by the fact that the mean center of participants' home and work locations are both within 2 km of the center of the Golden Square Mile district (the center of the downtown core). Few participants live or work towards the periphery of the island, which may explain why these areas were found to be much less prominent in participants' city image.

This finding is congruous with past literature (eg. Appleyard, 1969; Appleyard, 1970; Yeung and Savage, 1996) that describes how that an individual's experience in a given landscape informs how he or she perceives that landscape. The nature of an individual's familiarity with various parts of a city may be considered according to three concentric zones: the used, the visible, and the "hearsay world beyond" (Appleyard, 1969). An individual will be the most familiar with the parts of a city that he or she frequently uses, to some extent familiar with parts that he or she has seen before, and the least familiar with parts that he or she has only heard about. As landscapes surrounding an individual's home and work locations are likely to be the most frequently visited parts of the island for that individual, it follows that these landscapes would feature more prominently in that individual's image of the city.

Whereas one might expect that an individual's "temporal familiarity" (Appleyard, 1970) with a city has an impact on his or her ability to recognize various parts of the city; the number of years that an individual has lived in Montreal was not found to be a significant factor contributing to the recognition error values. The underlying assumption behind this expectation is that an individual who has lived in Montreal for longer will have had a greater breadth and depth of experiences throughout the city, leading to a greater overall understanding of the entire landscape. The lack of explanatory significance of this factor may indicate that the activity patterns of individuals do not necessarily expand when they have lived in a city for longer periods of time. A low level of variability in the data's values may also have contributed to its lack of statistical significance.

5.2.2 Legibility and Perceptual Features of the Environment

Past research on legibility, such as that of Yeung and Savage (1996), has demonstrated how the features of an urban environment play a significant role in determining how legible that environment is to its residents and visitors. The tags indicating the perceptual features of each Street View panorama are a valuable source of information that allow for an exploration and comparison into the visual features commonly associated with landscapes of higher and lower legibility.

Perceived building density was one of the most polarizing perceptual characteristics between landscapes with different levels of legibility. Street View panoramas that were not well recognized were often perceived to be in low-density landscapes and Street View panoramas that were well recognized were more often perceived to be in high and medium-density landscapes. One can infer that greater perceived building density is connected to more recognizable and legible urban landscapes. This inference is reinforced up by the results indicating that many unrecognizable landscapes were perceived to have higher amounts of vegetation (likely also reflecting lower density) than those that were more recognizable.

The perceptual tags also indicate that features such as signage, landmarks, distinctive architectural styles, and notable building facades were associated with more legible landscapes. These findings follow those of Ewing and Clemente (2013), whose work identifies urban design features such as memorable architecture, signage, public art, and buildings with identifiers as significantly explaining variations in legibility (as measured by “experts”) in various neighbourhoods. These findings are also consistent with Lynch (1960), whereby the presence of landmarks is described as one of the key city elements that facilitate the creation of a clear city image.

To illustrate the role of perceptual features in contributing to legibility, sets of screen shots from the Street View panoramas with the lowest, median, and highest recognition error scores are shown in Figure 5.3. Note that the street labels visible in these panoramas were not visible to the Geo-MTL survey participants. When examining these three sets of urban landscapes, one can see significant differences in building density across each set. For example, the most legible landscapes are densely populated with two to three storey attached buildings, whereas the least legible landscapes contain detached single-family homes. There also is a stark difference in the amount of distinct visual information that is present in each set of images. Each of the images from the most legible landscapes has many distinctive features that engage the viewer and draw attention. Various perceptual characteristics of the more legible landscapes, such as moderately-sized buildings, greater enclosure, and narrow streets, create the feeling of an intimate environment that is pleasant and engaging (Ewing and Clemente, 2013). The features in the remaining images (e.g., gas stations, highways, and empty green space) exemplify the homogenous and unconnected urban form critiqued by Salingaros (2000).

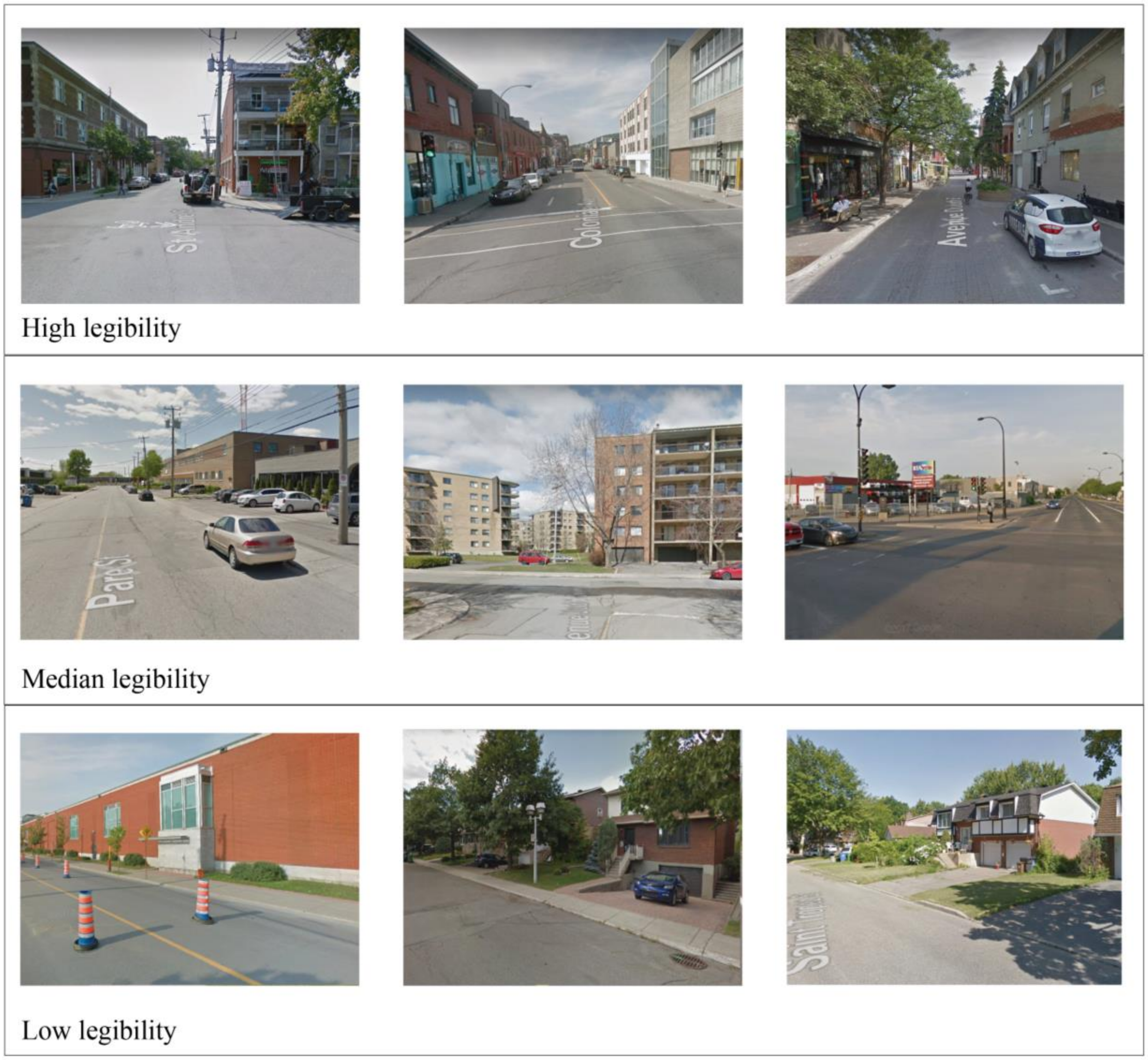


Figure 5.3. Street View Panoramas from throughout Montreal

These results echo past work that has explored connections between the concepts of legibility and complexity (Appleyard, 1969; Salingaros, 2000). Complexity refers to the interconnectedness of urban elements and the perceptual richness of urban form. As legibility is considered to be a characteristic of an urban environment that facilitates the creation of a clear city image, it is likely that environments which are more engaging, attention-grabbing, distinct, and memorable will be more legible. Jonge (1962), finds that that individuals have unclear cognitive formulations for places with uniform and undistinguishable elements. In addition to the nature of the distribution of survey participants' home and work locations, Jonge's finding may in part explain why boroughs such as Baie D'Urfe and Beaconsfield, were not found to be prominent in participants' cognitive understandings of Montreal. The landscapes in these parts of the island contain relatively little heterogeneous visual information and do not demand the same level of perceptual engagement as many landscapes in the downtown region. Boroughs such as Ville Marie and Plateau Mont Royal contain a variety of land uses and building forms and were found to be prominently featured in participants' city image of Montreal.

This connection between the visual features of the environment to legibility points to the value of urban design and planning paradigms that advocate for densification and diversification of urban environments. Calls from urbanists to put "eyes on the street" (Jacobs, 1961), create environments of activity and vitality (Montgomery, 1998), and diversify functionalities (Alexander, 1964) are rarely directly rationalized in the context resident's cognitive well-being. The findings of this study indicate that environments designed in such a way are likely to be more clearly cognized and retained in the minds of citizens. A diversity of architectural styles throughout a city or neighbourhood, for instance, may facilitate an individual in his or her efforts to differentiate between landscapes and lead to the creation of a more complete and clear city image. A diversity of land uses also may result in a more visually rich and engaging environment, which may make it more distinctive to an individual and thus more legible.

While there is still room for further statistical testing, the analytical approaches employed in this research project begin to offer a strategy for urban design that will necessarily result in more legible urban environments. This section highlights how legibility could be considered when designing urban environments and how this concept may be connected to many existing theories and paradigms of urban design and planning. Planners and designers aiming to create liveable and navigable cities can continue to quantify and elicit information on urban perceptual characteristics such as legibility.

5.3 Reflections on Geo-MTL

5.3.1 Survey Usability and Accessibility

One of the primary aims of this project was to explore the appropriateness of a gamified, web-based approach to implementing an image recognition survey. The appropriateness of this approach was evaluated by examining the usability of the Geo-MTL platform, and the extent to which it facilitates the implementation of manual survey approaches.

The results of the focus group and the overall contributions to the platform indicate that the Geo-MTL platform was effective in engaging users and collecting data on their perceptions of various landscapes throughout Montreal. The focus group participants reported on the ease of use of the platform and the enjoyment brought by its gamified nature. The focus group results also indicate that participants engaged with the content of the Street View panoramas in a meaningful way, as they spent time navigating through the panoramas and paid attention to the visual features of the built environment. As only 7% of the total number of responses collected from the survey were incomplete, one can conclude that survey participants were easily able to understand the tasks that were required of them in the survey. The framing of image recognition tasks as a test in “how well do you know your city?” can thus be considered as an effective way to present this survey approach to participants.

It was hoped that the online, gamified nature of the survey platform would facilitate the implementation of manual image recognition surveys and allow data to be collected from a large and geographically widespread population sample. Online survey dissemination strategies proved successful in collecting data from a satisfactorily large population sample (209 participants) in a relatively brief time period (two months). While the geographic distribution of participants is more concentrated towards the center of the city, Geo-MTL was capable of collecting responses from a geographically widespread study area. The home and work locations of participants extended into boroughs such as Baie D'Urfe and Pointe aux Trembles- Riviere des Prairies, which are on the Northeastern and Southwestern most tips of the island. These populations would be difficult to reach with manual survey approaches.

The population sample from this survey is nevertheless biased towards McGill students or employees who live in the Plateau and surrounding Milton-Parc region. It is likely that the bias in the population sample is a result of the survey dissemination strategies, rather than a result of limitations in the survey itself. This sample bias may be a result of the survey dissemination strategies that primarily targeted McGill students. It is likely that those in the same (or similar) social communities as myself were much more aware of the survey and thus much more likely to have participated. While an online survey may functionally be accessible to a large and geographically widespread population, appropriate dissemination strategies are still critical to achieving a representative population sample.

The Geo-MTL platform may also be limiting as it assumes a certain degree of map (digital or otherwise) literacy from its users. During focus group discussions, for example, one participant noted that she felt intimidated by the prospect of navigating and panning through a web map. Some participants may not be familiar with the representation of Montreal on Google Maps and thus have trouble guessing Street View locations on a map.

Using the criteria previously outlined, Geo-MTL can overall be considered as an appropriate tool for investigating the legibility of urban landscapes in Montreal. Future work, however, should employ a greater variety of survey dissemination and publicity strategies to obtain more geographically representative survey population samples.

5.3.2 Theoretical Foundations

As an abstractly defined concept that represents an intangible form of spatial knowledge, legibility cannot be directly measured or evaluated. Thus, research that seeks to learn about the legibility of specific urban environments must carefully choose how to operationalize this concept. In Chapter 2 of this thesis, I have discussed the various approaches that have been used to operationalize legibility. The conceptual and intangible nature of legibility also makes it challenging to assess whether survey approaches effectively capture what is intended. The construct validity of survey approaches to capturing legibility, such as image recognition tests, have not been evaluated in existing literature. Each of these approaches address different dimensions of legibility and have associated advantages and disadvantages.

My choice to investigate legibility by measuring the recognizability of various urban landscapes is advantageous as it allows legibility to be quantified. By collecting point-based quantitative data on recognition error distance of various urban environments, it is possible to employ many statistical and cartographic techniques that are commonly applied to spatial data. These approaches allow one to discuss legibility in new ways and compliment descriptive results with empirical results bearing statistical power. As is evidenced here, techniques such as the Moran's I can be used to identify any spatial autocorrelation. This approach also demonstrates how interpolation, buffer analysis, choropleth mapping, and cartograms can be used to display the patterns of legibility unfolding over space. Such visualization and analysis can provide greater insight into the nature of legibility and its contributing factors.

Recognizability is a metric that is well suited to capturing legibility as a factor of the visual characteristics of urban environments. During image recognition tests, participants must make judgements based on the visual information that is present in the images before them. Survey results can then be analyzed to investigate how different types of visual information are associated with different levels of legibility (by looking at recognition performance). For example, I have previously outlined how the results of this study indicate that more legible environments may be those that are more visually differentiated and diverse.

Recognizability is a metric that is not well suited to capturing legibility as a factor of the morphological properties of urban environments. Morphological properties, such as road network structure, are not apparent in images or Street View panoramas and thus do not likely impact an individual's recognition performance. Wayfinding exercises are more appropriate for investigating how the structural complexity of an environment may impact its legibility. O'Neill (1996), for example, uses the wayfinding performance of individuals to investigate how topological floor plan complexity impacts legibility within a building.

As each approach for operationalizing legibility invariably focuses on one dimension of the concept and disregards others, some studies have combined different survey methods to obtain a more full-bodied understanding of legibility (eg., Yeung and Savage, 1996). The use of a variety of survey approaches, however, is demanding of both researcher and survey participant time and effort. I chose to limit the scope of this thesis by only focusing on one approach for operationalizing legibility and acknowledge that I do not address every facet of this multidimensional concept.

5.4 Geo-MTL and the Scale of Analysis

As with any study involving spatial phenomena, it is important to address the impacts of spatial scale on the results that were obtained. The spatial extent chosen for this study was defined as the Island of Montreal and the spatial granularity of the data collected was at the level of the street. As legibility was determined based on individuals' ability to recognize Street view panoramas, the results are focused on data relating to perceptions of streetscapes (rather than single buildings or entire neighbourhoods).

Legibility is a phenomenon that can be considered at many different scales. Past research, for example, has examined legibility within a single building (O'Neill, 1991; Weisman, 1981) and along a single road (Yeung and Savage, 1996). Whereas this research project operationalizes the concept of legibility in the context of *city* image; it would be entirely possible for one to investigate the concept in the context of *building* image or perhaps even *country* image. At different scales of analysis, other factors could be significant. Little research has been conducted on the scale-dependent nature of legibility so it would be interesting to conduct this type of research at other scales of analysis. Geo-MTL could be adapted to suit other scales of analysis by adjusting the geographic extent of the study area that Street View panoramas are selected from. Changes in the scale of analysis would also necessitate changes in the desired survey population sample.

CHAPTER 6. CONCLUSION

Following the call of many scholars (e.g., Appleyard, 1970; Gollege and Spektor, 1978; Nasar, 1990; Lynch, 1960) this research explores how cities are understood in the minds of the people that inhabit them. By doing this, one can more effectively plan and design liveable environments. The notion of a city as existing in an objective container in space does not capture the various ways that factors such as urban design and individual experiences morph how a given city is known in the minds of residents. As the results of this study suggest, the residents of a city will not have a consistent amount of spatial knowledge about the various landscapes and environments that make up that city. Whereas one can talk about space in cities in terms of objective measurements; the fundamental spatial knowledge that citizens have is subjective and inconsistent.

In this research project, I have demonstrated a quantitative approach to investigating legibility that is based on existing image recognition testing. The results of this research project indicate how the legibility of Montreal varies through space. The center of Montreal was found to be the most legible part of the city, with legibility decreasing as one moves further towards the boundaries of the city. These results suggest that survey participants' city image of Montreal is clearer towards the center of the city and less clear towards the periphery.

The variability in Montreal's legibility is owing to a complex array of contributing factors. I have found that the proximity of an individual's home and work locations to a given environment in Montreal will impact how legible that environment is to the individual. As legibility was found to be a spatially-dependent phenomenon, environmental characteristics such as building density, architectural distinctiveness, and the presence of landmarks also were connected to more legible environments. These findings echo past connections that have been made between legibility and visual complexity. Such findings point to the efficacy of current paradigms in urban design that advocate for densification and diversification of environments in contributing to enhanced legibility.

This research project reflects a unique approach to learning about the perceptual characteristics of urban environments. I have demonstrated Geo-MTL to be an appropriate approach to collecting data on the legibility of various urban landscapes. By reworking a traditional manual survey approach into a web-based crowdsourcing platform, I have presented a means to facilitate the implementation of existing survey approaches in the field of urban perception and cognition to collect data from a large and geographically dispersed population of citizens. This application is enabled by Web 2.0 technologies that collect user-generated content and allow the creation of mash-ups of different sources of existing geospatial data (e.g., Google Maps and Google Street View). My approach is an example of an effort to gamify an online survey tool to encourage more enjoyable (and thus more widespread) participation.

There is much potential for the research approach presented in this project to be expanded and applied to new research questions in the field of urban perception and cognition. Aside from the set of coordinates used to access Street View panoramas for Montreal, the Geo-MTL tool is generalizable to other geographic contexts. This research can easily be conducted to determine the patterns of legibility in other cities throughout the world with the approach demonstrated here. Comparative research could be conducted to determine if the findings from this study on the factors that contribute to legibility are consistent in other urban settings. Future efforts should also focus on obtaining a larger sample of respondents that is more geographically diverse throughout a given study area. Results could thus be more generalizable across an entire population of citizens. Future research should also perform more testing on the perceptual image tags to determine the statistical significance of urban form features such as density and land use on legibility. Finally, research should be conducted to examine the scale-dependent nature of legibility. By repeating this methodology at different scales of analysis (e.g., within a single neighbourhood or within an entire country), research efforts can contribute to the creation of a more comprehensive understanding of the urban perceptions and cognitions and the concept of legibility.

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APPENDIX A: Focus Group Questionnaire

(adapted from online Google Forms format)

1. Please rate the ease with which you navigated this platform:

   1 (very easy)   2   3   4   5 (very difficult)

2. Please rate how much you enjoyed playing this game:

   1 (very enjoyable)   2   3   4   5 (not enjoyable)

3. On average, how long did you spend looking at each Street View panorama?
   a. 15 seconds or less
   b. 15 seconds to 1 minute
   c. over 1 minute

4. What factors did you focus on most in each of the panoramas?

5. Would you play this game again? Please briefly explain your answer.

6. What did you like about the interface design?

7. What did you dislike about the interface design?

8. Would you recommend any changes?

APPENDIX B: Research Ethics Board Certification

McGill

Research Ethics Board Office
James Administration Bldg.
845 Sherbrooke Street West. Rm 325
Montreal, QC H3A 0G4

Tel: (514) 398-6831
Fax: (514) 398-4644
Website: www.mcgill.ca/research/researchers/compliance/human/

Research Ethics Board I
Certificate of Ethical Acceptability of Research Involving Humans

REB File #: 117-0817

Project Title: Spatial Legibility in Montreal through Google Street View

Principal Investigator: Hannah Ker

Department: Geography

Status: Undergraduate Student

Supervisor: Prof. Renee Sieber and Prof. Raja Sengupta

Approval Period: **August 28, 2017 to August 27, 2018**

The REB-I reviewed and approved this project by delegated review in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Participants and the Tri-Council Policy Statement: Ethical Conduct For Research Involving Humans.

Deanna Collin
Ethics Review Administrator, REB I & II

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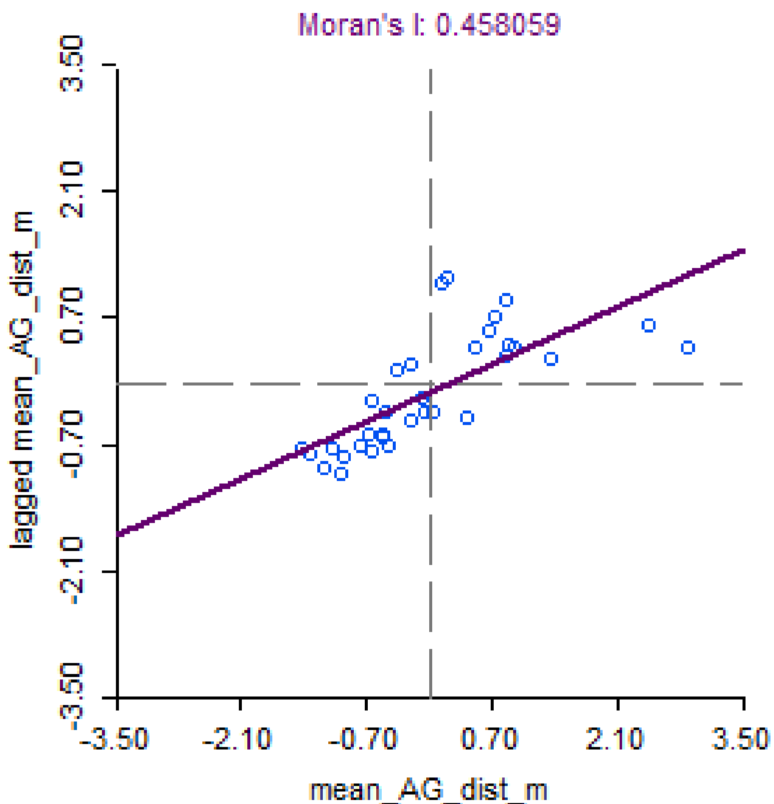
* Approval is granted only for the research and purposes described.
* Modifications to the approved research must be reviewed and approved by the REB before they can be implemented.
* A Request for Renewal form must be submitted before the above expiry date. Research cannot be conducted without a current ethics approval. Submit 2-3 weeks ahead of the expiry date.
* When a project has been completed or terminated, a Study Closure form must be submitted.
* Unanticipated issues that may increase the risk level to participants or that may have other ethical implications must be promptly reported to the REB. Serious adverse events experienced by a participant in conjunction with the research must be reported to the REB without delay.
* The REB must be promptly notified of any new information that may affect the welfare or consent of participants.
* The REB must be notified of any suspension or cancellation imposed by a funding agency or regulatory body that is related to this study.
* The REB must be notified of any findings that may have ethical implications or may affect the decision of the REB.

APPENDIX C: Statistical Output



Appendix Figure 4. GeoDa output from Moran's I of average recognition error by borough

Source	SS	df	MS			
				Number of obs	=	976
				F(33, 942)	=	11.28
Model	1.85679565	33	.056266535	Prob > F	=	0.0000
Residual	4.70056008	942	.004989979	R-squared	=	0.2832
				Adj R-squared	=	0.2581
Total	6.55735573	975	.006725493	Root MSE	=	.07064

error	Coef.	Std. Err.	t	P>|t|	Beta
hdist	.2207074	.0408901	5.40	0.000	.2226881
ahuntsic	.035763	.0135336	2.64	0.008	.087527
anjou	.0808549	.017577	4.60	0.000	.139753
cdnnddg	.0211518	.0121289	1.74	0.082	.0589957
lachine	.0534257	.0167136	3.20	0.001	.0988715
lasalle	.0681987	.013546	5.03	0.000	.1669108
sudouest	.0344293	.0135217	2.55	0.011	.0822699
lbsg	.1578355	.0343156	4.60	0.000	.1374707
hochelaga	.0921324	.013324	6.91	0.000	.2280978
montrealnorth	.0460654	.0123722	3.72	0.000	.1284837
outremont	.0114036	.0144762	0.79	0.431	.024775
prox	.0786439	.0200938	3.91	0.000	.1325588
rdppat	.1329956	.0176201	7.55	0.000	.2354286
rosemont	.0331708	.0111312	2.98	0.003	.1051042
saintlaurent	.0189478	.0192408	0.98	0.325	.0302414
stleonard	.0656199	.012819	5.12	0.000	.169655
verdun	.0691492	.0124499	5.55	0.000	.1877388
villemarie	.0066713	.0120631	0.55	0.580	.0186074
villeray	.043941	.0116813	3.76	0.000	.1297644
westmount	.0244044	.0138571	1.76	0.079	.0561168
pc	.088329	.0230693	3.83	0.000	.1187526
hampstead	.0165295	.018256	0.91	0.365	.0271324
dollard	.0876776	.0201283	4.36	0.000	.1399371
dorval	.0407618	.0265889	1.53	0.126	.044838
csl	.0470347	.0147505	3.19	0.001	.1006297
baie	.1857462	.0341431	5.44	0.000	.1617801
beaconsfield	.0420574	.0372731	1.13	0.259	.0327805
kirkland	.0709583	.0211197	3.36	0.001	.1132525
senneville	.0590951	.0523697	1.13	0.259	.0326029
mtleast	.1083897	.050549	2.14	0.032	.0597989
mtlwest	.0399324	.0192475	2.07	0.038	.0618632
stanne	.0172206	.0384063	0.45	0.654	.0134222
montroyal	.0325054	.0179251	1.81	0.070	.0547898
_cons	.0174233	.0074958	2.32	0.020	.

Appendix Figure 5. STATA output of regression analysis